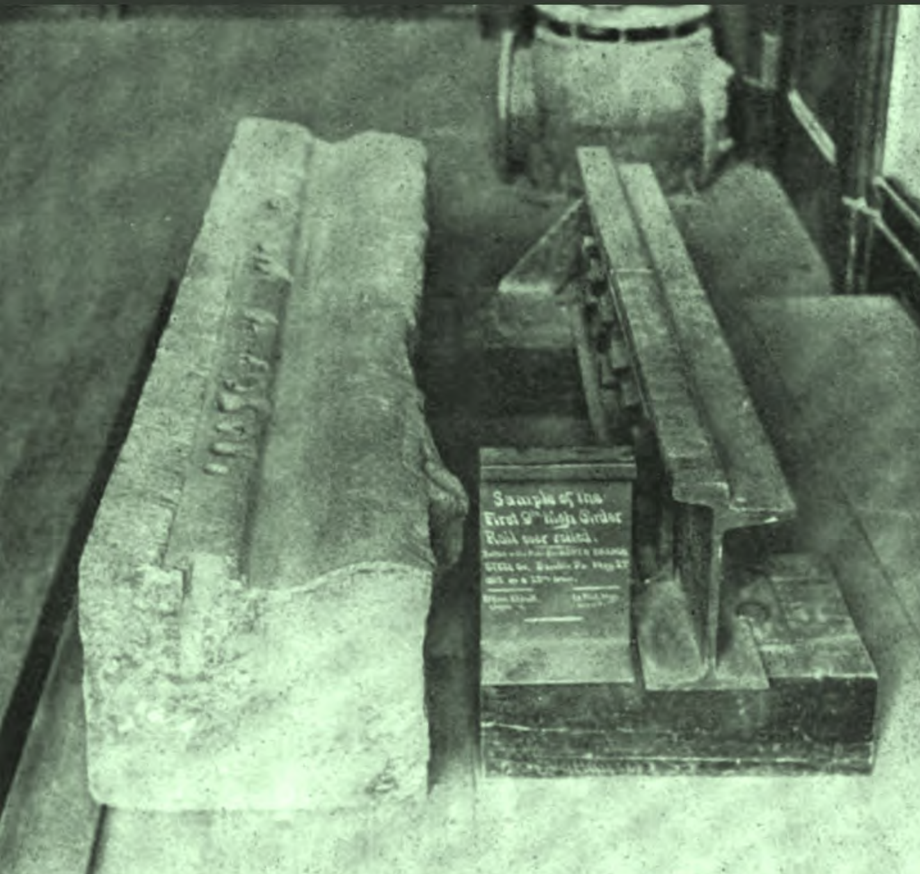

Elements of railroad track and construction

Winter Lincoln Wilson

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ELEMENTS

OF

RAILROAD TRACK

AND

CONSTRUCTION

BY

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SECOND EDITION, REVISED AND ENLARGED

FIRST THOUSAND

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PREFACE TO SECOND EDITION.

The former edition has been rearranged and a large portion rewritten.

The principal change is in the theoretical discussion of Switches, Turnouts, and Crossovers. The theory of circular turnouts has been extended to cover the usual cases occurring in practice, and a new chapter on the Practical Turnout, following the recommendations of the American Railway Engineering Association, has been added. The chapter on Railroad Construction has been enlarged by the addition of material that should help the young engineer on his first construction work. A chapter has been added which gives a simple method of computing the elevations on a vertical curve, and also a general idea of grades and their significance. Data and tables have been brought up to date as far as obtainable and consistent with the scope of the text. Two chapters, eight Articles, twenty-nine illustrations, and thirty-five problems, a total of seventy pages, have been added.

South Bethlehem, Pa.,
June, 1915.

PREFACE TO FIRST EDITION.

In this volume no attempt has been made to treat the subjects of railroad track and construction with any considerable amount of detail, but rather to present a few of the fundamental principles in such manner that the inexperienced engineering student can form a general idea of the subjects. There are a number of excellent treatises on track which go into the subject with a wealth of detail and a thoroughness of discussion which is of immense value to the maintenance-of-way engineer with some experience; but, unfortunately, these books are not suitable for class-room work, both on account of the student not being able to appreciate the value of the details and also on account of the impossibility of reading these books in the time usually given to such subjects in an engineering course. Details of practice can be much more readily learned and appreciated from actual experience. There is not much time in the four years of an engineering course that can economically be given to the details of practice, but it is essential that the student should understand the fundamental principles of the subjects. In this volume some of the general principles of track and of the part of railroad construction with which the young engineer may come in contact early in his experience are presented.

The author wishes to thank Prof. L. D. Conkling for his valuable assistance in preparing this book.

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CHAPTER I.

HISTORY OF RAILROADS IN THE UNITED STATES.

ARTICLE I.

DEVELOPMENT OF RAILROADS.

1. Definition of Term Railroad.—The terms "railroad" and "railway" are about the same age, and originally they were synonymous. After the introduction of steam locomotives and before electric motive power, the term railway was more commonly used in England and railroad in the United States. In recent years railway has been commonly used in the United States in connection with electric car lines; and quite recently they have been defined as follows:

"Railways refer to all kinds of roads where vehicles are moved on metallic rails by steam or electric motors."

"Railroads refer particularly to those railways which have 4 feet 8½ inches track gage; a private right-of-way and private terminals; freight and passenger traffic, with cars in trains; and the Master Car Builders' standards, for interchange of equipment with other railroads."

2. Development of Railroads.—The railroad of today has developed from the tramway. The first tramways consisted of trams of wood or flat stones laid flush with the surface of the road; these developed to stone and wooden stringers covered with strap-iron, and finally to the permanent way now in use. The date of the first tramway is not known; they were designed so that horses could pull heavier loads with less effort, the wheels being plain, or without flanges. In 1789, *edge* rails were introduced, the wheel running on the upper edge and having flanges. The motive power on the first tramways was horses; * but as the rail was developed and became stronger, heavier cars could be used and something stronger and faster than horses was needed. Some of the tramways were operated, their length being short, by means of a stationary engine winding up a rope on a drum, the cars running back by gravity.

3. History of the Locomotive Engine.—James Watt, 1736–1819, for many years worked on the problem of perfecting an apparatus which would draw wagons on the common highway, and patented a locomotive carriage in 1784. Watt was an advocate of the low-pressure steam-engine, which proved unsuitable for the purpose. In 1802, an Englishman, Trevithick, built a high-pressure locomotive. It worked, but the velocity was low and the adhesion of the wheels to the rails was poor, so a system of rack rails was used. George Stephenson, 1781–1848, made a successful trial of a *traveling engine* worked by steam, over a tram road between the colliery and the port, at Killing-

* See Railroad Gazette, Sept. 22, 1905.

worth, England, in 1814. The exhaust of this engine opened directly into the air, and people along the line objected to the clouds of condensed steam, so Stephenson tried the experiment of turning the exhaust into the stack; thus by accident he discovered that he could double the original speed of three miles per hour. Stephenson made many other improvements, such as increasing the weight over the driving wheels in order to obtain better adhesion, and demonstrated that the locomotive engine was to be the motive power of the future.

4. **The First Railroad.**—Stephenson then became engineer of the Stockton and Darlington Railroad, which was opened on Sept. 27, 1825, and was the first railroad to carry both passengers and goods by steam power. It was originally intended that the wagons should be pulled by horses. The locomotive used on this road could run seven miles per hour on the level places. As is usually the case with new ideas, public opinion was greatly against locomotives and predicted that a speed of fifteen miles per hour could never be obtained in this way. Stephenson, however, was of a different opinion. He continued his experiments and influenced others to begin similar work. In 1829, the Stockton and Darlington Railroad offered a premium of $2500 for a locomotive that would not cost more than $2700, that would draw three times its own weight, and reach a speed of ten miles per hour. A competition was held in October, 1829, and five locomotives were entered. The Rocket, manufactured by Stephenson, weighed seven and one-half tons, and

pulled forty-four tons at the rate of fourteen miles per hour. Without the load, the Rocket made thirty-five miles per hour.

5. Railroads in the United States.—The first railroad built in the United States was at Quincy, Mass. In 1825, sufficient funds had been collected to warrent the commencement of the Bunker Hill monument. The contractor bought a granite quarry located in West Quincy, from which to obtain stone for the foundation, and designed a railroad to bring the stone from the quarry to tidewater.

The road was four miles long and was completed in 1826. At the quarry the empty cars were pulled up an incline by an endless chain arrangement. The rails for a part of the distance were wooden longitudinal stringers covered with strap-iron, and the balance consisted of stringers resting on cross-ties.

The second railroad in the United States was built in 1827, at Mauch Chunk, Pa., and ran between Mauch Chunk and Summit Hill, a distance of nine miles. Coal cars were run over it by gravity and were pulled back empty by horses.

6. First Locomotive in the United States.—In 1828 the Delaware and Hudson Railroad Company sent their engineer, Horatio Allen, 1802–1889, to England to inspect the locomotives of the Stockton and Darlington Railroad. Allen ordered a locomotive from a firm in Stourbridge, England. This locomotive had a lion painted on the front and was known as the "Stourbridge Lion." In 1829, this locomotive arrived in New York and was sent to Honesdale, Pa., and on

August 9, 1829, it was put on the track and, with Horatio Allen as engineer, it was run six miles over the Delaware and Hudson Railroad. There were several timber trestles on the road, and as they were thought to be too weak to support the locomotive, its use was abandoned temporarily. This was the first trip made by a locomotive in the United States. Allen lived for sixty years after this incident, and at the time of his death, Dec. 31, 1889, there were over 150,000 miles of steam roads in this country.

7. Locomotives in the United States.—The next experiment at locomotive running was made on the Baltimore and Ohio Railroad in August, 1830, by Peter Cooper, who took a small stationary engine with a single cylinder of three and one-quarter inches diameter, and fourteen and one-quarter inches stroke, and mounted it on a flat car.

"This small engine was placed on wheels 30 inches in diameter which were made for other cars."* "The wheels being small, gearing was used to give velocity." "It worked smoothly, and went from Baltimore, Md., to Ellicott's Mills, 13 miles, with a speed varying from 5 to 18 miles per hour—propelling before it a car with twenty-three persons." "It traversed in half an hour, about four miles in a continued ascent of 13 to 18 feet per mile, and on much of this distance were curves of 400 feet radius." "It returned through the 13 miles in 57 minutes, propelling the car and 30 persons." "It ran through part of the

*Early Motive Power of the Baltimore and Ohio Railroad, Bell.

way, which is level and curved, with a radius of 400 feet, at the rate of 15 miles per hour."

By this time a foundry at West Point, N. Y., was engaged in building locomotives. One was built for a railroad in South Carolina, and in 1832 another was built and put on the Mohawk and Hudson Railroad. This road claims to have run the first passenger train in the United States, in 1833.

8. Miles of Railroad in the United States.—As stated in ¶ 5 the first railroad in the United States was built in 1825, and the second in 1827. By 1830, 122 miles of railroad had been completed and 154 miles were in course of construction. The railroads forming this mileage were the Delaware and Hudson, Baltimore and Ohio, Baltimore and Susquehanna, Camden and Amboy, Mohawk and Hudson, and the South Carolina Railroad, which was the first railroad to have 100 miles of continuous track in operation. All of these railroads were commenced before the trial of the Rocket, with the intention of using horses for motive-power. They were not built with the idea of growing into a system of railroads, with the possible exception of the Baltimore and Ohio Railroad, but were built where traffic demanded easier transportation to central points. After the success of the Rocket, railroads began to develop in an increasing ratio until they formed the vast systems which now join the different parts of the United States. The following table shows the growth of railroads in the United States, the later information being from the Interstate Commerce Commission Reports:

TABLE I.

Year.	Single Track. Miles.	Second Track. Miles.	Third Track. Miles.	Fourth Track. Miles.	Yards and Sidings. Miles.	Total Track. Miles.
1830	122	..	..	..	..	..
1840	2,816	..	..	..	..	..
1850	9,015	..	..	..	..	..
1860	30,600	..	..	..	..	..
1870	52,850	..	..	..	..	..
1880	93,530	..	..	..	..	..
1890	161,400	..	..	..	..	..
1895	180,657	10,640	975	733	43,181	236,186
1896	182,777	10,685	990	764	44,718	239,934
1897	184,428	11,018	996	780	45,934	243,197
1898	186,396	11,293	1010	794	47,589	247,082
1899	189,295	11,547	1047	790	49,224	251,903
1900	193,346	12,151	1094	829	52,153	259,574
1901	197,237	12,845	1154	876	54,915	267,027
1902	202,472	13,721	1204	895	58,220	276,512
1903	207,977	14,681	1304	963	61,560	286,486
1904	213,904	15,284	1467	1047	66,492	298,734
1905	218,101	17,056	1610	1216	69,942	307,924
1906	224,363	17,936	1766	1280	73,761	319,106
1907	229,951	19,421	1960	1390	77,749	330,471
1908	233,468	20,209	2081	1409	79,453	336,621
1909	236,834	20,949	2169	1454	82,376	343,783
1910	240,293	21,659	2206	1489	85,582	351,229
1911	243,979	23,446	2414	1747	88,974	360,565
1912	246,816	24,951	2512	1903	92,019	368,201
1913	249,803	26,271	2589	1964	94,400	375,027
1914	..	27,604	2696	2071	97,333	..

CHAPTER II.

PERMANENT WAY.

ARTICLE II.

BALLAST.

9. Permanent Way.—The permanent way consists of the roadbed, ballast and track, the latter consisting of the ties, rails, rail-joints, spikes, switches and switch mechanism.

10. Function of Ballast.—The main function of ballast is to keep the track in true line and surface. The weight of the engine and train comes on the rails, is carried to the ties by the rails, and the pressure on the ties should be uniformly distributed over the top of the subgrade by the ballast, thus causing the pressure per unit of area on the subgrade to be so small that the track will be firmly supported. Ideal ballast should have the following properties:

1. Give a firm support to the tie.
2. Distribute the pressure over the subgrade.
3. Retain no water.
4. Tamp easily.
5. Not form dust.
6. Not allow weeds to grow.
7. Low cost.

Ballast should allow the water that falls upon it to drain away quickly, thus preventing the premature decay of the ties and the softening of the subgrade. It should give a firm support to the tie and prevent the tie from moving laterally. If ballast drains readily it can be worked during the wet season and in winter, and prevents the heaving of the track by frost in the spring of the year. Ballast should not allow the growth of weeds or form dust in dry weather. Weeds aid in retaining moisture and in causing the ties to decay more quickly, and a dusty track is not only very disagreeable to passengers, but is injurious to the rolling stock, particularly the journals.

11. Materials Used for Ballast.—The materials most generally used for ballast are as follows:

1. Broken stone.
2. Slag.
3. Gravel.
4. Cinders.
5. Sand.
6. Special materials.
7. Sub-soil.

They conform to the above desired qualities in the order named, broken stone being the best.

12. Broken Stone Ballast.—Broken stone makes the best ballast, and is commonly called "Stone Ballast," or "Rock Ballast." It distributes the pressure over the subgrade better than any other form of ballast, the pieces of stone fitting together and acting almost like masonry. The area of support increases with the depth of the ballast, and at a less depth than any other ballast the pressure from the ties is distributed uniformly over the subgrade. It forms an excellent bed for the tie, prevents lateral movement of the tie, and water drains out readily, thus keeping the subgrade dry, and has a minimum tendency to cause the tie to decay. Stone ballast is not as easy to work as some other kinds of ballast, but it holds better than any other kind and can be more readily worked in wet or freezing weather, and despite its higher first cost and the difficulty of handling it, stone ballast is the most economical for heavy traffic. When carefully dressed, it presents the neatest appearance and forms the least dust, which makes it particularly desirable for railroads that have a large passenger traffic.

13. Size of Stone for Ballast.—Maintenance of way engineers differ as to the size to which the stone shall be broken for ballast. A few advocate stone that will pass through a 3½-inch ring, believing that a smaller size will retain too large a proportion of fine material and become too hard and compact. Others specify stone that will pass through a 1-inch ring, because it will tamp even, give a smooth surface and work easily. These sizes always allude to the largest size allowed, it being understood that smaller sizes go with them. It is sometimes specified that all the stone shall pass through a larger ring (from 1 inch to 3½ inches) and none through a smaller ring (¼ to 1 inch).

The Am. Ry. Eng. Assn. recommends that the stone in any position shall pass through a 2½ inch ring and shall not pass through a ¾-inch ring. All engineers agree that no loam or dirt should be allowed, as it would prevent proper drainage, tend to decay the ties, cause dust to form, and grass and weeds to grow; but many engineers prefer a small proportion of stone dust to be mixed with the ballast and to be used on the surface as much as possible. When no fine stone is allowed, the ballast must be handled with ballast-forks, which allows the finer material to sift out in handling.

14. Laying and Depth of Stone Ballast.—When the ballast varies in size the larger stones as much as possible should be placed in the bottom as shown at B, Fig. 1, which will give the best drainage possible. This is very difficult in most cases, however, on account of

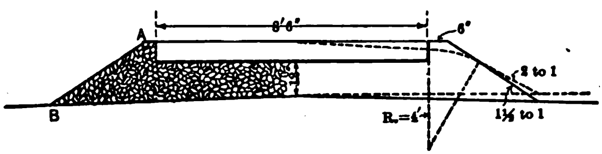

FIG. 1.

the ballast usually being dumped between the rails from hopper cars, or deposited along the sides of the track from flat cars, after the track has been spiked together, and the method of putting the ballast under the track allows very little chance of sorting it into different sizes, and it will be poor economy to go to much expense to arrange the bottom stones, particularly when the subgrade has been properly made, compacted, and shaped.

Stone ballast is the most expensive ballast in first cost, and it is poor economy to make it too shallow; a depth of twelve inches below the bottom of the tie is the minimum that should be used, and for railroads with heavy traffic a depth of eighteen inches below the bottom of the tie is the minimum that should be used.

15. Cross-section of Stone Ballast.—The standard plans for the cross-section of the ballast vary on different railroads, and sometimes on the same railroad there will be different cross-sections for different classes of track, there being a distinction made between main line and branches. The main points specified are as follows: (1) The depth of ballast between the bottom of the tie and the top of the subgrade at the center of the track; (2) the distance of the toe of slope B out from the center line; (3) the point A at which the slope begins; and (4) the shape of the slope.

An important function of the ballast is to keep the track in alignment. This is obtained mainly through the hold that the ballast takes upon the bottom and sides of the tie. The position of the point A is of doubtful importance; there is undoubtedly some resistance to lateral movement obtained from ballast placed at the end of the tie, but this presumably does not amount to much, as a number of standard plans show the ballast sloping directly from the end of the tie.

The cross-section of stone ballast varies from shape shown by the full lines in Fig. 1 to that indicated by the broken lines in Fig. 61, which is the A.R.E.A. standard. When rail-joints of the Bonzano type are used, the cross-section of stone ballast is shaped on the top as indicated by the broken lines, sloping from the center of track downwards towards the sides, so that the bottom of the splice-bars will not touch the ballast.

16. Dressing the Slopes of Ballast.—After the track has been surfaced, placed in full service, and resurfaced after a sufficient amount of use to insure that it will remain in surface and alignment for a reasonable length of time, the toe of slope of the ballast should be dressed to true parallel lines on each side of the track. This is best done by stretching a string and laying the outer and larger stones by hand. If these stones are laid with a bottom width of about six inches and to the true slope as shown in Fig. 2, it will be possible to dress the balance of the slope of the ballast to a true surface with the ordinary tools of the track gang. This adds greatly to the neatness of the roadbed. When there is more ballast than is required for the standard cross-section, it is customary to round the outer slope or to extend the toe of slope B sufficiently to use all the ballast and maintain an uniform shape.

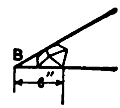

FIG. 2.

17. Rock for Ballast.—Any rock that will not disintegrate under the action of the weather and will not break up under wear and tamping will do for ballast; viz., trap rock, granite, hard limestone, etc. The accessibility of the supply to the point of demand will often influence the choice of rock for ballast. A large railroad system may either operate its own plants at convenient points, or contract with private parties at these points: The amount required will govern this to a great extent. In case the railroad company contracts for its ballast, it is usually delivered on board the cars (f. o. b.) at the quarry, and an inspector will probably be placed at the quarry to watch the quality of the stone crushed, as very few quarries have a uniform quality of rock throughout, particularly limestone near the surface of the ground.

18. Relative Value of Stone Ballast.—Stone ballast retains less water, gives a firmer support to the tie, holding it in surface longer, distributes the pressure over the subgrade, forms less dust than any other form of ballast. On the other hand, it cuts the tie, thereby aiding in its decay; it is hard to tamp, making it expensive to make tie renewals, and has a greater first cost. But everything considered it is the best form of ballast now in use.

19. Slag Ballast.—Slag of the right composition when broken to the proper size makes a ballast which compares very favorably with rock ballast, but its use is restricted to certain localities convenient to furnaces. Slag varies greatly in its suitability for ballast owing both to its composition and the manner of handling it while in a melted condition. Slag should contain no free lime and should be hard and solid with a vitrified or glassy appearance. A porous slag will disintegrate under the action of the elements and break up when tamped, and after a time the particles will cement together, forming a mass that is very difficult to handle when resurfacing the road. If the slag in its molten condition is dumped in a thick mass, the surface will be solid and vitrified, but the interior will be quite porous and unfit for ballast. If the slag is dumped so that it spreads into a thin sheet before cooling, it will be vitrified and solid throughout and can then be broken up into good ballast. This is usually attained by dumping it at the top of a steep slope over which it spreads.

Furnaces are usually glad to get rid of slag; therefore, if the railroad finds a conveniently situated furnace making a slag containing no free lime and dumped so as not to be porous, the first cost of the ballast is in breaking it to the proper size and loading it on cars.

20. Relative Value of Slag Ballast.—Slag ballast is handled with forks and placed under the track in exactly the same manner as broken stone. As stated in ¶ 19, the properties of good slag ballast correspond very closely to those of broken stone ballast, excepting that it has a greater tendency to cut and injure the tie. Some trackmen claim that slag ballast requires more tamping than broken stone, and also has a greater tendency to make the ties decay, and that it corrodes the rails. This can hardly be appreciable if care is taken to see that the slag contains no free lime or chemicals which cause the slag to disintegrate. Slag ballast should be laid with a thickness of twelve to eighteen inches below the bottom of the tie, the same as stone ballast.

In view of the great care required and difficulty experienced in obtaining slag of the right kind for ballast, and its limited use as ballast, it in reality ranks third in importance and comes after gravel ballast.

21. Cleaning Foul Ballast.*—Owing to the collection of dirt and filth on the roadbed the ballast becomes foul and it is necessary to clean it. This is accomplished to a certain extent in the surfacing of the track that is constantly being done by the track gang, but in some cases it is necessary to clean the track in addi-

* Am. Ry. Eng. Assn., 1911 Manual.

tion to the above. Under usual conditions no ballast, excepting stone or hard slag, need be cleaned.

Stone ballast should be cleaned in Terminals at intervals of one to three years. Roads with heavy coal or coke traffic should be cleaned every three to five years; and light traffic lines at intervals of five to eight years.

The cleaning is done with ballast forks. The ballast is cleaned out between the ties to the bottom of the ties; the center of double track is cleaned out to the subgrade. Then such of the ballast as may be fit is forked back together with sufficient new ballast. Usually from fifteen to twenty-five per cent. of new ballast is required.

22. Gravel Ballast.—The third variety of ballast in ¶ 11 is gravel ballast, but the relative rank of gravel ballast depends upon the quality of the gravel. In localities where there is no stone for ballast and there is a plentiful supply of gravel, when the gravel is well washed and assorted, gravel ballast easily ranks first. On the other hand, when the gravel is shoveled up and used without proper cleaning and assorting, it makes a poor ballast, but little better than a sand ballast, or fifth in rank.

Gravel occurs in two forms of deposit; viz., in banks and in the beds of streams. Bank-gravel consists of more or less rounded stones of varying sizes, mixed usually with sand or clay or both sand and clay found in deposits in places which in former ages was the bed of a stream. Stream-gravel is found in the beds of existing streams, and the pebbles forming the gravel are more rounded than those in bank-gravel and do not pack together when tamped as well as the sharper, more angular, bank-gravel.

In many cases a deposit of bank-gravel is found in which the pebbles are the proper size for ballast and the proportion of sand and clay or loam is so small that it makes a fair ballast without any manipulation other than stripping off the surface soil, the gravel being loaded on cars by steam shovels or otherwise, and distributed and used as ballast. It is deposits such as just described that cause gravel ballast to rank low as a ballast. Even the best of such deposits will contain enough sand, clay, or fine material to affect the quality of the ballast, and depending upon the proportion of such fine material the ballast will retain water, give a poor support to the tie, cause the tie to decay more readily, will not distribute the pressure over the subgrade so readily, and will form dust and cause weeds and grass to grow; but it will tamp easily and is cheap.

23. Washed Gravel.—In order to make the best ballast possible out of gravel, some railroad companies have established washing plants at their gravel beds. The Lake Shore & Michigan Southern R. R. had two plants in operation in 1906 for washing gravel for ballast,* being the pioneer in this work. The gravel is loaded on the cars by a steam shovel; the loaded cars are run over a hopper into which the raw gravel is dumped; the gravel is conveyed from the hopper to the top of the washer by a Link-Belt conveyor; the raw gravel and water are discharged together on a flume six feet wide and eight feet long, the water being delivered through an eight-inch pipe to which is attached a special nozzle which spreads the stream; the gravel and water are then discharged

* Railroad Gazette, Sept. 14, 1906.

upon a bar screen with two-inch spaces, thus removing all pebbles larger than two-inch, these large pebbles being discharged into a crusher. The material then passes successively over $\frac{3}{4}$-inch, $\frac{1}{4}$-inch, and $\frac{1}{8}$-inch mesh wire screens. Each size of gravel is run into a separate hopper, and the material that passes the last screen is run into the settler from which building sand is obtained, the sand being a by-product which reduces the cost of the ballast. Cars are run under the hoppers of the bins and any desired mixture of the different sizes of pebbles can be made.

The maximum daily capacity of the newer of these plants is 1500 cu. yds., and the washing costs 22.7 cents per cubic yard, which, added to the cost of 6.5 cents per cu. yd. for stripping the gravel pit, makes the total cost of the washed gravel on the car a little over 29 cents per cu. yd., which is about one-half the cost of crushed stone for ballast.

Washed gravel ballast will drain readily, give a good support to the tie, distribute the pressure over the road-bed fairly well, will tamp easily, will not form dust or allow weeds or grass to grow, and costs much less than rock ballast in some sections of the country. It is claimed by some engineers that gravel ballast gives a more elastic and better riding track than broken stone ballast.

24. Cinder Ballast.—Cinders make a much better ballast than is generally supposed, but as they can only be obtained locally in relatively small quantities, they are mostly used for railroad yards and side tracks. Cinders from roundhouse ash-pits do not contain a very large proportion of ash and undesirable materials and are composed principally of clinkers, slag, burned rock, etc. It is necessary to dispose of this material, and it must be loaded into cars, hauled away and dumped, so the only expense in connection with using it for ballast is that of hauling it to the place where it is to be used and distributing it along the track. The constant supply that comes from this source makes it very convenient for ballast renewals, but it is difficult to obtain enough cinders to use exclusively over a considerable stretch of road. Care must be taken to use cinder comparatively free from ashes. At best, cinder becomes pulverized during the process of tamping and under the action of traffic, and is also liable to disintegrate under the action of the elements and form a mass that will retain moisture in wet weather and form a bad dust in dry weather.

25. Sand Ballast.—The use of sand for ballast should be only temporary. It is far inferior to any of the ballasts mentioned above, and is superior to "mud" ballast only. Where the railroad is so situated that there is no better material for ballast along the line, and all material used must come in over the line from one end, then it will probably be necessary to put the track in temporary surface by using sand. In this case only enough to bed the ties and put the track in surface should be used, so that when the proper ballast is obtained, the sand may be considered as the top of the subgrade. The only advantage of sand ballast is that it is better than dirt ballast. It allows the water to drain out to a moderate degree and exerts a fair tendency to keep the track in surface and alinement. It retains sufficient moisture to hasten the decay of the tie, and it is quite difficult to

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keep it free from weeds and dust. The amount of dust formed by a fast train over a sand-ballasted roadbed is enormous. The sand should be clean, coarse, and sharp.

26. Miscellaneous Ballast.—The cost of transportation in many cases becomes the governing feature in obtaining suitable ballast at an economical cost, and it is more economical to use a poor local material than to transport a better material for ballast a long distance. This has led to the use of a number of materials for ballast. In the anthracite coal regions of eastern Pennsylvania and in some other mining regions, culm, or coal-dust from the breakers, has been used for ballast on branch roads carrying principally freight traffic. It is a mobile substance, having a tendency to spread at the sides of the track. It is not softened by water, does not heave by freezing, and does not grow vegetation. It is easily worked but will not stand bar tamping, and does not make a firm support for the tie.*

Oyster shells are used for ballast in some regions near the Chesapeake Bay. The material is too light for good results and encourages the growth of weeds and grass, but does not form dust, and can be used only under very light traffic.

Decomposed rock, granite, or shale is used extensively for ballast in some parts of the West and South. Decomposed granite makes a better ballast than sand, as it does not form dust or cause weeds and grass to grow, but decomposed shale makes a poorer ballast than clean sharp sand.

In some parts of Arizona volcanic cinder is used for

* Notes on Track, Camp.

ballast. It is excavated from pits with steam shovels and closely resembles burnt clay ballast. In ballasting track it is first tamped with shovels, and surfaced up later with tamping bars.

In regions where neither stone, slag, gravel, cinder, sand, nor any of the above-mentioned materials for ballast can be obtained without an excessive haul, and the subsoil is clay or gumbo, a great deal of *burnt clay* ballast has been used. The clay or gumbo is placed in alternate layers with fuel and burned, thus giving a material which resembles a poor grade of brick. It is drier, although it has a considerable affinity for water, than the original material, and is quite expensive compared to the results obtained, but under the circumstances gives a comparatively good roadbed. It is used extensively in the Mississippi Valley, and some roadmasters who have become familiar with it compare it favorably with gravel and even stone ballast.

27. Dirt Ballast.—Dirt ballast, commonly called *mud ballast*, is, as the name implies, simply the best dirt for the purpose that can be obtained from the excavations made in constructing the subgrade. Dirt is used for ballast only when no other material can be obtained, and then only when it is not of such poor quality that it must be first burned; after the subgrade is finished and the track laid, enough extra dirt is thrown under the ties to surface up the track, care being taken to exclude rubbish, the top soil, and all undesirable material as far as possible.

Dirt ballast gives the poorest drainage, the worst support to the ties, is the most liable to rot the ties, and it is almost impossible to keep weeds and grass out of the track. It is dusty in dry weather and causes the ties to *pump mud* in wet weather. No surfacing can be done between fall and spring, and the track is heaved by the frost. One of the worst features in connection with even the temporary use of dirt ballast is that the ballast becomes practically a part of the subgrade, which makes a very undesirable foundation on account of the uneven surface for a better grade of ballast.

28. Cross-section of Ballast.—The shape of the cross-section of all single track ballast, excepting rock and slag ballast, is shown in Fig. 3. The dimensions and slopes vary with the standards of the particular railroad company, but an outer slope of 1 on 1½ is the steepest slope that will stand. The depth of the ballast E F will depend upon the material used and whether or not it is to be replaced or covered by a better material. All ballast excepting stone, slag, and washed and assorted gravel should be considered temporary. For good gravel ballast it is customary to use a maximum depth E F of about twelve inches. Sand, burnt clay, and dirt ballast should have barely enough depth to allow the tie to be properly embedded and tamped without interfering with the finished surface of the subgrade any more than absolutely necessary. This small depth is much better than a greater thickness. If these inferior ballasts be made too thick, it may be necessary to dig them out before laying the stone ballast, otherwise in getting the proper depth of stone ballast it would require the grade to be raised higher

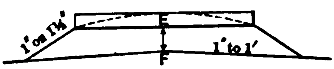


FIG. 3.

than desired, besides the disadvantages mentioned in ¶ 27.

In Fig. 3 it is seen that the tie is not imbedded as in rock ballast, Fig. 1, but that the ballast slopes away from the lower corner of the tie and rises to the height of the top of the tie only at the center. This is on account of the less perfect drainage of the ballast materials with the corresponding tendency to hasten the decay of the tie. It is seen that the track can be pushed out of line more easily than in stone ballast, both on account of the smaller surface of the tie in contact with the ballast, and also on account of all ballasts having a smaller holding force per unit of area of the tie than rock and slag ballast.

29. Laying Ballast.—The kind of ballast to be used is governed by the class of the railroad and the amount of traffic to be carried. On a first-class, or trunk line, railroad the ballast is essential as soon as the track is laid and before the track can be put in operation. The track is spiked together as near as possible to its final location on the roadbed, and put in condition that the construction train can be pushed slowly over it, cars of ballast are pushed ahead on it, and the ballast is deposited on each side of the track, and sometimes in the center of track. The track is jacked up, the ballast is forked under it, and the track is tamped into true line and surface. In this method of ballasting no traffic excepting the necessary construction trains pass over the road until it is thrown open to regular service.

30. Economy and Cost of Ballast.—On a line where the traffic is comparatively light and the ballast must be hauled a long distance, the track is first lined up and surfaced with as little sand or dirt ballast as possible, and is then ballasted by the maintenance of way force working between regular trains, the line in the mean time being in service with speed limits.

Ballast in first-class construction is almost entirely a matter of first cost, being laid immediately. After the full amount of ballast is laid very little more is required to keep the track in true line and surface. On light traffic roads the whole line will not be ballasted at first, and a continuous supply of ballast will be needed until the whole line is ballasted.

The cost of ballast in the track depends upon (*a*) the first cost of the material as it comes to the railroad, or f. o. b. if the supply is along the line, (*b*) on the distance from the source of supply to the place where it is to be used, and (*c*) on the method of handling. The cost of stone ballast in the track averages about $1.25 per cu. yd. Dirt ballast will cost possibly twenty-five cents per cubic yard in the track, the principal part of the cost being for surfacing the track. The other kinds of ballast cost somewhere between these limits.

Article III.

CROSS-TIES AND TIE PLATES.

31. The Function of Cross-ties.—Cross-ties received their name in the first place in order to distinguish this method of supporting the rails from the longitudinal supports, or stringers; they are now generally called *ties*. Cross-ties hold the rails in position and transfer the pressure of the engine and train through the ballast to the subgrade. There has been quite a

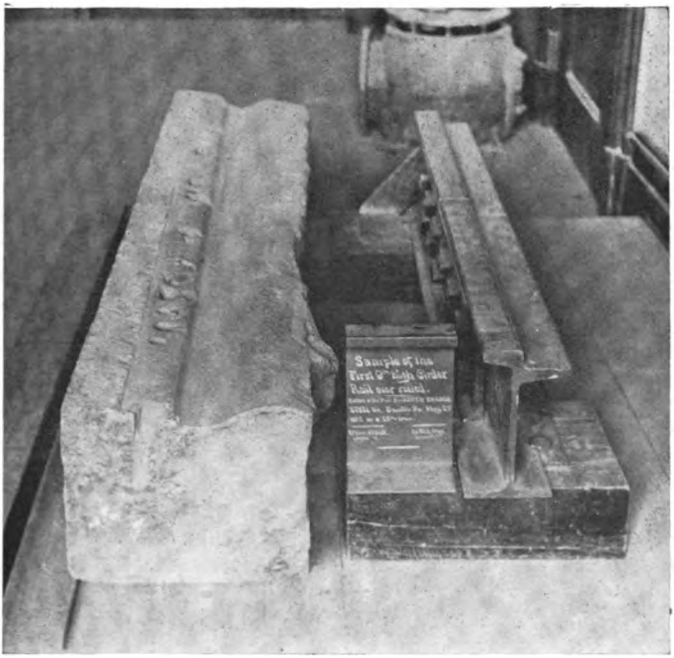


FIG. 4.—STONE STRINGER, PORTAGE RAILROAD.

development from the original rail support to the present tie. The first railroad had longitudinal stone or timber stringers upon which the rails were fastened, the rails consisting of simply enough iron to furnish a wearing surface, while the stringers carried the weight.

In Fig. 4 is shown a stone stringer, the holes by which the iron plate was fastened, and the mark made by the plate.

After rails which would carry the load between supports were invented, the ends of the rails rested on stone blocks, Fig. 5. As the design of the rail improved it was found that wooden cross-ties made a better riding track and were less expensive than stone blocks. There were many different designs for supporting the rail, but the above illustrate the general principle and indicate the line of development.

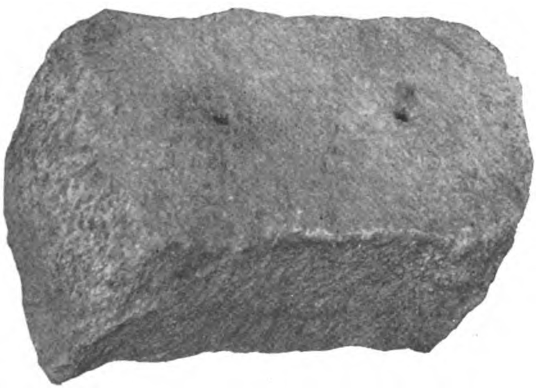


FIG. 5.—STONE BLOCK, FRENCHTOWN AND NEW CASTLE RAILROAD.

32. Kind of Wood for Ties.—When the demand for wood for commercial purposes was less and fewer ties were needed, ties were much cheaper and the better grades of wood could be easily obtained for them, nearly all railroad ties being white oak. Table II shows the cross-tie data for 1907 to 1911.

TABLE II.

Ties Purchased by Steam Railroads of the United States.*

Kind of Wood.	1911	1910	1909	1908	1907	Average Cost Per Tie.	
						1905	1909
Oak	59,508,000	68,382,000	57,132,000	48,110,000	61,757,000	$0.55	$0.60
Southern pine	24,265,000	26,264,000	21,385,000	21,530,000	34,215,000	.42	.52
Douglas fir	11,253,000	11,629,000	9,067,000	7,988,000	14,525,000	.33	.41
Cedar	8,015,000	7,305,000	6,777,000	8,172,000	8,954,000	.44	.46
Chestnut	7,542,000	7,760,000	6,629,000	8,074,000	7,851,000	.48	.44
Cypress	5,857,000	5,396,000	4,589,000	3,457,000	6,780,000	.33	.41
Tamarack	4,138,000	5,163,000	3,311,000	4,025,000	4,562,000	.36	.41
Hemlock	3,686,000	3,468,000	2,642,000	3,120,000	2,367,000	.33	.33
Western pine	2,696,000	4,612,000	6,797,000	3,093,000	5,019,000	.....	.53
Redwood	1,820,000	2,165,000	2,088,000	871,000	2,032,000	.20	.53
Gum	1,293,000	1,621,000	378,000	262,000	15,000	.....	.52
Maple	1,189,000	773,000	158,000	151,000	....	.40	.45
Beech	1,109,000	798,000	195,000	192,000	52,000	.40	.36
All other	2,682,000	2,895,000	2,603,000	3,421,000	5,574,000	.48	....
Total	135,053,000	148,231,000	123,751,000	112,466,000	153,703,000		

* Bulletins, Forest Service, U. S. Dept. Agriculture, Engineering Record, Aug. 16, 1913.

Oak is the most desirable timber for cross-ties, and is found in several varieties, white oak, post oak, and rock oak being the better varieties. Oak is used for many purposes other than ties, and on account of the great demand for it, its slow growth, and its increasing scarcity, the proportionate use of the softer and more quickly growing woods is becoming much greater; the same may be said for long-leaf yellow pine, the great demand for which will soon make it much more expensive. The use of cypress and redwood ties is increasing rapidly.

The price of ties has more than doubled in the last twenty years.

In the Manual of the American Railway Engineering Association for 1911, the following recommendations are made:

1. The following woods may be used for tie timber without preservative treatment:

White oak family.
Long-leaf yellow pine.
Cypress, excepting the white cypress.
Redwood.
White cedar.
Chestnut.
Catalpa.
Locust, excepting the honey locust.
Walnut.
Black cherry.

2. The following woods shall preferably not be used for tie timber without a preservative treatment:

Red oak family.
Beech.
Elm.
Maple.
Gum.
Loblolly, short-leaf, lodgepole, Western yellow pine, Norway, North Carolina and other sap pines.
Red fir.
Spruce.
Hemlock.
Tamarack.

33. Number of Cross-ties Required.—Cross-ties are becoming one of the greatest problems that confront railroad managements. There were on June 30, 1913, according to the Report of the Interstate Commerce Commission, 249,803 miles of steam railroads and 375,027 miles of steam railroad track in operation in the United States, see Table I. According to Table II, 135,053,000 ties were used in 1911, and in addition the steam roads only used about 93 per cent of the total number of ties, the electric railways using 9,454,000, or 7 per cent additional, making a grand total of 144,507,000 ties.

Assuming 2700 ties per mile, there were more than 1,000,000,000 ties in track in the United States in 1914 on the steam roads alone. Under normal conditions an oak tie will last ten to twelve years, and a hemlock tie will last about four years, the other woods having an average life somewhere between these two limits; consequently, as a greater proportion of the softer woods come into use, the average life of railroad ties decreases, being now about seven years. On this basis, 150,000,000 ties would be required by the steam roads in 1915, but the probability is that they will require considerably more.

34. Cost of Cross-ties.—The cost of cross-ties, like the cost of ballast, depends not only upon the purchase price at the point of supply, but also upon the cost of transportation to the place where they are to be used. For this reason the kind of tie used will be governed to a great extent by the available local supply. In Table II is given the average cost of each kind of tie in 1905. Oak is given as 55 cents per tie, but white oak was considerably higher, while some varieties of oak, see ¶ 32, were less. In 1909, the average cost per tie was 49 cents, white oak being about 75 cents and hemlock 33 cents per tie. In 1914, white oak ties could be bought in the East for 80 cents.

The cost of ties has not increased as rapidly as was feared ten years ago, due to preservative and conservation methods. Bulletin 118, Forest Service, U. S. Dept. of Agriculture, deals with methods for prolonging the life of ties. It is claimed that by treating the wood with chemical preservatives, protecting the ties from mechanical wear, and the use of sawed in place of hewed ties, that the annual consumption of cross-ties in the United States can be reduced by at least half.

"To produce the ties used for renewals in 1909, it was necessary to cut about 710,000 acres of timber-land, averaging 5000 board feet, or 150 ties per acre." "The amount of wood so cut is equivalent under present conditions to the annual growth on about 55 million acres of forest."

35. Life of Ties.—The three principal causes which tend to destroy a tie are as follows: (1) Decay; (2) injury in spiking; and (3) the cutting of the tie by the base of the rail. The decay of a tie is governed by the climate, the ballast, the time of the year it is cut, and the amount to which it is seasoned. In the colder and drier climates a tie lasts longer than in the warmer and damper climates. The warm, damp climate and the accompanying destruction by insects shorten the life of a tie to one or two years in some cases. There is a tendency for water to get into the tie through the fibers injured in spiking and to hasten its decay, particularly where traffic is heavy and rails must be replaced, which is done in many cases by driving the spikes in another part of the tie without plugging up the old holes. The amount of the cutting of the tie by the base of the rail depends upon the hardness of the wood and the weight and amount of traffic. This will be discussed later under the head of Tie-plates.

36. Cause of Decay of Wood.—The decay of timber depends upon the amount of sap and water in the wood. Water may occur in wood in three conditions: * (1) It forms the greater part (over 90 per cent.) of the protoplasmic contents of the living cells: (2) it saturates the walls of all cells; and (3) it entirely or at least

* Bulletin 41, Bureau of Forestry, U. S. Dept. of Agriculture.

partly fills the cavities of the lifeless cells, fibers, and vessels; in the sapwood of pine it occurs in all three forms; in the heart-wood only in the second form—it merely saturates the walls. This accounts for the greater durability of long-leaf yellow pine.

It is generally supposed that trees contain less water in winter than in summer. This is evidenced by the popular saying that "the sap is down in the winter." This is probably not always the case.

Decay is caused by low forms of plant life called fungi, which grow in wood, and by so doing disintegrate and dissolve portions of the wood fiber. The necessary conditions for the development and growth of wood-destroying fungi are—(1) water, (2) air, (3) organic food materials, and (4) a certain amount of heat. It is, therefore, necessary to get rid of the water, and as much of the organic food materials as possible.

37. Seasoning Timber.—Seasoning timber consists of drying it into such condition that it will best resist decay. This will be accomplished for most hard woods by cutting it at the best season and then allowing it to dry, or season, thoroughly. This is more important than ever before. Formerly timber was cheap and easy to obtain and very little attention was paid to its lasting qualities, particularly when used for ties. Good tie material has now become so scarce and the price has increased to such an extent that strict attention must be paid to the economy of the question.

Hardwood timber should be cut when the sap is down, as it will then contain a minimum amount of water and sap which contains albuminous substances, starch, sugar, and oils, which form the food-supply necessary to start the growth of the fungus which causes decay. If the timber is cut when the sap is down, there is not only less of the fermenting substance in the wood, but the pores of the wood are more closed and moisture has more difficulty in entering. The best time for cutting timber is between October and March, depending upon the particular region and the kind of timber, January being probably the best time.

All water should be thoroughly dried out of the wood, which is done either by proper exposure to the air for possibly a year or more, or by the quicker and artificial method of "kiln-drying." The better method to use will depend upon circumstances; the cost in the slow, natural method being simply that of piling the timber properly and the interest on the money invested. If ties are not kiln-dried, they should be piled as shown

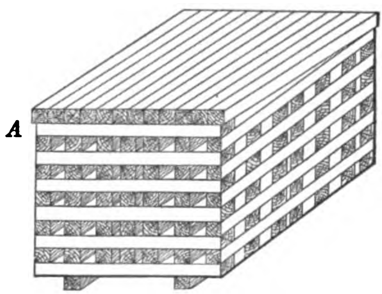


FIG. 6.

in Fig. 6, and allowed to season thoroughly. Spaces should be left between the ties, as shown in the figure, to allow the air free access, and if they are not put under roof, the top layer of ties should be placed as close together as possible in order to protect the pile from rain. It would probably be better to increase the pitch of the covering ties by putting another tie on top of the tie *A* in Fig. 6, and to use two layers of covering ties, the lower layer to have four to six inches space between them and the upper layer to cover these spaces.

After ties are seasoned and delivered for shipment, they are piled as above, excepting that the piles contain fewer ties, usually twenty-five or fifty.

38. Hewed vs. Sawed Ties.—Cross-ties are hewed or sawed to the specified dimensions. There is a quite general opinion that hewed ties are better than sawed ties because the hewing closes the surface pores of the wood, while sawing opens them, thus allowing the water to enter more readily, with the consequent greater tendency to decay. While there may be this difference for untreated timber, it will disappear when the timber is treated with a preservative. One hardwood tie is usually made from each length of small timber, and is dressed to the specified thickness within one-quarter of an inch with true parallel plane surfaces, and the bark removed from the other two faces, and is called a *pole tie.*

On account of the increasing scarcity of timber and the almost criminal waste with which some timber has been cut in the past, the United States Department of Agriculture in its Forest Service Bulletins is advocating various methods for conserving the timber supply, and recommends that all ties be sawed. When only one tie can be made from a length of timber, there is no more waste in hewing than in sawing, since the parts that are chipped or sawed off are too small to make lumber, but where the timber is larger than necessary for one tie, it is more economical to saw the log as shown in Fig. 7. In this case the lower part of the log can be cut into standard three- by four-inch timbers, which otherwise would be hewed into chips that would probably be allowed to decay.

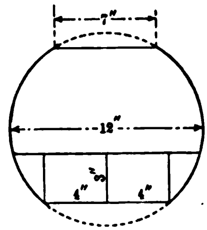


FIG. 7.

For the last eight or ten years, from seventy-five to eighty per cent. of all steam railroad ties have been hewed and the balance sawed, and there has been no apparent change in methods. The probable reason for this is that the railroads obtain the greater portion of their ties, either directly or indirectly, from farmers and small holders of timber who cut such small quantities that it is not economical to have even a portable saw-mill. In many cases the regular farm-hands employed by the year can be utilized for this purpose during slack times, which fortunately is during the winter months, the best season for cutting timber.

Sawed ties give a much more uniform bearing surface for the base of the rail or tie-plate. It is practically impossible to hew a good tie out of a very crooked or twisted log, but it is possible to saw a tie out of such a log, and the resulting tie may be too cross-grained for acceptance, consequently the inspector must pay particular attention to this feature.

39. Size of Ties.—Each railroad has had its own standard sizes for cross-ties, and hardly any two agreed. Many roads classified into first, second, and third class, but on account of the different standards a first-class tie on one road corresponded to a second-class on another, and vice versa. The American Railway Engineering Association, in the 1911 Manual, adopted the following proposed tie classification, which is a class heavier than the 1904 classification:

TABLE III.

Class.	Breadth. Inches.	Thickness. Inches.	Length. Feet.
A	10	7	8, 8.5, or 9
B	9	7	8, 8.5, or 9
C	8	7	8, 8.5, or 9
D	9	6	8, 8.5, or 9
E	8	6	8, 8.5, or 9

Ties in use on steam railroads range in dimensions as follows: Width of the narrowest of the faces, 7 to 12 inches; thickness, 6 to 8 inches; and length, 8 to 9 feet. The average size of a first-class tie is 9 inches wide, 7 inches deep, and 8½ feet long. The ends should be sawed off square. Ties should be laid on their broadest face, as in Fig. 7.

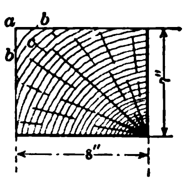


Fig. 8.

40. Inspection of Ties.—For all the softer kinds of wood it is specified that all sap-wood must be removed excepting a limited amount on the corners. The maximum amount of sap-wood allowed on the corners is not more than one inch radially across the grain (*ac*), or 1½ inches on the face of the tie (*ab*), as shown in Fig. 8.

Cross-ties must be smoothly hewed or sawed out of straight-growing timber. They must be of specified dimensions, the ends sawed square, and have parallel plane faces; the minimum width of either face must not be less than that given in the specifications. All bark must be removed before the tie is delivered on the company's ground, and they must be free from splits, worm-holes, wind-shakes, loose or decayed knots, or any other imperfections which may impair their durability. When delivered to the railroad, they must be piled in a specified manner and place. The manner of piling the ties must be such that they can not only be seasoned properly, but they must also be convenient for inspection. They are inspected for the above requirements, marked in a substantial manner, and all the ties not up to specifications are either rejected entirely or accepted as a lower class and paid for at a correspondingly lower rate.

All rejected ties must be removed from the railroad property immediately.

41. Spacing of Ties.—The number of ties per rail length depends upon the standards of the various railroads. These standards are governed to a great extent by the class and amount of traffic, the size and variety of the tie, and the kind of rail joint used. Most railroads have at least two standards of spacing, one for main line and another for yards and sidings. The number of ties used ranges from 14 per 30-foot rail to 19 ties per 33-foot rail. Some railroads use two more ties per rail on curves than on tangents; these railroads seem to be divided into two general classes; viz., those using 16 and 18, and those using 14 and 16 ties per 33-foot rail on tangent and curve respectively. One of the large eastern railroads specifies 16 ties 10 inches wide, 7 inches thick, and 8½ feet long per 33-foot rail. According to the above spacing the number of ties per mile of single track ranges from 2464 to 3040.

42. Planting Trees for Ties.—Ties are becoming scarce and are advancing rapidly in price. In the past, timber has been cut without any provision for the future, and the supply is rapidly becoming exhausted. Formerly it was possible, in the eastern part of the country, to contract for white-oak ties anywhere along the line of the railroads and have them delivered at a point convenient for storage or shipment; in some cases these same railroads are using pine ties and must haul them 1000 miles, and place their order far in advance. One of these roads paid sixty cents for yellow pine ties in 1905, and seventy-three cents in 1906, the price increasing seven cents per tie in six months. The growing scarcity of timber for ties has caused several railroads to plant large tracts of land in timber. Fortunately, land otherwise of little value may be used for this purpose. The Pennsylvania Railroad west of Pittsburg planted catalpa trees along its right of way thirty-five years ago, but the results were unsatisfactory. During the last few years they have been planting yellow locust trees on an extensive scale.* The trees thus planted are seedlings two or three years old, and cost, including labor of plant-

* Jos. T. Richards, before the American Forest Congress, 1905.

ing, about eight cents each. From 1902 to 1906 the above company planted about 1,300,000 trees. "There is probably no other timber which combines so well the qualities of durability and hardness as does the yellow locust." "Evidences of its longevity in use as tie timber are frequent on our road" (Pennsylvania). "The resistance of locust timber to cutting under the rail is said to exceed that of white oak, and it has been demonstrated upon our main lines that it is not so much the decay of the timber as it is the cutting in by the rail, which wears out or decreases the life of the tie." "The average life of a strictly white-oak tie is about ten years—we expect to get longer life out of the locust."

"The requirements for 1906 will cause more than 1,266,000 acres, or 1980 square miles, to be cleared."* "If conservative forestry methods were used and a perpetual supply preserved, a forest of more than 35,000 square miles, or the area of the state of Indiana, would have to be set aside for the timber alone."

43. Preservation of Ties.—On account of the increasing demand for ties, the softer woods used, and the advancing price, it has now reached the point where it is economical to use artificial means of prolonging the life of a tie. This is done in the following ways: (1) Treating the tie to prevent decay; and (2) the use of tie-plates to prevent the base of the rail from cutting into the tie.

The economy of treating depends principally upon two things; viz., the location and the traffic. In sections of the country where decay is rapid, owing to climatic conditions and poor ballast, it will pay to treat the tie

* Railroad Gazette, March 16, 1906.

with some process, not too expensive, that will make the tie last until the wear of the base of the rail causes its destruction, provided the increased life of the tie is great enough to warrant the expense of treating it. In the northern part of the United States, under heavy traffic, the tie is worn out by the base of the rail and respiking before the tie decays, even when tie-plates are used; consequently it would be a useless expense to treat the tie. One advantage of treating ties with a preservative process is that classes of wood that are otherwise of very little value for ties make a serviceable tie when so treated. These soft woods are cheaper in first cost and absorb the antiseptics much more readily than the harder woods, and consequently are cheaper to treat. The use of preservative methods is, therefore, an economical question that must be worked out by each railroad according to local conditions.

44. General Principles of Preservative Methods.—The principle of all preservative treatment of timber is to extract all the sap and then fill the pores of the wood with the antiseptic. Most of the sap and harmful elements are removed by cutting the timber at the proper season and by thorough seasoning (¶ 37). In some of the methods the thoroughness of the seasoning is not of vital importance. There are a number of methods of preserving timber, among the principal of which are kyanizing, Burnettizing, vulcanizing, and creosoting. The cost of all processes of timber preservation depends not only upon the process, but also upon the amount of the chemical used, consequently the cost of creosoting a tie varies from twenty to forty cents.

45. **Kyanizing.**—Kyanizing is the process of soaking the timber in a solution of bichloride of mercury, or corrosive sublimate, for several days, the length of time which the timber is soaked depending upon the dimensions of the timber. A tie seven inches thick should be allowed to soak eight days; and each tie will absorb about one-fourth of a pound of the bichloride. The tie is then allowed to dry in the air for about two weeks. The fumes from the chemical are poisonous and objectionable to work with, and its solubility makes it liable to wash out of the wood and leave it unprotected.

46. **Burnettizing.**—In the Burnettizing method chloride of zinc, $ZnCl_2$, is used. The timber is placed in a vacuum, which removes all of the remaining sap, and then has the solution forced into its pores by pressure. The process costs from twelve to twenty-five cents per tie, depending upon the amount of the chloride of zinc in the solution. This process is subject to the same objection as kyanizing, in that the chemical is rather easily washed out. A peculiarity of the process is that if too much of the chloride be used, the timber is made brittle and its strength reduced.

47. **Vulcanizing.**—In the process of vulcanizing no attempt is made to expel the sap from the wood, the theory being that the heat coagulates the albumen and the distillation of the sap transforms it into various wood-preserving compounds, such as wood creosote. The process consists in placing the timber in a cylinder, heating it to a temperature of 300° to 500° F., under an

air pressure of 100 to 200 pounds per square inch; this coagulates the albumen in the sap, evaporates the water, and partly closes the pores of the wood. It is claimed that the heat sterilizes the wood and produces chemical changes in the wood which give it an antiseptic character. The elevated railroads of New York city used it extensively. In one case where the life of an untreated tie was six years, the treated ties lasted over seventeen years. The treatment costs about 25 cents per tie, and requires about eight hours.

48. Creosoting.—Creosoting consists in impregnating the wood with creosote. Creosote is obtained by distilling either wood or coal-tar. The coal-tar product is called "dead oil of coal-tar," and the wood product is called "wood creosote." Dead oil of coal-tar is more expensive than wood creosote, but is much more efficient as an antiseptic, and is preferred in first-class work. The dead oil should contain no water, ammonia, or ingredients soluble in water, and should be completely liquid at 100° F. The oils most desirable in the oil of tar classes are those which boil at medium temperatures, as those that boil at low temperatures are too volatile and costly, while those that boil at the higher temperatures are too heavy for effective penetration. The latter contain too much solid matter, or substances that harden soon after penetrating the cooler parts of the interior, thus obstructing the pores of the wood before its impregnation is complete.

49. Blythe Process of Creosoting.—There are a number of different methods of creosoting, varying mostly in the details. In the Blythe process there are three stages; viz., seasoning, extraction of the sap and moisture, and the injection of the oil. The ties, if not well seasoned, are sometimes kiln-dried, so as to evaporate all moisture possible. They are then placed in large cylinders, into which live steam is admitted and held for several hours. The object of steaming is to liquefy the portions of the sap which have solidified during the process of seasoning. After the steam is let off the air is exhausted and a partial vacuum is maintained for a time, the result being that the moisture and liquids formed by the steam in the interior of the timber are drawn out, clearing the way for the ingress of the creosote. While the vacuum is held, heat is maintained by steam coils to prevent the vapors from condensing and remaining in the timber. After the products of this treatment are drawn off the cylinder is then filled with creosote at about 175° F., and held under pressure until the desired amount of creosote has been absorbed.

50. Columbia Process of Creosoting.—One of the latest methods is that of the Columbia Creosoting Company, a description of whose plant is given in the Railroad Gazette of March 16, 1906. This company has a two-retort plant with a capacity of 2,000,000 ties per year. The timber is not steamed before injecting the preservative. Only air-seasoned timber is treated and the timber is not exposed to heat of any sort, dry or steam, during the treatment. The ties are placed in the cylinder, and it is filled with oil by gravity from the storage tanks. The pressure pump is then started and additional oil pumped in to give the required saturation, the pressure maintained being 180 pounds per sq. in. The pressure is removed and the oil is allowed to flow from the cylinder to an underground tank; then the free oil in the timber is withdrawn by the creation of an almost instantaneous vacuum by a process which is one of the special features of the plant, and by means of which the amount of oil left in a tie can be varied from 1½ gallons up to any amount required. By this process a 20-inch vacuum can be obtained in fifteen minutes and a 25-inch vacuum in thirty-five to forty-five minutes, a temperature of 160° F. being maintained in the retort meanwhile.

The ties are loaded upon a tram car, which is run into the retort, the ties being held in place by steel bails which are 1⅜ inches in diameter and too stiff to be sprung out of shape by forcing in an extra tie. The loaded car is designed for a clearance of only ¾ inch in the cylinder. The cylinders, or retorts, are 7 feet in diameter and 130 feet long, and are made of ⅝-inch steel with double riveted circumferential joints and triple riveted double-butt longitudinal seams. The cylinders rest in cast-iron saddles bearing on cast-iron plates bolted to concrete foundations. Each cylinder is anchored at the middle, permitting expansion toward both ends, and has a door at each end.

51. Grade of Creosote Used.—"The creosote used is the highest grade obtainable in America, the specifications requiring a boiling point of 220° C., which insures the elimination, before use, of all light and volatile fractions." "The contract price with the Big Four at the Shirley plant is thirty cents a tie"; this contract required 2½ gallons, or eight pounds of oil per cubic foot. Creosoting has long been considered the best method of preserving timber, but the cost of the process has retarded its use. The higher price of timber, and particularly of railroad ties, together with the price of the process of treating the ties being reduced to reasonable figures, brings the economy of using treated timber with renewed force to all who are confronted with the cross-tie problem.

TABLE IV.

NUMBER OF CROSS-TIES TREATED.

1907	19,856,000
1908	23,776,000
1909	22,033,000
1910	30,544,000
1911	31,141,000

52. Tie-plates.—Tie-plates are steel or wrought-iron plates placed between the base of the rail and the tie. Ties are mechanically destroyed by the wear of the base of the rail and by being *spike killed.* The base of the rail wears into the tie as shown in Fig. 9, and this action is accompanied by a shattering of the tie that soon induces decay. The cutting of the tie by the rail is due to the pressure of the rail under traffic, and the movement of the rail, aided by sand and dust, which causes a grinding action. The tie-plate distributes the pressure uniformly over a much larger area, and if properly designed all crushing of the tie will be eliminated; and the wear will be between the rail and the plate.

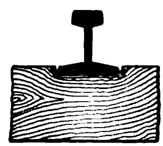


FIG. 9.

The use of tie-plates is economical only when the tie is

TABLE V.
NUMBER OF CROSS-TIES TREATED IN 1911.*

KIND OF WOOD.	CREOSOTE.	ZINC CHLORIDE.	CREOSOTE AND ZINC CHLORIDE.	MISCELLANEOUS.	TOTAL.
Southern pine	9,380,540	1,108,660	258,431	858,761	11,606,392
Oak	5,305,493	2,267,641	1,496,103	363,765	9,433,002
Douglas fir	28,903	3,515,119	....	84,684	3,628,706
Western pine	663,519	669,892	....	455,615	1,789,026
Gum	958,684	214,178	....	9,233	1,182,095
Tamarack	155,819	248,117	312,554	38,934	755,414
Beech	325,868	329,216	74,344	900	730,328
Birch and maple	395,357	101,068	123,122	500	620,047
Hemlock	7,936	....	527,319	....	535,255
Elm	145,670	47,015	98,423	900	292,008
Spruce	83,630	14,178	....	5,000	102,808
Cypress	4,100	....	97,764	....	101,864
Lodge-pole pine	....	92,158	....	....	92,158
White pine	78,273	....	....	....	78,273
Hackleberry	5,700	31,843	25,025	....	62,568
Chestnut	47,338	....	....	200	47,538
Sycamore	400	31,844	....	....	32,244
Cedar	26,000	....	....	....	26,000
Hickory	21,441	....	....	....	21,441
Walnut	....	....	2,000	....	2,000
Ash	1,390	....	....	....	1,390
Cherry	674	....	....	....	674
Total	17,636,735	8,670,929	3,015,075	1,818,492	31,141,231

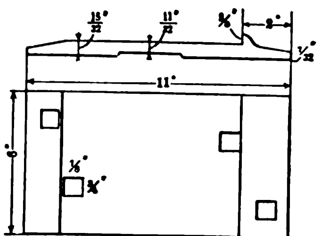
* Engineering Record.

soft enough to be worn out by the base of the rail before its life would be otherwise ended by decay or respiking. Tie-plates would be a useless expense if the tie would hold the rail without them until the end of the natural life of the tie, as will generally be the case with oak ties. The greatest economy comes in using them on soft woods of long-lasting capacity, such as cedar, pine, redwood, etc. In some woods, such as long-leaf yellow pine, the economy of using tie-plates is problematical. It has been estimated that from 10 to 75 per cent of unprotected ties fail by rail and spike cutting.

53. **Tie-plates on Curves.**—Ties on curves are subjected to rougher usage by the base of the rail than on tangents, hence in many cases it is economical to use tie plates on curves when the same class of ties would not need them on tangents. It is good economy to use tie-plates, even on hardwood ties, on curves with a radius of 1910 feet or less, as they also act as a rail brace. A great advantage in using tie-plates on curves comes from the fact that a spike in a tie-plate is twice as effective as a spike used in the ordinary way: Since extra spikes are usually driven on curves, the use of tie-plates reduces the number of spikes required, and therefore prolongs the life of the tie. The life of the tie should in any case be prolonged for a sufficient length of time to pay for the cost of the tie-plates. The conditions are often such that the use of tie-plates is of doubtful economy, in which cases the custom is to put tie-plates on a portion of the track and draw conclusions from the comparative results. Tie-plates that are used on curves should have a shoulder against which the outer flange

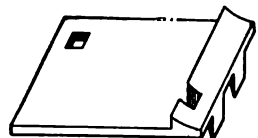
of the base of the rail rests, thus acting partially as a rail brace.

54. Types of Tie-plates.—There are many forms of tie-plates, varying in shape, size, method of holding to the ties, and in other details; but there are two general types, viz., those whose lateral movement is not prevented other than by the spikes, and those that have projections on their bottom face which sink into the



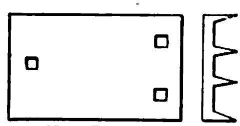
P.R.R. JOINT TIE PLATE

FIG. 10.



GOLDIE TIE PLATE

FIG. 11.



SERVIS TIE PLATE

FIG. 12.

tie. The first type is shown in Fig. 10, and the second type in Figs. 11 and 12.

Tie-plates are made of rolled steel, are from $\frac{3}{16}$ to $\frac{3}{8}$ inch in thickness, and were formerly 5 by 8 or 6 by 8 inches, the greater dimension being at right angles to the rail; but in the latest practice larger tie-plates are used. The Pennsylvania Railroad uses several standard forms of tie-plates, the largest being 6 by 9 by $\frac{15}{32}$ inches for intermediate ties and 6 by 11 by $\frac{15}{32}$ inches for joints. The dimensions for the joint tie-plate are shown in Fig. 10, for 100-pound rails. These plates weigh about 14 pounds per pair. The holes are $\frac{7}{8}$ by $\frac{3}{4}$ inch, which allows enough play for the spike so that the track can be spiked to true gauge.

The second type is illustrated by the Goldie tie-plate, shown in Fig. 11. It has four wedge-shaped points near the four corners of the plate, which cut into the wood at right angles to the grain. The projections or claws are on the ends and 1 inch in from the sides, 1 inch wide, and $\frac{7}{8}$ to $1\frac{1}{4}$ inches long, and have a sharp cutting edge. Another form of the second type is the Servis tie-plate shown in Fig. 12. This tie-plate is held in place on the tie by three or four wedge-shaped projections on the bottom, which sink into the wood parallel to the grain of the wood, and also by the spikes. The rail is held in place by the spikes in the same manner as if it rested on the tie direct, excepting that there are usually two spikes on the outer edge of the rail. This type simply causes the pressure of the rail to be spread over a greater area of the tie and prevents the rail from cutting the tie, and it is doubtful if there is as much resistance to the spreading of the rails as there would be with the same spiking without any plate. They are used on tangents.

It is essential at the present time to double spike all curves, particularly where electric motors with long rigid bases are used. In several serious accidents that have occurred the spikes and rail fastenings were sheared off. It is now customary on the more important railroads to use a tie-plate of the type shown in Fig. 10 or Fig. 11 on curves, with four spikes, two on each side of the rail.

55. Annual Cost.—The annual cost, or depreciation, and the economy of using untreated or treated ties may be determined by the following method:

Let T = cost of untreated tie laid in track.
P = cost of tie-plates and treating the tie.
n = life of untreated tie in years.
N = life of treated tie in years.
r = rate of interest.
S = capital necessary to provide for depreciation.
D = annual depreciation.
C = annual cost of untreated tie.

Placing S at compound interest:

$$S(1 + r)^n = T + S, \text{ from which}$$

$$S = \frac{T}{(1 + r)^n - 1} \quad (1)$$

$$D = Sr = \frac{Tr}{(1 + r)^n - 1} \quad (2)$$

The annual cost, C, of the untreated tie will be equal to the interest on the first cost, plus the annual depreciation, or—

$$C = Tr + \frac{Tr}{(1 + r)^n - 1} \quad (3)$$

56. Annual Cost of Untreated Ties.—From formula (3), assuming the annual rate of interest at five per cent, the following tables have been computed:

TABLE VI.
FOR n = FOUR YEARS.

Cost of tie in track	$0.50	$0.60	$0.70	$0.80	$0.90	$1.00
Annual interest	.025	.030	.035	.040	.045	.050
Annual depreciation	.116	.139	.163	.186	.209	.232
Annual cost	.141	.169	.198	.226	.254	.282

TABLE VII.
FOR n = SIX YEARS.

Cost of tie in track...	\$0.50	\$0.60	\$0.70	\$0.80	\$0.90	\$1.00
Annual interest......	.025	.030	.035	.040	.045	.050
Annual depreciation..	.074	.088	.103	.118	.132	.147
Annual cost..........	.099	.118	.138	.158	.177	.197

TABLE VIII.
FOR n = EIGHT YEARS.

Cost of tie in track...	\$0.50	\$0.60	\$0.70	\$0.80	\$0.90	\$1.00
Annual interest......	.025	.030	.035	.040	.045	.050
Annual depreciation..	.052	.063	.073	.084	.092	.105
Annual cost..........	.077	.093	.108	.124	.137	.155

57. **Annual Cost of Treated Ties.**—By a similar method, T + P being the cost of the treated tie laid in the track with tie-plates, the annual cost is

$$C' = (T + P)r + \frac{(T + P)r}{(1 + r)^N - 1} \quad (4)$$

From formula (4), assuming the annual rate cf interest at five per cent, the following tables have been computed:

TABLE IX.
FOR N = TEN YEARS.

Cost of tie, treatment, and tie-plates in track...........	\$0.90	\$1.00	\$1.10	\$1.20	\$1.30
Annual interest............	.045	.050	.055	.060	.065
Annual depreciation........	.071	.079	.087	.095	.103
Annual cost................	.116	.129	.142	.155	.168

TABLE X.
FOR N = TWELVE YEARS.

Cost of tie, treatment, and tie-plates in track...........	\$0.90	\$1.00	\$1.10	\$1.20	\$1.30
Annual interest............	.045	.050	.055	.060	.065
Annual depreciation........	.056	.063	.069	.075	.082
Annual cost................	.101	.113	.124	.135	.147

TABLE XI.

Estimated Annual Cost of Cross-ties.*

	Estimated Life.			Cost of Ties.					Annual Cost in Track.		
		Treated.			Laid in Track					Treated.	
						Tie-plates.				Tie-plates.	
	Untreated.	10 lbs. Creosote Per Cu.ft.	½ lb. $ZnCl_2$ Per Cu.ft.	Untreated.	Untreated.	Untreated.	10 lbs. Creosote Per Cu.ft.	½ lb. $ZnCl_2$ Per Cu.ft.	Untreated.	10 lbs. Creosote Per Cu.ft.	½ lb. $ZnCl_2$ Per Cu.ft.
	Yrs.	Yrs.	Yrs.								
Black locust	20	..	..	$0.60	$0.75	$1.00					
Redwood	12	..	..	.53	.68	.93					
Cedar	11	..	..	.46	.61	.86					
Cypress	10	..	..	.41	.56	.81					
White oaks	8	..	..	.60	.75	1.00			.155		
Long-leaf pine	7	20	..	.52	.67	.92	1.29				
Chestnut	7	14	11	.44	.59	.84	1.21	$1.01			
Douglas fir	6	15	11	.41	.56	.81	1.18	.98			
Spruce	6	14	11	.49	.64	.89	1.26	1.06			
Western pine	5	17	12	.53	.68	.93	1.30	1.10	....	....	.124
White pine	5	14	10	.43	.58	.83	1.20	1.00	....	....	.129
Lodge-pole pine	5	16	11	.46	.61	.86	1.23	1.03			
Tamarack	5	15	11	.41	.56	.81	1.18	.98			
Hemlock	5	15	11	.33	.48	.73	1.10	.90			
Red oaks	4	20	12	.45	.60	.85	1.22	1.02			
Beech	4	20	12	.36	.51	.76	1.13	.93			
Maple	4	18	12	.45	.60	.85	1.22	1.02			
Gum	3	16	11	.52	.67	.92	1.29	1.09			
Loblolly pine	3	15	10								
Column	1	2	3	4	5	6	7	8	9	10	11

* Bulletin 118, Forest Service.

In Table XI the quantities in column 5 are obtained by adding 15 cents, the cost of laying the tie in track, to the purchase price in column 4; column 6 by adding 25 cents, the cost of a pair of tie-plates, to column 5; column 7 by adding 37 cents, the cost of treating a tie with 10 pounds of creosote per cubic foot, to column 6;

and column 8 is obtained by adding 17 cents, the cost of treating a tie with ½ pound of zinc chloride per cubic foot, to column 6.

58. Cross-tie Economy.—As stated in ¶ 35, the three principal causes which tend to destroy a tie are as follows: (1) Decay; (2) injury in spiking; and (3) the cutting of the tie by the base of the rail. The three causes are all interrelated and the order in which they are given is not important. The means taken to prevent decay are discussed in ¶¶ 35, 36, 37, 38, 43, 44, 45, 46, 47, 48, 49 and 50; and those for preventing the cutting of the tie by the rail in ¶¶ 52, 53 and 54. Injury to the tie in spiking cannot be prevented by anything other than by driving the right kind of spikes in the proper manner, and this will be discussed later.

Columns 1, 2 and 3, Table XI, give the estimated life of ties under the different conditions; columns 4, 5, 6, 7 and 8 give the cost of the tie laid in track under the specified conditions; and columns 9, 10 and 11 are to be computed by the methods in ¶¶ 56 and 57.

Tables similar to VI, VII, VIII, IX and X may be used for comparison when the costs are given in multiples of \$0.10 and the values of n and N in the tables correspond to those in columns 1, 2 and 3, Table XI.

Example.—Suppose red oak ties can be bought and delivered for \$0.45, and laid in track for \$0.15, and the tie can be Burnettized (½ lb. $ZnCl_2$) for \$0.17, and can be laid in track with tie-plates for a total cost of \$1.00, then from Table XI we find that n = 4, and N = 12. From Table VI, the annual cost is \$0.169; and from Table X, the annual cost is \$0.113. This shows that there will be an annual saving of $0.056 per tie by treating it provided it is not *spike killed.*

In order to fill out columns 9, 10 and 11, Table XI, the quantities must be computed by formula (3), ¶ 56, and (4), ¶ 57. On account of the great variation in price in the same kind of ties at different places, columns 9, 10 and 11, Table XI, are computed for the average values given, in order to obtain comparative costs: For instance, the average price of white oak ties is given as $0.60, but they are none too plentiful in the east at $0.80 per tie.

59. Problem 1.—Compute columns 9, 10, and 11, Table XI, for each of the woods following long-leaf pine.

60. Metal Cross-ties.—Metal railroad ties have been in use in Germany for fifty years, a report having been made on them in 1868. At first they followed along the general lines of the earliest railway track in endeavoring to make a practically continuous rail by using longitudinal metal sleepers, or stringers, instead of cross-ties, and in 1889, the German railways had 6180 miles of stringers and 3720 miles of metal cross-ties, and in 1900 the metal stringers had almost disappeared and there were 10,695 miles of metal cross-ties. In 1903, 11,534 miles of main track had metal ties, and 32,102 miles had timber ties.* In 1911, about 6750 miles of track were laid with steel ties on Prussian Railways. In Switzerland, in 1902, about 55.4 per cent., and in 1911, about 64.9 per cent. of the railway

* Engineering News, June 26, 1913.

mileage was laid with steel ties. On the other hand, the Netherlands State Railways and the Belgium State Railways have abandoned steel ties.

61. Steel Cross-ties in the United States.—It is hardly more than ten years since the increasing scarcity of timber for ties began to be felt seriously in the United States, and instead of looking for a substitute for timber, railroads have been giving their attention to lengthening the life of timber cross-ties.

The use of steel ties in the United States on railroads is still in an experimental stage. A number of railroads have laid experimental stretches of track with steel ties containing from 10 to 3000 ties. In a number of cases they were removed in a short time, having been unsatisfactory for various reasons, one being that the method of fastening the rail to the tie was too weak. Manufacturers have improved these weak points until now it is a question of economy and maintenance. It is very difficult to get data on steel ties; as stated above, many of the earlier experiments were abandoned in a short time, and those still in track have been down too short a time to give a proper comparison, especially as, at the present prices, steel ties must last between twenty-five and thirty years in order to compete with wooden ties. Steel ties are probably better on industrial tracks, particularly where hot material is being conveyed, in mines, and in street railway tracks where the tie is embedded in concrete, and the use of steel ties in the United States is increasing along these lines. In 1906 about 50 miles of I-beam ties were laid, and in 1914, the Bessemer and

Lake Erie had about 380 miles of track laid with Carnegie steel I-beam ties.

62. Carnegie Steel Ties.—There are two general types of steel ties, viz., the I-beam and the trough-shaped tie. The Carnegie Steel Company makes both

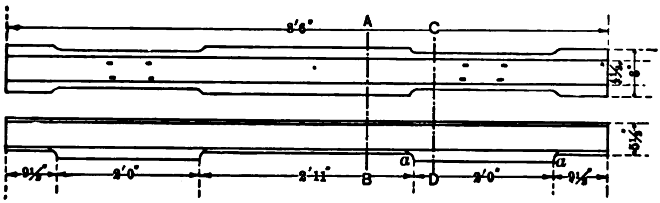


Fig. 13.

types, the I-beam tie being designed for the standard railroad use, and the trough-shaped for industrial and mine tracks. In Fig. 13 is shown the plan and eleva-

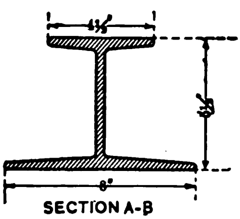


Fig. 14.

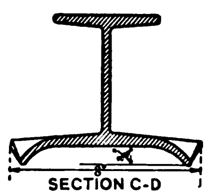


Fig. 15.

tion of the Carnegie M–21 ties, the holes punched for 80-pound and 100-pound A.S.C.E. rails also being shown. The tie is 5½ inches high, 8½ feet long, and weighs 170 pounds, or 20 pounds per foot of tie. The cross-section AB of the main part of the tie is shown in Fig. 14; the top or head to which the rail is fastened is 4½ inches wide, ½ inch thick at the center, and $\frac{5}{16}$ inch thick near the edges. The web is ¼ inch thick, and the base is 8 inches wide, ½ inch thick at the center, and $\frac{3}{16}$ inch thick near the edges. The cross-section CD is shown in Fig. 15. In order to prevent the tie from moving in the ballast, at 9½ inches from each end of the tie the base of the tie is bent down into a trough shape as shown at *aa*, Fig. 13, and in Fig. 15; the bent portion *aa* is 2 feet long and projects ¾ inch below the base of the tie; there are four of these projections as shown in Figs. 13 and 15.

The rail is fastened to the tie by means of the clips shown in Fig. 16, the right-hand part of the figure showing a joint clip, and the left showing an ordinary clip. These clips are designed and shaped so that the gauge can be adjusted a small amount, the holes in Fig. 13 being oval, and be tightened and hold the rail firmly in place after the parts become worn. The bolts are ¾ inch in diameter, 3 inches long from the inside of the head, and the head of the bolt is set at an angle so that it will have a firm bearing against the lower, beveled face of the head of the tie.

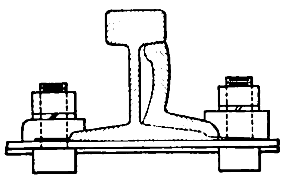


FIG. 16.

The cost of the tie includes the four bolts and four clips.

The first Carnegie tie consisted of a plate 4½ inches wide, riveted to the top, and a plate 8 inches wide, riveted to the bottom of a 4-inch I-beam. In the first rolled tie, the projections *aa*, Fig. 13, were only a few inches long.

Three other weights of the I-beam tie are made, the width of head, depth of tie, width of base, and weight per foot of tie respectively, being as follows: 5 inches, 6½ inches, 10 inches, 27.8 pounds; 4 inches, 4¼ inches, 6 inches, 14.5 pounds; and 3 inches, 3 inches, 5 inches, and 9.5 pounds. A special clip, in a general way like a tie-plate and clips combined riveted to the tie, is used on the heaviest tie.

63. The York Process for Rolling Steel Ties.—This method is shown in Fig. 17, the figure represent-

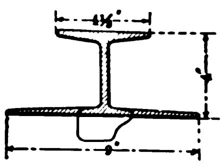


FIG. 17.

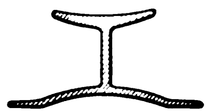


FIG. 18.

ing the section of a worn-out 65-pound rail, which has been rerolled so that the head of the rail has been changed into the base of the tie, the base of the rail and the web being unchanged. The tie is 4 inches high, 4½ inches wide on the head, and 9 inches wide on the base.

By the York Process the rail may be rolled into the shape shown in Fig. 18, with concave head and base, the idea being that this form gives elasticity to the track.

64. The Hartford Steel Tie.—The Hartford tie is of the trough-shaped type, and the cross-section of one form of it is shown in Fig. 19. There are several modifications in the shape of the Hartford tie, the principal one being in the amount the ends are turned down so as to resist lateral motion. In* 1889 the New York Central and Hudson River R. R. laid 721 Hartford steel ties 8 feet long under 80 pound rails on a stretch of 1576 feet of stone-ballasted main track. The ends of these ties curved downward about 6 inches; with the exception of the ends, the tie was straight. These ties were rolled Bessemer steel, weighed 150 pounds, including fastenings, and cost $3.11 each. Before laying the ties they were treated with a coating of asphaltum composition applied at a temperature of 300° F. The results with

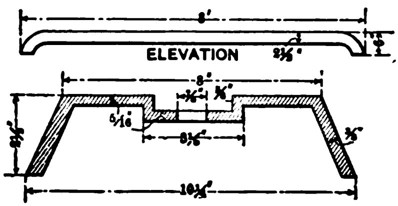


Fig. 19.

this tie were not entirely satisfactory. Although it made a good showing so far as durability was concerned, it was found difficult to throw the track in line and the expense of keeping the track in surface was about twice the cost of the same maintenance item in an equal length of track laid on wooden ties. The tendency of the ballast was to work away from the tie at the ends, loosening the tie and causing it and the fastenings to rattle while trains were passing. These ties were removed after ten years' service under about 50 trains per day.

* Camp's Notes on Track.

65. Cost and Economy of Steel Ties.—The disadvantages of steel ties in ordinary ballast are: (1) difficulty of keeping the track in line and surface, (2) the working loose of rail fastenings, and (3) the high cost. Steel ties seem to have given satisfaction in some parts of Europe and on short stretches of some railroads in the United States, but wooden ties have not become expensive enough in this country to warrant a change, excepting as mentioned in ¶ 61. There is no question of the durability of the metal itself, but, as mentioned above, they are harder to maintain, and the fastenings tend to work loose. The roads with heavy traffic will not take up the question of steel ties seriously until the scarcity and high cost of timber compel them to do so, although they seem willing to experiment with them.

The cost of a steel tie depends principally upon its weight, and in round numbers the cost in track may be said to range from $2.75 to $3.75. If a treated wooden tie with tie-plates costs $1.75 in track and lasts fifteen years, in order to be economical a steel tie which costs $2.75 in track must last about twenty-five years, give as good track, and be as cheap to maintain.

66. Concrete Cross-ties.—It would be useless to attempt to try to describe the many forms of concrete ties that have been invented. In the effort to find a substitute for wooden ties a number of different forms of concrete and reinforced concrete ties have been patented. A reinforced concrete tie which the Ulster and Delaware Railroad has laid as an experiment is described in the Railroad Gazette of Sept. 23, 1904. This tie is shown in

Fig. 20, and consists of a solid prism of concrete, 8 feet long, 7 inches thick, and battered from 10 inches wide on the bottom to 8 inches at the top. They are molded in wooden forms and are reinforced by a piece of $2\frac{1}{2}$ by $\frac{5}{16}$ inch angle-iron 7 feet long, placed with the corner $\frac{1}{4}$ inch below the top surface, and extending to within 6 inches of the ends of the tie. Tie plates 8 by 9 inches and $\frac{1}{4}$ inch thick are embedded flush with the top of the tie on intermediate ties and 8 by $10\frac{5}{8}$ inches under joints. The rails are fastened by two $\frac{3}{4}$ by $3\frac{1}{2}$ inch square-headed bolts passing through the angle-iron and plate as shown in the figure, and by means of cast-iron clips. The clips are shaped as shown in the figure, the dimensions being

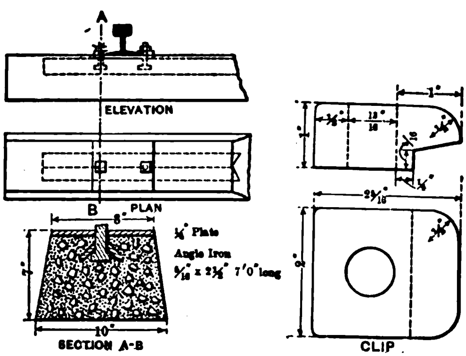


FIG. 20.

$2\frac{5}{16}$ by 2 by 1 inch over all, with a $\frac{13}{16}$ inch hole for the $\frac{3}{4}$ inch bolt, the grip of the clip having the proper angle to fit neatly over the flange of the rail. A mixture of one part of Portland cement, two parts of coarse sharp sand, and four parts of crushed limestone which would pass through a $\frac{3}{4}$ inch ring was used, and the reinforcement was old angle-iron, some of which was $\frac{3}{8}$ inch by $3\frac{1}{2}$ inches by 7 feet. The cost of the tie was 42 cents, exclusive of the reinforcement, and the weight was about 450 pounds. One of the first of these ties showed no signs of failure or of loose joints after being in the track more than a year.

67. Economy of Reinforced Concrete Ties.—Most forms of concrete ties cost nearly or quite as much as steel ties, and must have a long life in order to be economical. The results of some experiments show this form of tie to be a failure when placed in stone ballast under heavy traffic. In reinforced concrete ties the concrete shows a tendency to break away from the steel, and it is also difficult to keep the fastenings that hold the rail to the tie from working loose. The fact that some concrete ties laid on a concrete foundation for city railways have shown good wearing and lasting qualities leaves this method a possibility for the permanent way that all engineers hope to see perfected.

ARTICLE IV.

RAILROAD SPIKES.

68. Function of Spikes.—The functions of the spike are:—(1) to keep the rails from spreading, and (2) to hold the rail to the tie, both being of equal importance.

Close observation of a passing train shows that there are four supports that undergo depression under the moving locomotive, viz., the rail, the tie, the ballast, and the roadbed, each acting in the order named. If the rail is spiked tight against the tie, the first two depressions act together, but in either case the amount of the depression is quite noticeable. The depression of the ballast and roadbed is felt rather than seen. Fifteen or twenty years ago, when white oak ties were much cheaper and generally used, when the ballast was of poorer quality than is used now, and on account of the great holding force of the common spike in oak timber, there was considerable discussion about the kind of spike to use. The traffic lifts the spike, thus allowing a vertical play between the rail and the tie, and also allowing all four of the above depressions to take place.

It was maintained by a great many that since the wave movement of the track could not be prevented, it was better not to fasten the rail rigidly to the tie, in which case the tie would pump up and down in the ballast, which would destroy some kinds of ballast. Excessive play between the rail and the tie was prevented by driving the spike down whenever necessary.

At the same time others, foreseeing the conditions we have now, viz., softer ties with a smaller holding force and still less when the tie is treated, argued in favor of a spike which would hold the rail rigidly to the tie, and also contended that a better spike together with good ballast would give a much better track, both as to riding and maintaining.

Regardless of all arguments, the fact remains that the common spike in some form is still used upon the much greater part of the track mileage of the United States.

Practical experiments show that while a good track may be maintained by driving back the spikes in white oak ties, it is practically impossible to do so in soft timber. When the spike loosens, the tendency of the rail to spread causes the spike to crush the fiber of the wood and loosen still more, which not only kills its holding force but also allows rain to enter and cause decay, and also necessitates the driving of another spike; this soon causes the tie to be spike killed.

69. The Ideal Spike.—A well-designed spike should give a maximum holding force with a minimum injury to the tie. The life of the tie can be prolonged to such an extent by treatment and tie-plates that the injury to the tie due to spiking is now the most important item in the economic use of ties. If a driven spike is to be used, it is necessary to study the shape of the point of the spike and the manner of driving most suitable for the kind of timber used, viz., whether they are to be driven with or without first boring a hole of suitable size and depth. Where a driven spike will not give sufficient holding force, a screw spike must be used.

70. Common and Channeled Spikes.—The common spike is shown in Fig. 21; the shape of the head is an irregular oval, the cross-section of the main part of the spike is $\frac{9}{16}$ or $\frac{5}{8}$ of an inch square, the clear length is 5, $5\frac{1}{2}$, or 6 inches, and the end may be wedge-shaped, as shown, or beveled, as shown in Fig. 23, and from $\frac{3}{4}$ to $1\frac{1}{4}$ inches long. The angle *c b a*, Fig. 21, which the lower face of the head of the spike *b c* makes with the horizontal (when driven) *b a*, must be the same as the slope of the base of the rail, thirteen degrees, so that

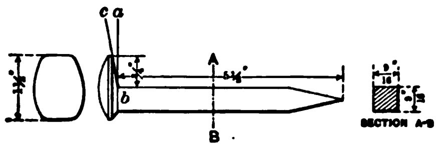


FIG. 21.

there will be perfect contact between the spike and the rail when the spike is driven vertically. The general custom is to use 5-inch spikes in hard wood and 5½-inch in soft wood when the tie-plates are not used, and spikes ½ inch longer when tie-plates are used.

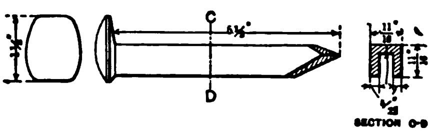


FIG. 22.

The channeled spike is shown in Fig. 22, the only difference between it and the common spike being in the size and shape of the cross-section, the open side of the channel being on the face opposite the edge of the rail. A series of tests * shows the channeled spike to have about 12 per cent. more holding force than the common spike.

The common spike is heavier than the channeled spike,

* Circular 46, Forest Service, 1906.

165 common spikes 5½ inches long weighing 100 pounds, and 200 channeled spikes weighing 100 pounds.

71. Points of Spikes.—One of the most important things in a spike is the shape of its point. If the point is too blunt, it damages the tie considerably in driving, the fibers of the wood being injured for quite a distance around the spike, which will allow moisture to enter and cause the tie to decay. On the other hand, if the point is too long, while there is less injury to the tie, a large portion of its holding force is lost. The point of the spike must be symmetrical in order to insure accurate driving, otherwise it will either crowd the rail out of true gauge or not hold firmly against the rail, which will allow the wheels to crowd the rail out of gauge.

The common spike has a simple wedge-shaped point, but many other and more elaborately shaped points have been designed. The wedge-shaped points are either rolled or cut with a die. When cut with a die, the point may be made sharper, but the edges are liable to be uneven, which tends to prevent the spike from driving true. The edges of a rolled spike will be slightly rounded, but perfectly uniform in shape.

In Fig. 23 is shown the point of the Goldie spike, the first sketch in the figure showing the wearing face, or the face toward the rail, and the second sketch shows the side view. The point of the spike is 1½ inches long, the lower part being beveled for a distance of ¾ of an inch as shown, making a sharp point.

In Fig. 24 is shown the standard spike of the N. Y. C. and H. R. R. R., for Carolina pine ties. It is quite similar to the Goldie spike, the proportions being different, the main point being longer and the sharpened part of the point being shorter.

The point of the Pennsylvania R. R. standard spike is shown in Fig. 25. It is 1¼ inches long and is rolled.

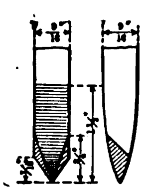


FIG. 23.

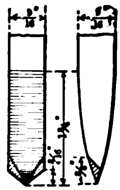


FIG. 24.

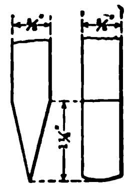


FIG. 25.

72. Screw Spikes.—As stated in ¶ 68, in soft wood ties the spike not only pulls out more easily, but works loose, destroying the fibers of the surrounding wood, etc. This tendency of spikes to work loose has, since the beginning of steam railroads, inspired men to invent a device to overcome this defect, and has led to the recommendation of screw spikes.

Screw spikes have taken two general forms, viz., a pointed lag screw, and a blunt screw (Fig. 26) weighing

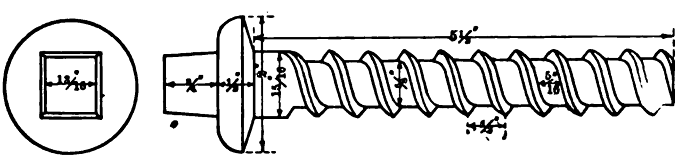


FIG. 26.

85 spikes per 100 pounds. In circular 46, Forest Service, U. S. Department of Agriculture, are given the results of a number of experiments on the holding

force of railroad spikes in wooden ties. The common channeled, and screw spikes were driven into white oak, red oak, loblolly pine, hardy catalpa, common catalpa, and chestnut. A comparison was also made on the relative holding force of clear wood and knotty wood, also between wood steamed at various pressures and natural wood; the latter being for the purpose of showing the effect of tie treatment on the holding force. The results show that the screw spike has in some cases from two to three times the holding force of driven spikes, excepting in loblolly pine they were equal. Steaming does not affect the holding force seriously.

Screw spikes are screwed into a hole that is bored with the same diameter as the main body of the spike. The spike in Fig. 26 would require a hole $\frac{5}{8}$ inch in diameter, and care must be taken to see that the hole is bored deep enough. This method was used in the above. The practical way to test screw spikes, or any other track detail, is to place them in the track and watch the results for a number of years. This method was used by Mr. G. J. Ray, Chief Engineer of the D. L. & W. R. R., and described in the A. R. E. A. March Bulletin, a synopsis of which is given in the Engineering Record, April 3, 1915, the general heading being, "Screw Spikes Give Satisfaction on Delaware, Lackawanna & Western Railroad."

73. Wear of Spikes.—In addition to the possibility of the spike shearing off under unusual strain, if the rail works loose, the inner face of the spike is worn away, as shown by the shaded portion of Fig. 27. To counteract this decrease of cross-section additional metal has been placed in the opposite face of the spike, as shown by the slanting portion *a b* of the same figure. This additional metal must never be put on the inner face of the spike, next the rail, as it would make the spike difficult to drive properly. It is very important that a spike should have this additional amount of metal to increase the strength against shearing, as several accidents have happened recently in which the spikes were sheared off for several rail lengths. In any case the rails will spread an amount equal to the depth to which the spike is worn.

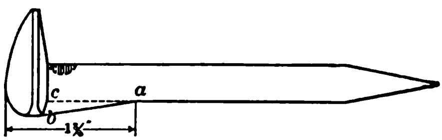


FIG. 27.

74. Common vs. Screw Spikes.—Where the common spike presents a square surface to the edge of the rail and the fiber of the tie, the screw spike presents a round surface, which possibly makes the tendency of the rails to spread greater with screw spikes, as the wear will be greater and the lateral pressure on the rail will cause a greater tendency to crush the fibers of the wood and allow the screw spike to move laterally in the tie. This difference will be eliminated when the screw spikes are shaped as in Fig. 26, particularly if tie-plates with special lugs around the outside holes are used.

In the case of poorly ballasted and tamped track the pumping of the tie may in some cases tear the heads off the screw spikes where the common spike would pull out a short distance; therefore the common spike a better adapted to the wave motions of the track in such cases, but the comparison would not hold for first-class track.

Special machines are necessary to insert screw spikes, making them both more costly and causing more delay than the common spikes in track-laying. This is so particularly in the case of replacing an occasional tie by the track gang. It has been suggested that in order to reduce the delay to traffic every third or fourth tie be spiked so the trains may pass with a slow-up order, and then use screw spikes on the other ties.

In hardwood ties, in relaying rail and regauging track, it has been found that after a certain time the thread of the screw spike united with the fiber of the wood by rust, and that the head of the screw spike will twist off before the screw will move, which requires a new spike to be driven in another place, with the consequent damage to the tie. These reasons tend to make the common spike a favorite with trackmen and maintenance-of-way officials.

The item of first-cost and expense of driving should not be allowed to prevent the use of screw spikes until their annual cost has been investigated by the methods of ¶ 57.

75. Rail Braces.—Rail braces are used to prevent the outer rail on a curve from overturning or spreading. If sound ties are used and the rail is double spiked or the proper form of tie plate is used, rail braces will be unnecessary; but if there are no tie plates and the spikes begin to hold poorly, rail braces must be used. The number of braces to use per rail length will depend upon the degree of curve and the condition of the ties. If the curve is sharper than a six-degree and the ties are poor, it may be necessary to have a brace on every tie, and almost certainly there should be a brace on every other tie; if the ties are in fair condition, three or four braces per rail length may be enough. The plainest and smallest rail brace for an intermediate tie is shown in Fig. 28, and is made of rolled steel. There are many forms of rail braces, most of them being larger and more elaborate in design than the form shown.

In the elevation Fig. 28 the surface represented by *a b* fits against the lower face of the head of the rail, *b c* against the web, and *c d* against the flange of the rail. Rail braces are used on the main rail opposite switch-point rails, in which case they are shaped as in Fig. 29,

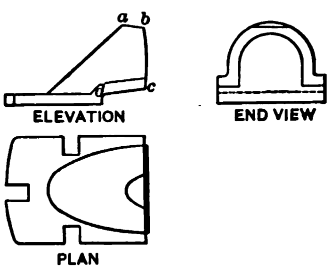


Fig. 28.

Fig. 29.

the part *e f* being long enough to be spiked at the end and to allow the switch-point rail to slide back and forth over it.

Article V.

RAILROAD RAILS.

76. Development of Railroad Rails.—The first trams or wagons used on railroads had flat, or flangeless, tires. The first form of iron rails for flangeless wheels consisted of plates of cast-iron fastened to longitudinal stringers, the plates being used to give a better wearing surface and less tractive resistance, and were three feet long.

In order to keep the flangeless wheels on the rails, angle rails (Fig. 30) were used. These rails were made of cast-iron in three-foot lengths, and were supported on stone blocks, the vertical flange being placed on the outside, the wheels running on the horizontal inner flange. These rails were in use as early as the year 1800. By the time of the introduction of the steam locomotive, 1825, flanged wheels were in use, and the rails had to be modified accordingly.

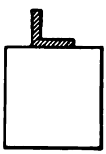


Fig. 30.

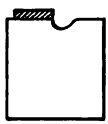


Fig. 31.

The arrangement of the plates was modified as in Fig. 31, and the angle rail in Fig. 30 was arranged so that the wheels ran on the top of the vertical flange. Angle rails were in use as late as 1837 on the Albany and Schenectady Railway.

77. Bridge Rails.—The term bridge rail was used to distinguish rails that rested upon supports placed at intervals from rails resting upon longitudinal stringers. This distinction has no significance now, as all rails are bridge rails, but in the early days of rail design it was of vital importance. One of the first attempts to do away with the continuous, or stringer, support is shown in the rail in Fig. 30 and described above. The first attempt to design a bridge rail resulted in the "fish-belly" rail shown in Fig. 32; it was made of cast-iron in three-

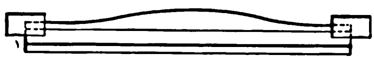


FIG. 32.

foot lengths, the rails being fastened in chairs which were fastened to and supported by stone blocks. Its name was derived from its shape, the belly being designed to put the additional metal where it was most needed. The fish-belly rail was invented before the steam locomotive came into use, and in 1820, in England, a process was invented by which the fish-belly rail could be rolled from wrought-iron in lengths of 15 to 18 feet. Until 1850 the flat wrought-iron strap spiked to longitudinal wood or stone stringers, the stringers resting on widely spaced cross-ties, was used extensively in the United States. A number of other forms of rail were used here, but they were imported from England.

78. Stevens Rail.—The first form of the present flange rail, or T-rail, section was invented in 1830 by Col. Robert L. Stevens, chief engineer of the Camden and Amboy Railroad. The Stevens rail was rolled in different forms: the form shown in Fig. 33 was used on the Boston and Albany Railroad and other roads;

another form, shown in Fig. 35, was called the *pear-shaped* rail, and was used extensively. In Fig. 36 is

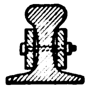


FIG. 33.

FIG. 34.

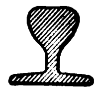


FIG. 35.

shown the section of one of the old-pear-shaped rails. A piece of this rail with its *chair-splice* is shown in Fig. 50. The rail and its splice were found in excavating along the Camden and Amboy Division, the end being sawed off and presented to the author.

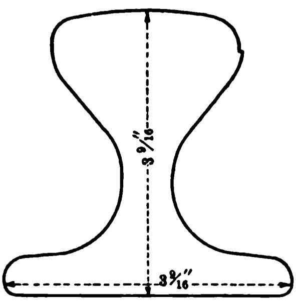
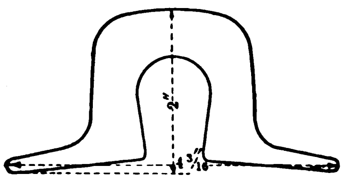


FIG. 36.

The Stevens rail necessitated a new method of fastening the rail to the ties and a new means of joining the rails together, and Col. Stevens, about the same date, invented the hook-headed spike and the flat splice bar, improved forms of both of which are in universal use.

After 1830 many forms of rails were invented, nearly every railroad having its own special form. In 1834, the hollow rail, Fig. 34, was invented and used to some extent, particularly in England. The first form of the hollow rail weighed 44 pounds per yard, the rail being 1¼ inches high, and was fastened to the supports by screws, the head of the inner screw being countersunk. The later forms of this rail weighed 70 pounds per yard, were 2½ inches high, and were screwed to longitudinal wooden stringers 9 by 15 inches in cross-section, the stringers being bolted to 5 by 8-inch cross-ties at intervals of 9 or 10 feet.*

79. Manufacture of Rails.—The hollow or *U-shaped* rail was first rolled in this country in 1844, and the Stevens rail in 1845. Wrought-iron was used for rails until 1855, when the first steel rail was made in England. Ten years later, 1865, steel rails were rolled



Rolled at Mt. Savage, Md., 1845.
FIG. 37.

experimentally, and to order in 1867, at Johnstown, Pa. The introduction of the Bessemer process of making steel marked the beginning of a great advance in the art of rail manufacture, the great reduction in cost of steel rails made by the Bessemer process causing them to come into general use. Up to 1905 practically all the rails in use in the United States were Bessemer rails, but about 75 per cent of all the rails rolled in 1914 were open-hearth, and a large portion of the remaining 25 per cent. were made by the duplex method. Until about 1900 no widespread fault was found with the steel rails in use. Of late years an increasing number of accidents have been attributed to defective rails,

* Roads and Railroads, Gillespie, 1857.

and a much greater proportion of rails prove defective under traffic. Several reasons have been advanced in explanation of the defects, the only unanimous verdict being that the rails are not standing their work and must be strengthened. One of the causes of rail failures is that the rolling loads and speed are now greater in proportion to the weight of the rail than they were formerly. Some engineers blame the method of manufacture, claiming that formerly rails were rolled at a lower temperature and passed through the rolls a greater number of times. Others claimed that the sections then rolled were of such size and shape that every particle of the cross-section did not receive the same amount of work in rolling; and there was also a difference of opinion as to the proper chemical composition of rails. This discussion led to the changes in composition and shape described in the following paragraphs.

80. Chemical Composition of Steel Rails.—There have been a great deal of discussion, scientific investigation, and experiment on the proper chemical composition of railroad rails. The main element governing the properties of steel is the percentage of carbon, and at one time those interested were divided into two parties, one advocating carbon as low as 0.20 per cent., and the other as high as 0.60 per cent., while at present some of the specifications call for carbon as high as 0.80 per cent. At the present time every prominent scientific society interested in the question, the manufacturers of steel rails, and many of the railroads have corps of experienced men working on the problem of the proper composition of steel railroad rails. The "American Railway Engineering Association," the "American Society for Testing Materials," and the "American Society of Civil Engineers" each have a standing committee on standard specifications for steel rails, and in April, 1908, the Pennsylvania Railroad published their new rail sections and specifications, the specifications being given in Table XII.

In addition to carbon, steel rails contain manganese, silicon, phosphorus, and sulphur. The amounts of these constituents also vary; taking all the specifications together, the lowest and highest percentages allowed are as follows: manganese, 0.75 to 1.20; silicon, 0.05 to 0.20; phosphorus, 0.03 to 0.10; and sulphur shall not be greater than 0.06.

TABLE XII.

Weight of Rail.	Pounds per Yard.		
	70 to 79	80 to 89	90 to 100
	Per cent. of Carbon.		
A. R. E. & M. W. Assoc.......	0.40–0.50	0.43–0.53	0.45–0.55
Am. Soc. C. E. (for Bessemer)	0.50–0.60	0.53–0.63	0.55–0.65
Am. Soc. C. E.(for Basic Open Hearth)...........	0.53–0.63	0.58–0.68	0.65–0.75
P. R. R. (for Bessemer)......	..	0.45–0.55	0.45–0.55
P. R. R. (for Open Hearth)...	..	0.70–0.80	0.70–0.80

81. Shape of Rail Section.—When the Stevens rail came into general use, nearly every railroad had its own standard shape, as well as each manufacturer, and at one time the rail mills had 188 different patterns which were considered standard, and 119 patterns and 27 different weights per yard were manufactured. In 1874 Mr. Robert H. Sayre invented a rail section quite similar to the A. S. C. E. section now in use, the principal difference being that the Sayre section had sloping sides to the head. The great number of different patterns of rails in use became so inconvenient that in 1890 the American Society of Civil Engineers appointed a committee of thirteen members to study the question of rail section. In 1893 this committee reported a set of standard sections for rails varying in weight from 40 to 100 pounds per yard. This report was adopted by the Society and recommended to the railroad companies, and is usually referred to as the A. S. C. E. section. In a tabulation of reports from fifty-four different railroad companies as to their standards ("Engineering News," Aug. 30, 1900), thirty-eight railroads use the A. S. C. E. section, three use the Dudley section, and thirteen use special sections, and probably more than 75 per cent. of the rails then in use were of the A. S. C. E. section.

In 1893, when the above report was made, 90 pounds per yard was considered a very heavy rail, and there were no data upon which to base the design of the heavier rails. Rails having begun to prove unsatisfactory in an increasing ratio, and part of the trouble being attributed to the design, in 1905 the American Society of Civil Engineers appointed another committee to design a new set of standard sections to conform with present requirements.

√ **82. A. S. C. E. Rail Sections.**—The durability of a railroad rail depends upon its chemical composition, the amount of the ingot discarded, the method of manufacture, and the proportion of its cross-section, viz., its wearing volume or size of head, its shape, and the moment of inertia of its cross-section. The higher the rail, the stiffer it is. The base must be wide enough to make the rail stand up, and the more metal in the head, the more can be worn away before the rail is unfit for service. The A. S. C. E. sections have the same proportions for all weights of rail, and have 42 per cent. of the metal in the head, 21 per cent. in the web, and 37 per cent. in the

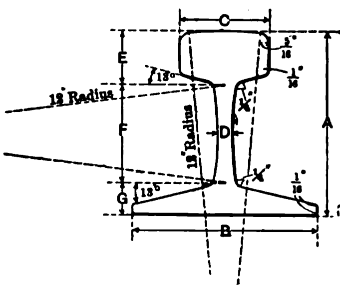


FIG. 38.

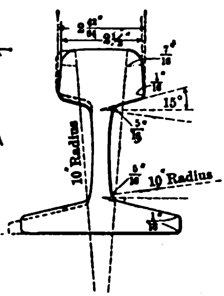


FIG. 39.

flange, or base, and the width of the base is the same as the height of the rail.

In Fig. 38 is shown the cross-section of the A. S. C. E. rail. The following dimensions are constant for all weights of rail: (1) the radius of the top of the head and of the sides of the web is 12 inches; (2) the slope of the bottom of the head and the top of the base is 13 degrees; (3) the radius of the top corners of the head is $\frac{5}{16}$ inch;

(4) the radius of the four corners of the web is $\frac{1}{4}$ inch: (5) the lower corners of the head and the four corners of the base are rounded off with a radius of $\frac{1}{16}$ inch.

In Fig. 39 is shown the cross-section of the P. R. R., 1908, rail. The broken lines in the left side of Fig. 39 show the A. S. C. E. section and indicate the differences between the two sections.

The following dimensions vary with the weight of the rail: (A) the height; (B) the width of the base; (C) the width of the head; (D) the thickness of the web; (E) the thickness of the head; (F) the height of the web; and (G) the thickness of the base. These dimensions are given in the following table for rails weighing from 60 to 100 pounds per yard:

TABLE XIII.

Pounds per Yard.	A	B	C	D	E	F	G
	Height of Rail, Inches.	Width of Base, Inches.	Width of Head, Inches.	Thickness of Web, Inches.	Depth of Head, Inches.	Height of Web, Inches.	Thickness of Base, Inches.
100	$5\frac{3}{4}$	$5\frac{3}{4}$	$2\frac{3}{4}$	$\frac{9}{16}$	$1\frac{45}{64}$	$3\frac{5}{64}$	$\frac{31}{32}$
100*	$5\frac{11}{16}$	5	$2\frac{1}{2}$	$\frac{9}{16}$	$1\frac{53}{64}$	$2\frac{59}{64}$	$1\frac{1}{32}$
90	$5\frac{3}{8}$	$5\frac{3}{8}$	$2\frac{5}{8}$	$\frac{9}{16}$	$1\frac{19}{32}$	$2\frac{55}{64}$	$\frac{59}{64}$
85*	$5\frac{1}{8}$	$4\frac{5}{8}$	$2\frac{1}{2}$	$\frac{17}{32}$	$1\frac{21}{32}$	$2\frac{15}{32}$	1
80	5	5	$2\frac{1}{2}$	$\frac{35}{64}$	$1\frac{1}{2}$	$2\frac{5}{8}$	$\frac{7}{8}$
70	$4\frac{5}{8}$	$4\frac{5}{8}$	$2\frac{7}{16}$	$\frac{33}{64}$	$1\frac{11}{32}$	$2\frac{15}{32}$	$\frac{13}{16}$
60	$4\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{3}{8}$	$\frac{31}{64}$	$1\frac{7}{32}$	$2\frac{17}{64}$	$\frac{49}{64}$
50	$3\frac{7}{8}$	$3\frac{7}{8}$	$2\frac{1}{8}$	$\frac{7}{16}$	$1\frac{1}{8}$	$2\frac{1}{16}$	$\frac{11}{16}$

* P. R. R., 1908, sections.

The 1915 section of the New York, New Haven and Hartford Railroad is $6\frac{1}{8}$ inches high, the base is $5\frac{1}{2}$

inches wide, and the rail weighs 107 pounds per yard, the base being $\frac{1}{8}$ inch thicker than a former section.

Some of the new sections are also thicker in the web.

83. Relation between Weight of Engine and Weight of Rails.—The weight of rails has increased empirically, but for a long time there was a striking coincidence between the weight of the locomotive in tons and the weight of the rail in pounds per yard, beginning with a 50-ton locomotive on a 50-pound per yard rail, and increasing by increments of ten to the 80-ton locomotive on an 80-pound per yard rail; but in recent years the weight of the locomotive has increased in a much faster ratio, which, as mentioned before, is one of the reasons why the composition and proportions of the rail must be improved unless the rail is made so heavy as to be almost prohibitive. The largest locomotive in use in 1905 weighed 167 tons, exclusive of the tender, or had a total weight of 167 tons on the drivers, having six pairs of driving-wheels.

Experiments have been made with high-grade steel in the endeavor to procure a longer life under excessive use, nickel-steel rails having been tried in at least one case, but sufficient time has not elapsed to prove or disprove the economy of the experiment. In the summer of 1907 the Bethlehem Steel Company accepted a large contract for a higher grade open-hearth steel rails at a cost per ton greater than the market price of ordinary steel rails according to newspaper reports. Open-hearth rails are now used extensively, see ¶ 79.

84. Length of Rails.—After various shorter lengths had been used, a standard length of 30 feet was adopted.

In an endeavor to reduce the number of joints and produce smoother riding, lengths of 45 and 60 feet were tried, but have been abandoned. The 60-foot rail was hard to load and unload and difficult for the track layers to handle; it was also difficult to transport, as it required two cars per length of rail. The committee of the American Society of Civil Engineers, about the same time that they reported the standard sections, recommended a length of 33 feet, which is now in general use. The clause of these specifications relating to the length of the rail is as follows: "The standard length of rails shall be 33 feet:" "Ten per cent. of the entire order will be accepted in shorter lengths, varying by even feet to 27 feet, and all No. 1 rails less than 33 feet long shall be painted green on the ends." "A variation of $\frac{1}{4}$ inch in length from that specified will be allowed."

85. Inspection and Tests of Rails.—In addition to the process of manufacture and the chemical composition, the majority report of the special committee of the American Society of Civil Engineers has the following clauses in its specifications for steel rails: Drop test, section, weight, length, drilling, straightening, branding, and inspection.

The following quotations from the 1908 Pennsylvania Railroad* specifications represent the latest practice: "Ingots shall be kept in a vertical position until ready to be rolled, or until the metal in the interior has had time to solidify"; "No 'bled' ingots shall be used"; "There shall be sheared from the end of the bloom

* Railroad Gazette, April 17, 1908.

formed from the top of the ingot sufficient discard to insure sound rails."

86. Drop Test.—One drop test shall be made on a piece of rail, not less than four and not more than six feet long, selected from each blow of steel. The test piece shall be taken from the top of the ingot. The rails shall be placed head upward on the supports, and the sections shall be subjected to the following impact tests under a free falling weight:

70 to 79 pound rails	18 feet.
80 to 89 " "	20 "
90 to 100 " "	22 "

If any rail breaks, when subjected to the drop test, two additional tests may be made of other rails from the same blow of steel, also taken from the top of the ingots, and if either of these latter rails fails, all the rails of the blow which they represent will be rejected; but if both of these additional test pieces meet the requirements, all the rails of the blow which they represent will be accepted.

In Fig. 40, some of the principal features of a drop-testing machine as outlined by the Am. Ry. Eng. Assn., are shown: *A* is the lower end of the tup, which shall weigh 2000 pounds, the striking part *aa* being a cylinder one foot long and five inches in diameter. *B* is the test rail resting upon the movable castings *CC*; the castings can be moved outward so that the distance between bearings may be varied from three (3) feet to four feet six inches (4′ 6″). The anvil *D* shall be a solid casting which, with all the parts moving with it, shall weigh 20,000 pounds. The anvil rests upon 20 springs, *sss*, arranged in sets of five at each corner, the springs being countersunk into the base of the anvil and resting upon the base plate *E*. The base plate is cast-iron or cast-steel and eight inches thick over the area covered by the anvil. The base plate *E* rests upon a solid timber grillage made from 12×12-inch timbers firmly bolted together, the base

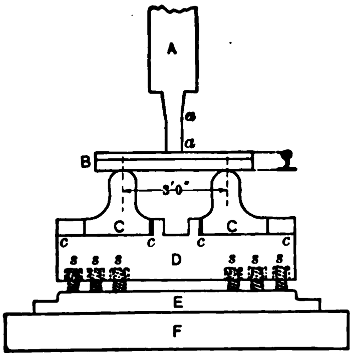


Fig. 40.

plate being firmly bolted to the timbers *F*. The timbers of the grillage *F* project nine inches beyond the base plate and rest upon five feet of concrete foundation, which in turn rests upon firm subsoil. In addition to the above, elaborate details of vertical supports and guides for the tup are given, the machine providing for a free fall of 25 feet.

87. Inspection of Section and Weight.—Unless otherwise specified, the section of the rail shall be the American Standard, recommended by the American Society of Civil Engineers, and shall conform as accurately as possible to the templet furnished by the railroad company, consistent with the paragraph relative to specified weight. A variation in height of $\frac{1}{64}$ inch less, or $\frac{1}{32}$ inch greater, than the specified height, and $\frac{1}{16}$ inch in width will be permitted. The section of rail shall conform to the finishing dimensions.

The weight of the rails will be maintained as nearly as possible, after complying with the preceding paragraph, to that specified in contract. A variation of one-half of 1 per cent. for an entire order will be allowed. Rails will be accepted and paid for according to actual weights.

For length see ¶ 84.

88. Inspection of Drilling and Straightening.—Circular holes for splice bars shall be drilled in accordance with the specifications of the purchaser. The holes shall conform accurately to the drawing and dimensions furnished in every respect, and must be free from burrs.

Care must be taken in hot-straightening the rails, and it must result in their being left in such a condition that they shall not vary throughout their entire length more than 5 inches from a straight line in any direction, when delivered to the cold-straightening presses. Those which vary beyond that amount, or have short kinks, shall be classed as second quality rails and be so stamped.

Rails shall be straight in line and surface when finished—the straightening being done while cold—smooth on head, sawed square at ends, variation to be not more than $\frac{1}{32}$ inch, and, prior to shipment, shall have the burr occasioned by the saw-cutting removed, and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

89. No. 2 Rails.—No. 2 rails shall be accepted up to 5 per cent. of the whole order. They shall not have flaws in their heads of more than ¼ inch, or in the flange of more than ½ inch in depth, and, in the judgment of the inspector, these shall not be so numerous or of such a character as to render them unfit for recognized second-quality rail uses. The ends of No. 2 rails shall be painted white, and shall have two prick-punch marks on the side of the web near the heat number brand, and placed so as not to be covered by the splice-bars. Rails from heats which fail under the drop-hammer test shall not be accepted as No. 2 rails.

90. Branding.—The name of the maker, the weight of the rail, and the month and year of manufacture shall be rolled in raised letters on the side of the web; and the number of the blow shall be plainly stamped on each rail, where it will not subsequently be covered by the splice-bars.

91. Privileges of Inspectors.—The inspector representing the purchaser shall have free entry to the works of the manufacturer at all times when the contract is being filled, and shall have all reasonable facilities afforded him by the manufacturer to satisfy him that the finished material is furnished in accordance with the terms of these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment.

The manufacturer shall furnish the inspector, daily, with carbon determinations for each blow, and a complete chemical analysis every twenty-four hours, representing the average of the other elements contained in the steel, for each day and night turn. These analyses shall be made on drillings taken from small test ingots.

92. Life of a Rail.—Rails wear out much more rapidly on curves than on tangents; the sharper the curve, the quicker it wears out. On account of the great variation in the amount and class of traffic that passes over different roads, the length of time a rail lasts conveys very little idea of the actual service it has given. Twenty years on a light traffic road would not be equivalent to five years on a road with heavy traffic. It is more logical to estimate the life of a rail in terms of millions of tons of traffic passing over it. In England one set of data showed a life of 17½ millions of tons. For the above reasons it is practically impossible for a manufacturer to guarantee the life of a rail. In some instances it is less than the life of the tie, possibly lasting only four or five years, and replacing the rail also shortens the life of the tie, owing to the injury caused by the additional spiking.

ARTICLE VI.

RAIL JOINTS.

93. Definition of Rail Joints.—The rail joint has been the subject of more thought and discussion on the part of railroad men, and more has been written on the subject than in almost any other part of railroad track.

The ideal joint is one that will make the rails act the same as if it were one continuous rail. Many devices have been patented and experiments made in the endeavor to accomplish this, but the rail joint still remains weaker than the rail. This is shown by the fact that the ties near the joint require more tamping to keep them in surface than the ties near the center of the rail. With new rails and splice-bars fitted and screwed up properly, for a time there will be little or no give to the joint, but under the continued hammering of heavy traffic, even with the greatest care and attention, the parts will move and wear against each other, and the joint will gradually weaken.

Strictly speaking, the term *rail joint* refers solely to the ends of the rails, but the general use of the term means everything that helps to connect the rails, Fig. 41, the shape of ends of rails, splice-bars, bolts, nut locks, manner of resting on the ties, and the position of the joint in the track.

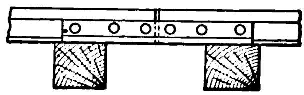


FIG. 41.

94. Shape of Ends of Rails.—The A. S. C. E. specifications require the ends to be sawed off square, and this is the form used in the United States. On account of the space that must be left between the ends of the rails to provide for expansion, a blow is struck by each wheel as it leaves the end of one rail and strikes the end of the adjacent rail. The bad effects of this space and the accompanying damage have been greatly exaggerated in the past and have led to the trial of a number of especially formed ends to obviate the defect. In the United States the miter, or Sayre joint, Fig. 42, has been used on the Lehigh Valley Railroad, and can still be seen in some of the old rails. There were several objections to this joint. Owing to excessive heat or the creeping of the rails, the ends of the rails are liable to push past each

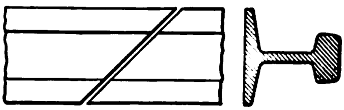


FIG. 42.

other sufficiently to be damaged by the wheel flanges, even if not far enough to cause a derailment by the wheel flanges striking the projection and mounting the rail. It was very difficult to cut the rail in laying switches or in replacing a length of rail other than the standard length. The lap joint shown in Fig. 43 was tried in

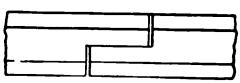


FIG. 43.

Europe, and in at least one case proved a failure. The argument in favor of these joints was that the wheel would rest on the second rail before it had entirely left the first rail, thus preventing the blow due to the square rail ends. If the space between the ends of the rails is made as small as possible and the joint is strong and the rails are of good quality, practically no damage is done to the head of the rail, the main disadvantage being, as stated above, that the ties under the joint need more tamping and the joint must be kept screwed tight.

95. Square and Broken Joints.—Rails are laid in track so that the joints are directly opposite each other, called square joints, or so that the joint in one rail is opposite the middle of the other rail, called broken joints. Square joints are shown in Fig. 44, and broken

Fig. 44.

joints in Fig. 45. There is considerable difference of opinion as to which is better, or makes the train ride easier, but broken joints are in most general use. Square joints are better where supported joints are

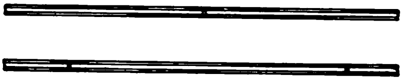


Fig. 45.

used. Square joints cannot be held to strictly on curves unless special-length rails are used on the inside rail of the curve, but they can be made approximately square by using some of the short rails that are accepted with an order. In the same way on a sharp curve or a long light curve broken joints on tangent may become practically square on a part of the curve. The argument against broken joints is that a wheel causes the rail to sink at a joint more than the opposite wheel on the middle of its rail, thus causing the train to sway sideways.

96. Suspended and Supported Joints.—There is considerable difference of opinion and discussion of the question of suspended *vs.* supported joints. A suspended joint is shown in Fig. 41, in which the ties are placed a little less than the regular spacing apart, so that there is a tie under each end of the splice-bar. A supported joint is shown in Fig. 46, in which one tie

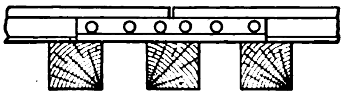


FIG. 46.

comes directly under the ends of the rails, and the space between this tie and the tie next to it on each side is considerably less than the regular spacing, and the splice-bars have less bearing on the outside ties. The objection to the supported joint is that the middle tie does part of the work of the joint, and the work that comes on the middle tie is so much more than comes on the other ties, particularly when a weaker joint is used, that it is difficult to keep it in surface. The middle tie prevents the use of many of the stronger forms of splice-bars. Most of the joints in use are suspended joints.

97. Bonded and Insulated Joints.—Rail joints are further divided into bonded and insulated joints. This is necessary in connection with electric automatic signals. If a joint could be kept tight and free from rust, probably no other form of bond would be necessary;

but this is too uncertain, and in order to provide a good bond, various means are used. One of the most common methods of bonding the rails is shown in Fig. 47, holes being drilled in the rails just beyond the ends of the splice-bars and copper wires attached by means of copper plugs. One or two wires are used, both wires being outside of the splice-bar, or one outside and one between the splice-bar and the rail, as shown in the figure.

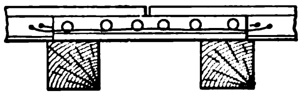


Fig. 47.

An insulated joint is so designed that there is no chance for the electric current to pass the joint. Opposite joints on the two rails of the track are insulated, and the rails are bonded by copper wires across the track in the same general manner as shown in Fig. 47, thus completing a circuit. The regular joint splice cannot be insulated and a special splice is always used. An insulated joint in common use is shown in Fig. 48. It consists of a channel-shaped piece of rolled steel with unequal legs, *abcd*, with bolt holes spaced the same

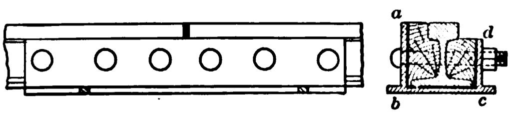


Fig. 48.

distance apart as in the ordinary splice-bars, and is also the same length as the ordinary joint. A non-conductor, such as rubber, is placed between the ends of the rails at *e*, between the wooden blocks and the channel, between the blocks and the rail, between the base of the rail and the channel., and also around the bolt, so that the bolt cannot touch the web of the rail. Wooden blocks are fitted in as shown in the figure, and all are bolted together. By this means the rails are joined together by a strong splice without any possibility of the electric current passing from one rail to the next one.

Another form of insulated splice in common use is shown (Fig. 49). It consists of an angle iron *abc* and two blocks

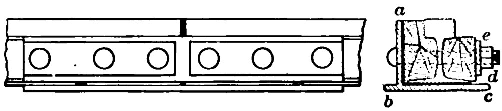


FIG. 49.

of wood fitted in as shown, with a non-conductor inside the angle iron and around the bolt. The inside plate *de* is made in three forms. The simplest arrangement is shown in the first sketch of Fig. 49, and consists of two pieces of rectangular flat steel bar with a space of about one-half inch between the ends of the bars at the center of the splice, and in some cases an angle bar is cut in half and used instead of the plain bars. In the second form one rectangular bar extending the entire length of the splice is used; and in the third form an ordinary angle bar is used. A non-conductor is placed between the ends of the rails in all cases.

98. Splice-bars.—Most of the attempts to strengthen the rail joint have been along the line of strengthening the splice-bars. This feature of the rail joint has passed through four stages, as follows: First, chairs which rested on the tie and into which the rails rested; second, fish plates; third, angle bars; and fourth, bridge joints. This development has been necessitated by the increasing weight of locomotives and rolling loads.

In Fig. 50 is shown a piece of one of the earliest forms of the pear-shaped rail with its chair, the end view

FIG. 50.

being shown in Fig. 36. The weakness of this form of joint is shown by the condition of the end of the rail, particularly of the head of the rail.

The first form of fish plate is shown in Fig. 51, and consisted of a rectangular strap of wrought-iron with

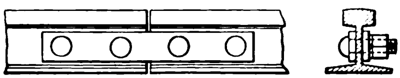


FIG. 51.

four holes in it; practically all the strength of the joint depended upon the bolts. The rectangular strap was followed by the splice-bars shown in Fig. 52, the top and bottom edges of which fitted against the bottom of the head and the top of the base of the rail respectively, and the center of the bar curved away from the web of the rail, which gave the bolt a better chance to hold the bars firmly. In this form the splice-bars bore most of the stress in the joint, the bolts simply holding the parts of the joint firmly together.

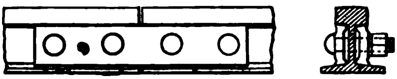


FIG. 52.

Under increasing loads the last-mentioned form of splice-bar proved too weak, and angle splice-bars were invented and are now in use on most of the railroad track in the United States.

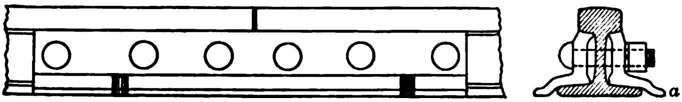


FIG. 53.

There are a number of forms of the angle splice-bar, the principal variation being in the length and shape of the lower leg of the angle at *a*, Fig. 53, some reaching only as far as the edge of the base of the rail and others as shown in the figure. At the same time that angle splice-bars came into use a change was made from four bolts to six bolts per joint.

99. Bridge Joints.—Any form of splice bar joint in which the splice bar projects below the base of the rail may be called a bridge joint. Many forms of bridge joints have been invented, the one in most general use being the Bonzano joint, which is shown in Fig. 54 The horizontal legs *ac* have a bearing on the tie ranging from about $1\frac{1}{4}$ to $2\frac{1}{4}$ inches, depending upon the specifications of the purchasing railroad. This extra width of flange is bent into a vertical between the ties, as

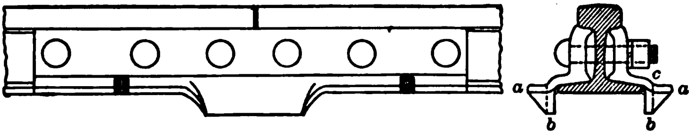


FIG. 54.

shown in Fig. 54. Bending the flanges in this manner distributes the metal at the middle of the joint so that it gives a greater moment of inertia of the cross-section at the point where it is most needed and adds greatly to the strength and stiffness of the joint.

The "M. W. 100 per cent. splice" was invented by an engineer of the Pennsylvania Railroad, and derives

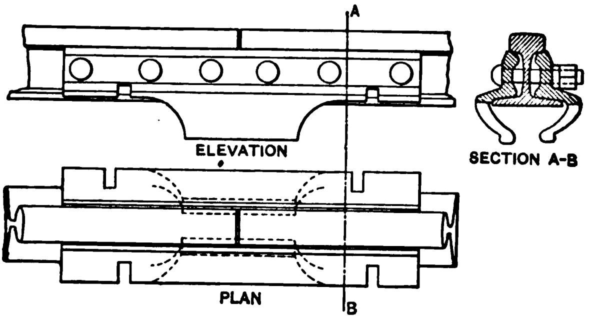


FIG. 55.

its name from having been designed to give the same strength and stiffness as would be given by a continuous rail, or an efficiency of 100 per cent, as is also the reason for the Bonzano joint. The elevation, plan, and a section of this splice are as shown in Fig. 55. The ends of this splice are shaped as shown by the shaded portions in the section AB; the middle third of the splice is the same as the ends with the legs projecting diagonally downward in addition. The plan in Fig. 55 shows only the general outlines of the splice-bars, no attempt being made to show the bolts, etc., as the additional lines would obscure the principal feature. As can be seen from Fig. 55 this splice has a bearing on the tie equal to the thickness of the angle, and the splice bars receive very little support directly from the tie.

Splices of the above general type can only be used on suspended joints, Fig. 41.

100. Continuous Splice and Permanent Splice.—A cross-section of the "Continuous Splice" is shown in Fig. 56, the difference between this form and the ordinary angle bar splice being the additional horizontal parts which grip the base of the rail.

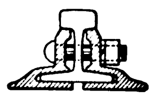


FIG. 56.

The "Permanent Splice" is shown in Fig. 57. The lower legs of the angle bars are beveled so that they fit neatly into the clamp *b c*, which holds the joint together and is as long as the clear space between the ties. The principal feature of this splice is that no bolts are used.

There are many special forms of splices besides those described in this article, but the forms described illustrate the general types of the rail joints, or splices, used in the United States. A much better idea of rail splices can be obtained from advertisements in Engineering periodicals.

Splices of the general types in Fig. 56 and 57 are used on supported joints, Fig. 46.

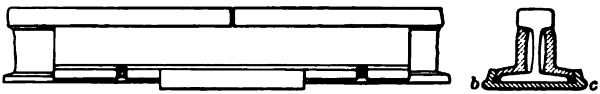


FIG. 57.

101. Splice Bolts.—After the angle bar splice came into general use and the rail was made heavier, six bolts were used in a splice instead of four. One of the heaviest angle bars is shown in Fig. 58, the six bolts

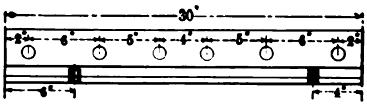


FIG. 58.

being spaced as shown, at intervals of four, five and six inches, the total length of the splice being thirty inches. The bolts near the center of the splice are placed closer together, as they stand a greater proportion of the stress in the joint. The end holes in the splice-bar are drilled at a distance of two inches from the end of the bar.

There is not a great amount of uniformity in the size and shape of splice bolts used by different railroads. In general they vary from $\frac{3}{4}$ to 1 inch in diameter and from 4 to $5\frac{1}{4}$ inches in length, exclusive of the head. There is also no uniformity of practice in proportioning the diameter of the bolt to the weight of the rail. The usual diameter of bolts is $\frac{3}{4}$, $\frac{7}{8}$, or 1 inch, but some railroads use $\frac{13}{16}$ and $\frac{15}{16}$ of an inch. The length of the bolt depends upon the style of the splice weight of the rail, the thickness of the nut lock, and the thickness of the nut.

In Fig. 59 are shown three views of a standard bolt and two views of the nut for an 85-pound rail splice. The oval shoulder of the bolt corresponds to the thickness of the splice-bar and fits into the oval-shaped hole in the

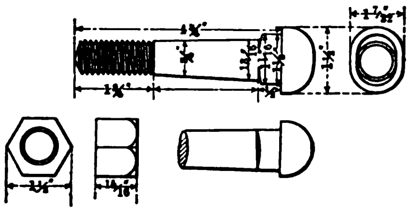


FIG. 59.

splice-bar, thus preventing the bolt from turning and thereby loosening the nut. The holes in both splice-bars are made oval in shape and $\frac{1}{16}$ inch larger than the shoulder of the bolt, which allows the bolts to be put in with the heads facing either way. There is a difference of opinion as to which way the bolts in a splice should face. Some railroads face all the nuts in a joint toward the center of the track, others face them outward, and some face half of them outward and half inward, alternating them. In a single-track road it is much easier for a trackwalker to inspect the bolts if all the nuts face inward, but the objection is that in case of a derailment a wheel might shear off all the bolts in a joint, thus adding to the chances of a serious accident. For this reason some railroads face half of the bolts in a splice each way, as it is then practically impossible to shear off all the bolts.

102. **Nut-locks.**—If there is any movement to the parts connected by a bolt, there is a tendency for the nut to work loose. There is a decided movement in the best laid and maintained track, particularly at a rail splice, consequently nut-locks must be used on every bolt.

FIG. 60.

Nut-locks are of various forms; the simplest and the form in most general use is shown in Fig. 60. They are made of spring-steel, the steel being rectangular in cross-section and bent into a circular form and then hardened. The inside diameter is made large enough to slip loosely over the bolt, and the cross-section varies from about $\frac{1}{8} \times \frac{3}{16}$ to $\frac{3}{16} \times \frac{5}{16}$ of an inch, the greater dimension being at right angles to the bolt. The ends are cut beveled, sharpened, and one is bent upward and the other downward, thus tending to grip both the nut and the splice-bar and to prevent both the nut and the nut-lock from turning.

FIG. 61.

A spring-nut is shown in Fig. 61. One leg of this nut is too long to allow a complete turn of the nut to be made, consequently the nut is tightened by turning the bolt by means of its hexagonal head.

Numerous other forms of nut-locks are in common use, a common form being similar to that shown in Fig. 60, except that it is ∽ shaped and is placed on two adjacent bolts.

103. Bolt Holes in Rails.—The bolt holes in rails are drilled $\frac{1}{4}$ of an inch larger than the diameter of the bolt, being 1 inch in diameter for a $\frac{3}{4}$-inch bolt. For a six-bolt joint the holes in the rails are spaced as shown in Fig. 62, the end hole being $1\frac{23}{32}$ inches from the end of the rail, and since the corresponding holes in the splice-bar are 4 inches apart, the space between the ends of the rails may be varied so that the proper allowance can be

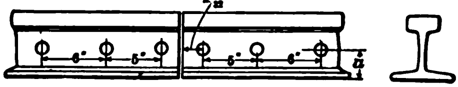



FIG. 62.

made for expansion and contraction of the rail due to changes of temperature.

104. Expansion Shims.—In laying rails expansion shims should be used in order to get the proper distance between the ends of the rails. Shims are made of wood or wrought-iron. Wooden shims are not very satisfactory on account of being crushed if the rail strikes them hard, which destroys the shim and gives irregular spacing. In using wooden shims it is customary to have strips of wood, about like a lath, hold it until the rail is pushed against it, and then break it off, the piece of wood being allowed to remain.

Wrought-iron shims are made in sets varying in thickness by sixteenths from $\frac{1}{16}$ to $\frac{1}{4}$ inch. They are] shaped and their thickness is plainly marked on them.

When laying the rails, a shim of proper thickness is hung upon the head of the rail already laid, and after the next rail is pushed against it and the joint screwed up, the shim is removed.

105. Space between Ends of Rails.—The proper distance between the ends of the rail or the thickness of the shim is computed in the following manner: A 33-foot rail will vary in length per degree of temperature Fahr.

$$0.0000065 \times 33 \times 12 = 0.0026 \text{ inches.}$$

If the temperature of the rail is liable to vary from 110° to —20° F., and the track is being laid at a temperature of 70° F., then there should be a thickness of shim of

$$(110 - 70)\ (0.0026) = 0.104, \text{ or } \tfrac{1}{8} \text{ inch approximately,}$$

and the joint should allow a maximum range of movement of

$$(110 + 20)\ (0.0026) = 0.33, \text{ or } \tfrac{3}{8} \text{ inch approximately.}$$

The play of $\frac{1}{4}$ inch of the bolts in the holes and the $\frac{6}{32}$ inch between the ends of the rails provide amply for this variation. In most cases the temperature of rail may be taken the same as the temperature of the air, but it is quite easy to get the temperature of the rail, which in many cases will be higher than that of the air.

The unit stress caused in a rail by a rise in temperature when the rails have been laid with their ends closely abutting will be given by the formula,

$$S = \alpha t E \quad (5)$$

in which α is the coefficient of linear expansion per degree Fahr. (0.0000065), this the difference in temperature, E is the modulus of elasticity of steel (30,000,000 pounds per square inch), and S is the stress in pounds per square inch.

Example: Suppose rails are laid at a temperature of 40 degrees and the temperature of the track becomes 110 degrees, then

$$S = 0.0000065 \times 70 \times 30{,}000{,}00 = 13{,}650 \text{ pounds per sq.in.}$$

which not only strains the rail but also tends to throw the track out of alignment.

Problem 2.—Assuming the maximum temperature of the rails to be 110 degrees, compute the thickness of shim required when the track is laid at 40, 50, 60, 70, 80, 90, and 100 degrees.

CHAPTER III.

CIRCULAR TURNOUTS.

ARTICLE VII.

DEFINITIONS. SWITCHES.

106. Definition of Point Switch.—A turnout or switch is a device by means of which a train may pass

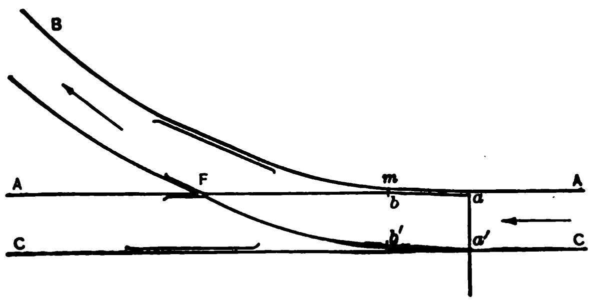


FIG. 63.

from the main track to another line or to a siding. Fig. 63 shows the outline of a point switch which is open for the train to turn off of the main track. Fig. 64 shows the outline of a point switch in which the main line is in operation. Except in case of absolute necessity, the switch is always placed so that the train on the main line runs into the heel of the switch as indicated by the arrow in Fig. 64. With the best of care it is difficult to keep the point of the switch-rails *a* and *a′* firmly against the rail, and if it should become battered or loose and a train run into it from a direction opposite to that indicated by the arrow, Fig. 64, there would be grave danger of a derailment. The above discussion holds good only on a double-track railroad; on a single track, of course, there is no choice.

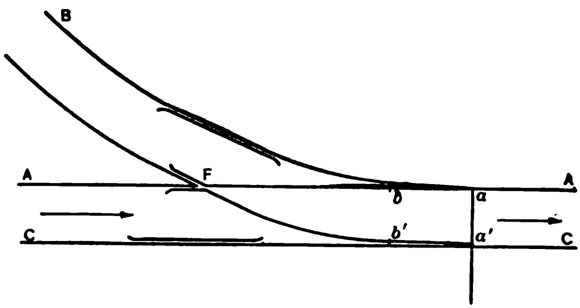


FIG. 64.

If the switch is at a point where all trains run slowly, then running into the point of a switch does not make so much difference.

Switches are of two general types, viz., point-switches, frequently called *split-switches*, and *stub-switches*. A point-switch is shown in Figs. 63 and 64. The main rail CC is continuous, but the rail AA is bent at *a* so that it becomes part of the turnout rail A*a*B.

107. Stub-Switch.—The stub-switch, Fig. 65, is a crude device only placed in sidings that turn out from a siding that is not used much. Both the main rails are broken and the parts *a b* and *a′ b′* of the main rail are not spiked, all the rest being spiked. Fig. 65 shows the switch set for the turnout; when set for the main line, the rails *a b* and *a′ b′* are pulled over into the position indicated by the dotted lines. At first the stub-switch was the only switch used, but now it can only be found on railroads on tracks that are used

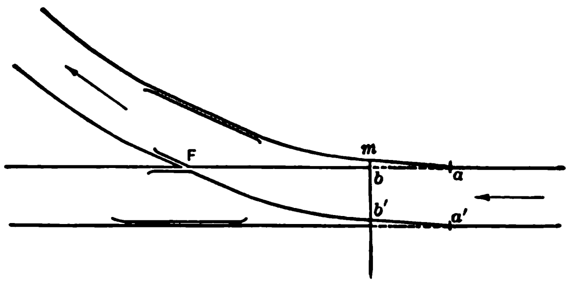


Fig. 65.

very little. They are used, however, on narrow-gauge industrial tracks.

The principal objection to the point switch is that one of the main rails is broken. A number of devices have been patented by which a turnout could be made without breaking either main rail, but no device has proved successful enough to replace the point-switch. A switch was invented which carried the wheels over the main rail by means of raised inclined planes, and was extensively used for a number of years, but it proved defective in that the rails forming the device were liable to turn over, causing considerable extra expense in maintenance.

108. Definitions.—In Fig. 66 is shown a circular arc turnout from a straight track, the center of the turnout curve being at O.

The *gauge line* is the projection of the inside face of the head of the rail, at ⅝ inch down from top of head, the rails in the figure being represented by their gauge lines.

The *gauge of track*, G, is the normal or radial distance between gauge lines of the rails of a track.

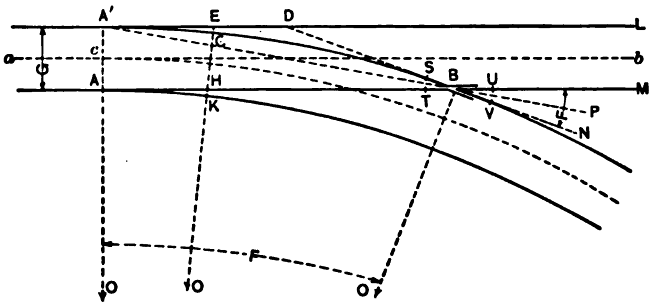


FIG. 66.

The *point of switch* is the point A, also A′ at which the turnout curve begins or is tangent to the main rail.

The *lead*, l, is the distance A B from the point of switch to the point of frog.

The *frog-distance* is the distance A′ B from the point of switch on the outer rail to the point of frog.

The *theoretical point of frog* is at the intersection of the gauge lines at B.

The *switch-point rails*, or *switch-points* or *point-rails*, S, are the parts A K and A′ C.

The *stub-lead* is the distance B H from the heel of the switch-points to the point of frog.

The *throw* of the switch, t, is the distance the points *a* and *a'* are moved by the switch lever in opening and closing the switch, Figs. 63 and 64.

The *heel-distance*, or *heel-spread*, *h*, is the distance between gauge lines at the heel of the switch-points, E C and H K.

The *radius of the turnout*, R, is the radius of the center-line of the turnout track, O *c*.

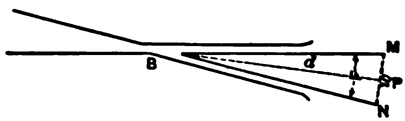


FIG. 67.

The *frog-angle*, F, is the angle between the gauge lines at B.

The *frog-number* is the ratio of the distance BP, Fig. 67, to the distance M N, B P being the distance from the point of frog to any point P, and M N being the distance between gauge lines measured through P and normal to B P.

A turnout consists of the point-rails A' E and A K, the lead-curve rail C S, the frog S T V U, and the rail H T.

109. The Heel-distance.—The heel-distance, E C, is the spread between the gauge-lines of the rails A' L and C S, Fig. 66, which is the same as the distance E C, Fig. 68, and must be equal to the width of the base of rail plus a spiking space of $\frac{5}{8}$ inch. A heel-distance of 6¼ inches will be sufficient for 100-lb. A.S.C.E. rails or 120-lb. rails of the newer types which have a proportionately narrower base. The heel-distance governs the theoretic length of the switch-point rails. Some railroads specify a clear space of three inches between the gauge of the main rail and the outside of the head of the turnout rail, both rules giving about the same distance.

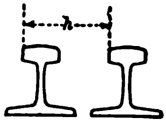


FIG. 68.

ARTICLE VIII.

CIRCULAR TURNOUTS FROM STRAIGHT TRACK.

110. Circular Switches.—By circular switch is meant a switch such as shown in Fig. 66, in which the switch-point rail A′ C, the lead curve rail C S, and the frog S V are supposed to lie in a true circular curve swung from the center O. This assumption does not take into account the fact that in all turnouts from straight track, S V is usually made straight and that A′ C is made straight in practically all cases. The circular turnout was correct in the days when frogs were made of cast-iron and were quite short and the stub-switch was used.

111. Frog-number.—The frog is an arrangement of rails placed at B where the gauge lines intersect, by means of which the flanges of the wheels may cross either rail at that point. The number of a frog is found by dividing the length of a line bisecting the frog angle by the distance between gauge lines. In Fig. 67, which is a more detailed sketch of the corresponding part of Fig. 66, draw B P bisecting M B N, and M N normal to B P, measure B P and M N, then

$$\cot \tfrac{1}{2} F = \frac{d}{\tfrac{1}{2} w},$$

or, since from the definition of frog number,

$$N = \frac{BP}{MN} = \frac{d}{w},$$

we have

$$\cot \tfrac{1}{2} F = 2 N \quad (6).$$

112. The Lead in Terms of Gauge and Frog Number.—In Fig. 66 draw the radial lines O A′, O E, and O B, the tangent D N through B, and the line A′ P through B, then the angle A′ O B = M B N = L D B = F, A′ B D = A B A′ = ½ F, and the distance A′ D = D B. From the triangle A B A′ we have:

$$AB = AA' \cot ABA', \text{ or}$$

$$l = G \cot \tfrac{1}{2} F \quad (7).$$

Substituting (6) in (7), we have

$$l = 2\,GN \quad (8)$$

113. The Radius in Terms of the Lead and Frog-number.—From the triangle A O B, Fig. 66, we have,

$$\overline{OB}^2 - \overline{AO}^2 = \overline{AB}^2, \text{ or}$$

$$(R + \tfrac{1}{2} G)^2 - (R - \tfrac{1}{2} G)^2 = l^2, \quad \text{or} \quad 2\,GR = l^2.$$

Substituting (8) in the last expression, we have

$$R = \frac{l^2}{2G} = 2GN^2, \text{ or}$$

since from (8) $l = 2GN$,

$$R = 2GN^2 = lN \ (9).$$

114. Length of Switch-point Rails.—The switch-point rails A K and A′ C, Fig. 66, will not be equal in length if E C and H K are on the same radial line, nor will the heel-distances E C and H K be exactly equal, but in practice A K is made equal to A′ C, and E C to H K. If the length of the switch-point rails is made equal to $\frac{1}{2}$ (A K + A′ C), and the heel-distances to $\frac{1}{2}$ (E C + H K), the variation from the theoretical distances will not be appreciable. In practice the heel-distance is governed by the weight of the rail, ¶ 109. From Fig. 66,

$$EC = \frac{\overline{A'E}^2}{2OC + EC} = \frac{\overline{A'E}^2}{2(R + \frac{1}{2}G) + EC}, \text{ and}$$

$$HK = \frac{\overline{AH}^2}{2(R - \frac{1}{2}G) + HK},$$

neglecting E C and H K in the denominators of the above expressions as very small compared to 2 R, making A′ E = A′ C = A H = A K = S, and taking the mean,

$$h = \frac{EC + HK}{2} = \frac{1}{2}\left(\frac{S^2}{2(R + \frac{1}{2}G)} + \frac{S^2}{2(R - \frac{1}{2}G)}\right) = \frac{4RS^2}{8R^2 - 2G^2},$$

and neglecting $2G^2$ in the denominator as very small compared to $8R^2$,

$$h = \frac{S^2}{2R}, \text{ or}$$

$$S = \sqrt{2Rh} = 2N\sqrt{Gh} \ (10)$$

115. Circular Turnout Tables.—From the above formulas, assuming a heel-distance of 6¼ inches, and the gauge as 4 feet 8½ inches, the following table has been computed for theoretical curved turnouts from straight track. In the first seven columns theoretical values are given. The lengths of the switch-rails in column eight are assumed, and the practical leads in the ninth column are the sums of the corresponding quantities in the seventh and eighth columns. Many railroads use two lengths of switch-rail with each frog, for example, in a No. 8 turnout from main track a 20-foot switch-rail would be used, and in a No. 8 turnout from a siding a 16-foot switch-rail would be used, giving a *long-lead* and a *short-lead.*

TABLE XIV.

CIRCULAR TURNOUTS.

Frog No.	Frog Angle	Turnout Radius, Feet.	Degree.	Theoretical. Lead, Feet.	Theoretical. Switch-Rail, Feet. h = 6¼″.	Theoretical. Lead, Stub-Feet.	Short. Switch Rail, Feet.	Short. Lead, Feet.
4	14° 15′ 00″	150.67	38° 03′	37.67	12.53	25.14	10	35.14
5	11 25 16	235.42	24 23	48.08	15.66	31.42	10	41.42
6	9 31 38	339.00	16 55	56.50	18.79	37.71	10	47.71
7	8 10 16	461.42	12 26	65.92	21.92	44.00	16	60.00
8	7 09 10	602.67	9 31	75.33	25.05	50.28	16	66.28
9	6 21 35	762.76	7 31	84.75	28.19	56.56	18	74.56
10	5 43 29	941.67	6 05	94.17	31.32	62.85	18	80.85
12	4 46 19	1356.00	4 14	113.00	37.58	75.42	22	97.42
16	3 34 48	2410.67	2 23	150.67	50.05	100.62	33	133.62
18	3 10 56	3051.00	1 53	169.50	56.37	113.13	33	146.13
20	2 51 51	3766.67	1 31	188.33	62.64	125.69	33	158.69
24	2 23 13	5424.00	1 03	226.00	75.16	150.84	33	183.84

PROBLEM. 3. Compute the frog-angle, lead, and radius of a No. 6 turnout from straight track.

PROBLEM 4.—Compute the frog-angle, lead, and radius of a No. 8 turnout from straight track.

PROBLEM 5.—Compute the frog-angle, lead, and radius of a No. 12 turnout from straight track.

PROBLEM 6.—Compute the frog-angle, lead, and radius of a No. 24 turnout from straight track.

PROBLEM 7.—For a heel-distance of $6\frac{1}{4}$ inches, compute the theoretical length of switch-rail, and stub-lead of a No. 6 turnout from straight track.

PROBLEM 8.—For a heel-distance of $6\frac{1}{4}$ inches, compute the theoretical length of switch-rail, and stub-lead of a No. 8 turnout from straight track.

PROBLEM 9.—For a heel-distance of $6\frac{1}{4}$ inches, compute the theoretical length of switch-rail, and stub-lead of a No. 12 turnout from straight track.

PROBLEM 10.—For a heel-distance of $6\frac{1}{4}$ inches, compute theoretical length of switch-rail, and stub-lead of a No. 24 turnout from straight track.

ARTICLE IX.

CIRCULAR TURNOUTS FROM CURVED TRACK.

116. Turnout from Concave Side of Main Curve.—

Given the radius, R, of the main curve and the frog-number, to find the radius, R_2, and the lead, l, of the turnout.

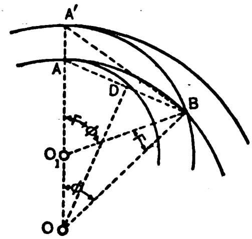


FIG. 69.

In Fig. 69, A′ B is the outer rail of the turnout, and A B the inner rail of the main curve. In Fig. 69 $O_1 A' = O_1 B = R_2 + \frac{1}{2} G$, $O A' = R + \frac{1}{2} G$, $O B = R - \frac{1}{2} G$. In the triangle $O A' B$, $O_1 A' B = A' B O_1$, O B A′ − O A′ B = F, and O B A′ + O A′ B = 180° − ϕ. Having two sides and the included angle gives by trigonometry,

$$\frac{OA' + OB}{OA' - OB} = \frac{\tan \frac{1}{2}(OBA' + OA'B)}{\tan \frac{1}{2}(OBA' - OA'B)}, \text{ or}$$

$$\frac{(R + \frac{1}{2} G) + (R - \frac{1}{2} G)}{(R + \frac{1}{2} G) - (R - \frac{1}{2} G)} = \frac{\tan \frac{1}{2}(180° - \phi)}{\tan \frac{1}{2} F} = \frac{\cot \frac{1}{2} \phi}{\tan \frac{1}{2} F}, \text{ or}$$

$$\frac{2R}{G} = \frac{\cot \frac{1}{2} \phi}{\tan \frac{1}{2} F}, \text{ transposing}$$

$$\cot \tfrac{1}{2} \phi = \frac{2R}{G} \tan \tfrac{1}{2} F = \frac{R}{GN} \text{ (11).}$$

From the triangle O A B, drawing the line O D, bisecting the angle A O B and the line A B, we have

$$AB = 2OA \sin \tfrac{1}{2} AOB, \text{ or}$$
$$l = 2(R - \tfrac{1}{2} G) \sin \tfrac{1}{2} \phi \text{ (12).}$$

To find R_2: In the triangle O O_1 B, O_1 O B = ϕ, O_1 B O = F, and O O_1 B = 180° − (F + ϕ), from trigonometry

$$O_1B = OB \frac{\sin O_1OB}{\sin OO_1B}, \text{ or}$$

$$R_2 + \tfrac{1}{2} G = \frac{(R - \frac{1}{2} G) \sin \phi}{\sin (F + \phi)}, \text{ or}$$

$$R_2 = \frac{(R - \frac{1}{2} G) \sin \phi}{\sin (F + \phi)} - \tfrac{1}{2} G \text{ (13).}$$

Also in the triangle B O_1 A, O_1 B = $R_2 + \frac{1}{2}$ G, O_1 A = $R_2 - \frac{1}{2}$ G, A O_1 B = F + ϕ, O_1 A B + O_1 B A = 180° − (F + ϕ), and O_1 A B − O_1 B A = F, and from trigonometry,

$$\frac{O_1B + O_1A}{O_1B - O_1A} = \frac{\tan \frac{1}{2}(O_1AB + O_1BA)}{\tan \frac{1}{2}(O_1AB - O_1BA)}, \text{ or}$$

$$\frac{(R_2 + \frac{1}{2} G) + (R_2 - \frac{1}{2} G)}{(R_2 + \frac{1}{2} G) - (R_2 - \frac{1}{2} G)} = \frac{\tan \frac{1}{2}(180° - (F + \phi))}{\tan \frac{1}{2} F},$$

from which we find

$$R_2 = \frac{G}{2} \cot \tfrac{1}{2} F \cot \tfrac{1}{2} (F + \phi) \quad (14):$$

But since

$$\cot \tfrac{1}{2}(F + \phi) = \frac{1 - \tan \frac{1}{2} F \tan \frac{1}{2} \phi}{\tan \frac{1}{2} F + \tan \frac{1}{2} \phi},$$

and also since

$$\cot \tfrac{1}{2} F = 2N, \quad \tan \tfrac{1}{2} F = \frac{1}{2N}, \quad \text{and} \quad \tan \tfrac{1}{2} \phi = \frac{GN}{R},$$

and substituting in (14) we have

$$R_2 = \frac{2GN^2(R - \frac{1}{2} G)}{R + 2GN^2} \quad (15).$$

If R_1 = radius of turnout from a straight track then from (9) $R_1 = 2\,G\,N^2$, substituting R_1 in (15) there results

$$R_2 = \frac{R_1(R - \frac{1}{2} G)}{R + R_1} \quad (16),$$

neglecting the $\frac{1}{2}$ $G\,R_1$ as small compared to $R\,R_1$, we have

$$R_2 = \frac{RR_1}{R + R_1} \quad (16').$$

Substituting

$$R = \frac{5730}{D}, \quad R_1 = \frac{5730}{D_1}, \quad \text{and} \quad R_2 = \frac{5730}{D_2},$$

in (16) gives

$$D_2 = D_1 + D_2 \quad (17).$$

In Fig. 69, assuming O D as equal to O A or O B, the difference being assumed small, we have from the triangle A O B,

$$l = 2\,(R - \tfrac{1}{2} G) \tan \tfrac{1}{2} \phi = 2\,(R - \tfrac{1}{2} G)\frac{GN}{R} = 2\,GN - \frac{G^2N}{R} \quad (18)$$

If the last term in (18) be dropped, $l = 2\,G\,N$, the same as in the turnout from a straight track. Computations will show that (18), (16′), and (17) give results, in many cases, that vary materially from the true values from (12), (15), and (16), and are given here only because they are given in many Handbooks.

117. Turnout from Convex Side of Main Curve.—Given the radius, R, of the main curve and the frog-number, to find the radius, R_2, and the lead, l, of the turnout.

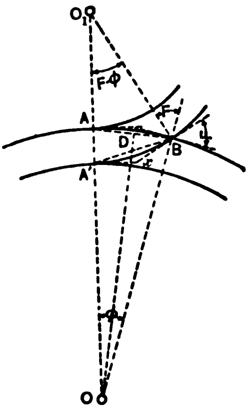


Fig. 70.

In the triangle A′ O B, Fig. 70, $O\,A'\,B + O\,B\,A' = 180° - \phi$, $O\,A'\,B - O\,B\,A' = F$ (this is proved by drawing the tangents Bx and A′ x, then $O\,A'\,B = 90° + B\,A'x$, $O\,B\,A' = A'\,B\,x + x\,B\,O$, and since $B\,A'\,x = A'\,B\,x$, $O\,A'\,B - O\,B\,A' = 90° + B\,A'x - A'\,B\,x - x\,B\,O = 90° - x\,B\,O = F$), $O\,A' = R - \frac{1}{2}\,G$, and $O\,B = R + \frac{1}{2}\,G$, then from trigonometry,

$$\frac{(R + \frac{1}{2}\,G) + (R - \frac{1}{2}\,G)}{(R + \frac{1}{2}\,G) - (R - \frac{1}{2}\,G)} = \frac{\tan \frac{1}{2}\,(180 - \phi)}{\tan \frac{1}{2}\,F},$$

from which

$$\cot \tfrac{1}{2}\,\phi = \frac{2\,R}{G} \tan \tfrac{1}{2}\,F = \frac{R}{GN} \quad (19).$$

In the triangle O A B, drawing the line O D, bisecting the angle A O B and the line A B,

$$AB = 2\,OA \sin \tfrac{1}{2}\,AOB, \quad \text{or}$$

$$l = 2\,(R + \tfrac{1}{2}\,G) \sin \tfrac{1}{2}\,\phi \quad (20).$$

Also assuming O D = O A = O B, the difference being assumed negligible,

$$l = 2\,(R + \tfrac{1}{2}\,G)\tan\tfrac{1}{2}\,\phi = 2\,GN + \frac{G^2N}{R}\ \ (21),$$

and neglecting the last term in (21), we have

$$l = 2\,GN\ \ \ (22).$$

To find R_2: In the triangle $O\,O_1\,B$, $O_1\,O\,B = \phi$ is known from (19), and since F and R are given, we have

$$O_1B = \frac{OB\sin O_1OB}{\sin OO_1B},$$

substituting and transposing as in ¶ 116, we have

$$R_2 = (R_1 + \tfrac{1}{2}\,G)\frac{\sin\phi}{\sin\,(F - \phi)} - \tfrac{1}{2}\,G\ \ (23).$$

In the triangle $O_1\,A\,B$, $O_1\,A\,B = 180° - O\,A\,B$, $O\,A\,B = 90° - \frac{1}{2}\,\phi$, $\therefore O_1\,A\,B = 180° - (90° - \frac{1}{2}\,\phi) = 90° + \frac{1}{2}\,\phi$; $O_1\,B\,A = O\,A\,B - A\,O_1\,B$, $A\,O_1\,B = F - \phi$, $\therefore O_1\,B\,A = 90° - \frac{1}{2}\,\phi - (F - \phi) = 90° - F + \frac{1}{2}\,\phi$; and from trigonometry,

$$\frac{O_1B + O_1A}{O_1B - O_1A} = \frac{\tan\frac{1}{2}\,(O_1AB + O_1BA)}{\tan\frac{1}{2}\,(O_1AB - O_1BA)} = \frac{\tan\frac{1}{2}\,(180 - (F - \phi))}{\tan\frac{1}{2}\,F},$$

combining and transposing,

$$\tan\tfrac{1}{2}\,(F - \phi) = \frac{G\cot\frac{1}{2}\,F}{2\,R_2}:$$

since the angles are small $\tan\frac{1}{2}\,(F - \phi)$ is practically equal to $\tan\frac{1}{2}\,F - \tan\frac{1}{2}\,\phi$, the last expression may be written

$$\tan\tfrac{1}{2}\,F - \tan\tfrac{1}{2}\,\phi = \frac{G\cot\frac{1}{2}\,F}{2\,R_2}.$$

Substituting

$$\cot \tfrac{1}{2} F = 2 N, \quad \text{and} \quad \tan \tfrac{1}{2} \phi = \frac{GN}{R},$$

from (19), we have

$$\frac{1}{2N} - \frac{GN}{R} = \frac{GN}{R_2},$$

dividing through by G N

$$\frac{1}{2 GN^2} - \frac{1}{R} = \frac{1}{R_2} \quad (24).$$

If R_1 = radius of turnout from a straight track then from (9) $R_1 = 2 G N^2$, substituting R_1 in (24), gives

$$\frac{1}{R_1} - \frac{1}{R} = \frac{1}{R_2}, \text{ or}$$

$$R_2 = \frac{RR_1}{R - R_1} \quad (25),$$

and substituting as in ¶ 116,

$$D_2 = D_1 - D \quad (26).$$

Computations will show that (21), (22), (25), and (26), give results that vary materially, in some cases, from the true values from (19) and (23) and are given for the reason stated in ¶ 116.

118. Turnout from Curve.—Theoretical Length of Switch-point Rail. In Figs. 69 and 70, draw a common tangent to the curves at A, and let y be the offset from the tangent to the main rail and y_2 the offset from the tangent to the turnout rail, then from (10),

$$y = \frac{S^2}{2R} \quad \text{and} \quad y_2 = \frac{S^2}{2R_2}.$$

When the turnout is from the concave side as in Fig. 69,

$$h = y_2 - y_1 = \frac{S^2}{2}\left(\frac{1}{R_2} - \frac{1}{R}\right),$$

$$\therefore \quad S = \sqrt{\frac{2\,hRR_2}{R - R_2}} \quad (27).$$

When the turnout is from the convex side as in Fig. 70,

$$h = y + y_2 = \frac{S^2}{2}\left(\frac{1}{R} + \frac{1}{R_2}\right),$$

from which as above

$$S = \sqrt{\frac{2\,hRR_2}{R + R_2}} \quad (28).$$

Substituting

$$R = \frac{5730}{D} \quad \text{and} \quad R_2 = \frac{5730}{D_2},$$

in (27) and (28), gives

$$S = 107.05\sqrt{\frac{h}{D_2 - D}} \quad (29),$$

and

$$S = 107.05\sqrt{\frac{h}{D_2 + D}} \quad (30),$$

respectively.

PROBLEM 11.—(*a*) In a No. 24 turnout from the concave side of a 2-degree main-track curve ($R = 2864.93$), compute ϕ, the lead, and the radius of the turnout curve. (*b*) Same from the convex side.

PROBLEM 12.—(*a*) In a No. 12 turnout from the concave side of a 4-degree main-track curve ($R = 1432.69$), compute ϕ, the lead, and the radius of the turnout curve. (*b*) Same from the convex side.

PROBLEM 13.—(*a*) In a No. 8 turnout from the concave side of a 6-degree main-track curve ($R = 955.37$), compute ϕ, the lead, and the radius of the turnout curve. (*b*) Same from the convex side.

PROBLEM 14.—(*a*) In a No. 6 turnout from the concave side of an 8-degree main-track curve ($R=716.78$), compute ϕ, the lead, and the radius of the turnout curve. (*b*) Same from the convex side.

ARTICLE X.

CIRCULAR THREE-THROW TURNOUTS FROM STRAIGHT TRACK.

119. Turnout from Both Sides, Main Frogs Equal.—Required the frog-angle, F_c, of the crotch-frog.

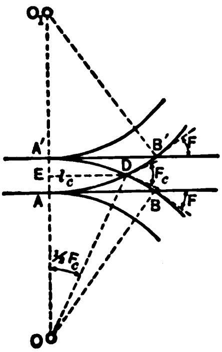


FIG. 71.

In Fig. 71, the radii are equal and the frog-numbers at B and B′ are the same, and all are given. In the triangle E O D

$$\cos EOD = \frac{OE}{OD}, \text{ or}$$

$$\cos \tfrac{1}{2} F_c = \frac{R}{R + \frac{1}{2} G},$$

and since $R = 2\,G\,N^2$

$$\cos \tfrac{1}{2} F_c = \frac{4\,N^2}{4\,N^2 + 1} \quad (31).$$

120. In the above three-throw switch, required the crotch-lead and the number of the crotch-frog.

From the triangle E O D, Fig. 71,

$$ED = OE \tan EOD,$$

and since from (6) by analogy, $\cot \frac{1}{2} F_c = 2 N_c$, and from (9) $R = 2 G N^2$,

$$l_c = R \tan \tfrac{1}{2} F_c = \frac{R}{2 N_c} = \frac{GN^2}{N_c} \quad (32):$$

Also

$$ED = \sqrt{\overline{OD}^2 - \overline{OE}^2}, \text{ or}$$

$$l_c = \sqrt{(R + \tfrac{1}{2} G)^2 - R^2} = \sqrt{RG + \tfrac{1}{4} G^2} = G\sqrt{2 N^2 + \tfrac{1}{4}} \quad (33)$$

placing (32) equal to (33) and solving gives

$$N_c = \frac{N^2}{\sqrt{2 N^2 + \frac{1}{4}}} \quad (34).$$

If the $\frac{1}{4}$ in (33) and (34) be neglected as small compared to $2 N^2$, making a difference of less than 0.22 inch for No. 24 frogs, we have

$$l_c = \sqrt{2}\, GN \quad (35),$$

and

$$N_c = \frac{N}{\sqrt{2}} \quad (36).$$

The distance between the main frogs and the crotch-frog measured along the main rail is

$$l - l_c = 2 GN - G\sqrt{2 N^2 + \tfrac{1}{4}} \quad (37),$$

or approximately

$$l - l_c = (2 - \sqrt{2})GN \quad (38).$$

121. In the above three-throw switch, required the radius of turnout and the crotch-lead in terms of the crotch-frog number.

Referring to Fig. 71 and (36), we have $N^2 = 2 N_c^2$, substituting this in (9), there results

$$R = 2 GN^2 = 4 GN_c^2 \quad (39),$$

and substituting in (32), we have

$$l_c = \frac{GN^2}{N_c} = 2\,GN_c \quad (40).$$

122. Turnout from Both Sides of Straight Track, Main Frogs Unequal, All Three Frogs Given.—Required the radii of the compound curves.

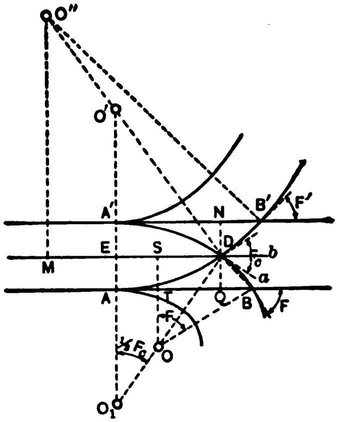


Fig. 72.

In order to use frogs of given numbers, it is necessary to compound the lead-curves at the point of the crotch-frog.

In Fig. 72, $O_1 E = O' E = R_1$, $O D = O B = R + \frac{1}{2} G$, and $O'' B' = O'' D = R_2 + \frac{1}{2} G$. The numbers of the frogs at B, B′, and D are given, all being different, and it is required to find $O_1 E = R_1$, $O D = R + \frac{1}{2} G$, and $O'' B' = R_2 + \frac{1}{2} G$.

From (39) $R_1 = 4\,G\,N_c^2$, and from (40) $l_c = 2\,G\,N_c$.

Let F, F′, and F_c be the angles of the frogs N, N′, and N_c, at B, B′, and D respectively, then the angles $DOB = SOB - SOD = F - \frac{1}{2} F_c$, $DBQ = BDb$ $= bDa + aDb = \frac{1}{2} F_c + \frac{1}{2}(F - \frac{1}{2} F_c) = \frac{1}{2}(F + \frac{1}{2} F_c)$.

In the triangle DBQ, $DQ = \frac{1}{2} G$, and

$$QB = \tfrac{1}{2} G \cot \tfrac{1}{2}(F + \tfrac{1}{2} F_c) \quad (41).$$

From trigonometry,

$$\cot \tfrac{1}{2}(F + \tfrac{1}{2} F_c) = \frac{1 - \tan \frac{1}{2} F \tan \frac{1}{4} F_c}{\tan \frac{1}{2} F + \tan \frac{1}{4} F_c};$$

assuming

$$\tan \tfrac{1}{4} F_c = \tfrac{1}{2} \tan \tfrac{1}{2} F_c,$$

and since

$$\tan \tfrac{1}{2} F = \frac{1}{2N},$$

and

$$\tfrac{1}{2} \tan \tfrac{1}{2} F_c = \frac{1}{4N_c}$$

and substituting in (41), we have

$$QB = \tfrac{1}{2} G \left(\frac{1 - \frac{1}{2} \tan \frac{1}{2} F \tan \frac{1}{2} F_c}{\tan \frac{1}{2} F + \frac{1}{2} \tan \frac{1}{2} F_c} \right),$$

$$QB = \tfrac{1}{2} G \left(\frac{1 - \frac{1}{2} \cdot \frac{1}{2N} \cdot \frac{1}{2N_c}}{\frac{1}{2N} + \frac{1}{4N_c}} \right) = \frac{2GNN_c}{2N_c + N} - \frac{G}{4(2N_c + N)} \quad (42)$$

The last term in (42) is small and may be neglected in some cases, being 0.78 inch for No. 6 frogs,

$$\therefore \quad QB = \frac{2GNN_c}{2N_c + N} = \frac{l_c N}{2N_c + N} = \frac{lN_c}{2N_c + N} \quad (43).$$

From the triangles DSO and BTO we have OS =

$(R + \frac{1}{2}G)\cos\frac{1}{2}F_c$, and $OT = (R + \frac{1}{2}G)\cos F$, $\therefore$ since $OS = OT = TS = \frac{1}{2}G$, we have

$$(R + \tfrac{1}{2}G)\cos\tfrac{1}{2}F_c - (R + \tfrac{1}{2}G)\cos F = \tfrac{1}{2}G, \text{ or}$$

$$(R + \tfrac{1}{2}G)(\cos\tfrac{1}{2}F_c - \cos F) = \tfrac{1}{2}G, \text{ or}$$

$$R + \tfrac{1}{2}G = \frac{G}{2(\cos\frac{1}{2}F_c - \cos F)}, \text{ and}$$

$$R = \frac{G}{2}\left(\frac{1}{\cos\frac{1}{2}F_c - \cos F} - 1\right) \quad (44).$$

In the same way we get

$$R' = \frac{G}{2}\left(\frac{1}{\cos\frac{1}{2}F' - \cos F} - 1\right) \quad (45).$$

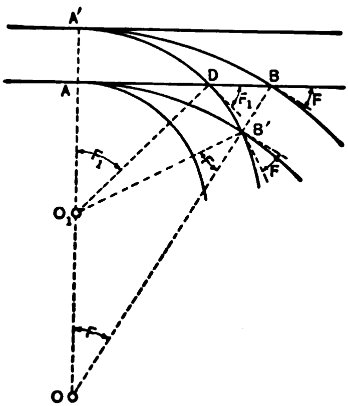


FIG. 73.

123. Double Turnout on Same Side of Main Track.—The Numbers of the Frogs at B and B′ being Given, Required the Radii of the Curves and the Frog N_1 at D.

In Fig. 73, assuming the frogs at B and B′ equal, the angle $O_1 B' O = O_1 O B' = F$, $O_1 B' = O O_1 = O_1 D = O_1 A' = \frac{1}{2} O A' = R_1 + \frac{1}{2} G$,

$$\therefore \quad R_1 + \tfrac{1}{2} G = \tfrac{1}{2} (R + \tfrac{1}{2} G),$$

and

$$R_1 = \tfrac{1}{2} R - \tfrac{1}{4} G \quad (46).$$

Since $R_1 = 2 G N_1^2$, combining with (46)

$$N_1 = \sqrt{\frac{R_1}{2G}} = \sqrt{\frac{R}{4G} - \tfrac{1}{8}} \quad (47).$$

Substituting $R = 2 G N^2$ in (47), we have

$$N_1 = \sqrt{\frac{R}{4G} - \tfrac{1}{8}} = \sqrt{\frac{N^2}{2} - \tfrac{1}{8}} \quad (48).$$

Neglecting the $\frac{1}{8}$ in (48) as very small compared with $\frac{N^2}{2}$,

$$N_1 = \frac{N}{\sqrt{2}} \quad (49),$$

which is the same as (36) for turnouts on opposite sides of main track.

Since $l_1 = 2 G N_1$ and $l = 2 G N$, from Fig. 73

$$DB = l - l_1 = 2 G (N - N_1) \quad (50).$$

Problem 15.—In a three-throw turnout from both sides of a straight track with No. 8 main frogs, compute the number and lead of the crotch-frog.

Problem 16.—In a three-throw turnout from both sides of a straight main track with a No. 7 frog at B, a No. 8 at B′, and a No. 6 crotch-frog, compute the lead of the crotch-frog and the radii of the curves from the crotch-frog to the main frogs.

ARTICLE XI.

CIRCULAR TURNOUTS TO PARALLEL TRACK.

124. Turnout to Parallel Straight Track.—Given the Frog-number and Distance between Centers of Tracks.

In Fig. 74, $B\,O\,A' = B\,O_1\,D = F$, $B\,O = R + \frac{1}{2}\,G$, $B\,O_1 = R_1 - \frac{1}{2}\,G$, $O_1\,E = R_1 + \frac{1}{2}\,G - p$.

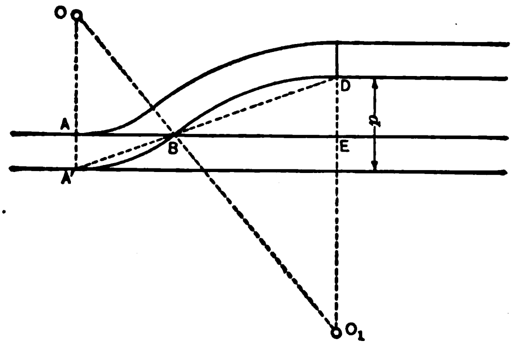


FIG. 74.

In the triangle $B\,O_1\,E$, we have from trigonometry,

$$\frac{O_1B + O_1E}{O_1B - O_1E} = \frac{\tan\frac{1}{2}(O_1EB + O_1BE)}{\tan\frac{1}{2}(O_1EB - O_1BE)}, \text{ or}$$

$$\frac{(R_1 - \frac{1}{2}G) + (R_1 + \frac{1}{2}G - p)}{(R_1 - \frac{1}{2}G) - (R_1 + \frac{1}{2}G - p)} = \frac{\tan\frac{1}{2}(180° - F)}{\tan\frac{1}{2}F}, \text{ or}$$

$$\frac{2R_1 - p}{p - G} = \frac{\cot\frac{1}{2}F}{\tan\frac{1}{2}F} = \cot^2\frac{1}{2}F = 4N^2,$$

from which

$$R_1 = 2(p - G)N^2 + \frac{1}{2}p \quad (51).$$

From the right-angled triangle O_1 B E,

$$BE = (R_1 - \tfrac{1}{2} G) \sin F \quad (52).$$

From the similar triangles A′ B A and B D E,

$$BE = \frac{AB \cdot DE}{AA'} = \frac{(p - G)l}{G} = \left(\frac{p}{G} - 1\right) l \quad (53).$$

125. Turnout to Parallel Curved Track, from

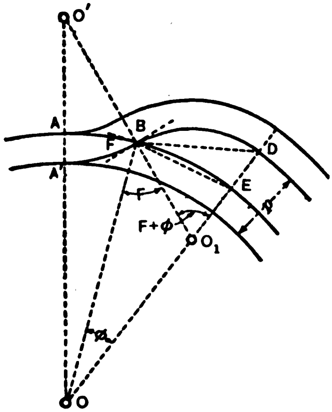


FIG. 75.

Convex Side of Main Curve.—The Radius of Main Curve, Frog-number, and Distance between Centers of Tracks being Given, Required the Radius and Central Angle of the Connecting Curve.

In Fig. 75, let O be the center of the main curve whose radius R is known, O_1 the center of the required curve, O A′ $= R - \tfrac{1}{2}$ G, O_1 B $= R_1 - \tfrac{1}{2}$ G, O D $= R + p - \tfrac{1}{2}$ G, and O B $= R + \tfrac{1}{2}$ G.

In the triangle O B D, by trigonometry,

$$\frac{OD + OB}{OD - OB} = \frac{\tan \frac{1}{2} (OBD + ODB)}{\tan \frac{1}{2} (OBD - ODB)}, \text{ or}$$

$$\frac{(R + p - \frac{1}{2} G) + (R + \frac{1}{2} G)}{(R + p - \frac{1}{2} G) - (R + \frac{1}{2} G)} = \frac{\tan \frac{1}{2} (180° - \phi)}{\tan \frac{1}{2} F} = \frac{\cot \frac{1}{2} \phi}{\tan \frac{1}{2} F},$$

$$\therefore \quad \cot \tfrac{1}{2} \phi = \frac{2 R + p}{p - G} \tan \tfrac{1}{2} F = \frac{2 R + p}{2 N (p - G)} \quad (54),$$

from which ϕ is found, and then the central angle of the connecting curve, $F + \phi$, is known. In the triangle $O O_1 B$,

$$O_1B = \frac{OB \sin BOO_1}{\sin OO_1B}, \text{ or}$$

$$R_1 - \tfrac{1}{2} G = (R + \tfrac{1}{2} G) \frac{\sin \phi}{\sin (F + \phi)},$$

from which

$$R_1 = (R + \tfrac{1}{2} G) \frac{\sin \phi}{\sin (F + \phi)} + \tfrac{1}{2} G \quad (55).$$

From the triangle O B E,

$$BE = 2 (R + \tfrac{1}{2} G) \sin \tfrac{1}{2} \phi \quad (56).$$

126. Turnout to Parallel Curved Track, from Concave Side of Main Curve.—The Radius of Main Curve, Frog-number, and Distance between Centers of Tracks being Given, Required the Radius and Central Angle of the Connecting Curve.

In the triangle B O E, Fig. 76, $OB = R - \frac{1}{2} G$, $OE = R - p + \frac{1}{2} G$, $OEB + OBE = 180° - \phi$, and $OEB - OBE = F$, and

$$\frac{OB + OE}{OB - OE} = \frac{\tan \frac{1}{2}(OEB + OBE)}{\tan \frac{1}{2}(OEB - OBE)}, \text{ or}$$

$$\frac{(R - \frac{1}{2}G) + (R + \frac{1}{2}G - p)}{(R - \frac{1}{2}G) - (R + \frac{1}{2}G - p)} = \frac{\tan \frac{1}{2}(180° - \phi)}{\tan \frac{1}{2}F} = \frac{\cot \frac{1}{2}\phi}{\tan \frac{1}{2}F},$$

from which

$$\cot \tfrac{1}{2}\phi = \frac{2R - p}{p - G}\tan \tfrac{1}{2}F = \frac{2R - p}{2N(p - G)} \quad (57),$$

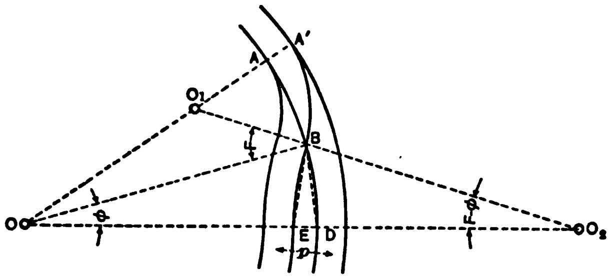


FIG. 76.

from which ϕ is found, and then the central angle of the connecting curve, $F - \phi$, is known. From the triangle $O\,B\,O_2$,

$$O_2B = OB\frac{\sin BOO_2}{\sin BO_2O}, \text{ or}$$

$$R_1 - \tfrac{1}{2}G = (R - \tfrac{1}{2}G)\frac{\sin\phi}{\sin(F - \phi)},$$

from which

$$R_1 = (R - \tfrac{1}{2}G)\frac{\sin\phi}{\sin(F - \phi)} + \tfrac{1}{2}G \quad (58).$$

Also from the triangle O B D,

$$BD = 2(R - \tfrac{1}{2}G)\sin\tfrac{1}{2}\phi \quad (59).$$

And from the triangle B O_2 E,

$$BE = 2 (R_1 - \tfrac{1}{2} G) \sin \tfrac{1}{2} (F - \phi) \quad (60).$$

Problem 17.—In a circular No. 8 turnout to a parallel straight track 13 feet center to center, compute the radius of the curve from the frog to the parallel track.

Problem 18.—In a No. 8 turnout from the outside of a 2-degree (R = 2864.93) main-track curve, compute the angle ϕ and the radius of the curve from the frog to the parallel track.

Problem 19.—In a No. 8 turnout from the inside of a 4-degree (R = 1432.69) main-track curve, compute the angle ϕ and the radius of the curve from the frog to the parallel track.

CHAPTER IV.

PRACTICAL TURNOUTS.

ARTICLE XII.

THE PRACTICAL TURNOUT.

127. Switch-point Rails.—The term *practical* is applied to turnouts, etc., when straight switch-point rails and straight frogs are used as recommended by

FIG. 77.

the Am. Ry. Eng. Assn., the principal advantage being that it greatly reduces the number of stock switch parts that need be carried and avoids *rights* and *lefts*. The Am. Ry. Eng. Assn. recommends only four lengths of straight switch-rails for all frog-numbers from 4 to 24, and that the thickness of the point of all switch-rails shall be ¼ inch. The length of switch-rail corresponding to the frog-numbers is given in Table XV. In Fig. 77 only the heads of the rails are shown, A_1M is the gauge of the main rail,

A_1 is the theoretical point of the straight switch-rail, A is the actual point at which the switch-rail is ¼ inch thick, B is the *heel of the switch*, A_1B is the theoretical and AB the actual length of switch-rail, and B *b* is the heel-distance *h*, which is taken as 6¼ inches in all cases discussed in this book.

128. The Switch-angle *s*.—In Fig. 77, draw A*b* parallel to A_1M, then since the thickness at A is ¼ inch and B *b* is 6¼ inches, B *b*′ is 6 inches, and the angle $b\,A_1B = b'A\,B = s$; and in the triangle *b*′A B.

$$\sin s = \frac{Bb'}{AB} = \frac{6''}{S} = \frac{1}{2S}, \quad (61)$$

from which Table XV may be computed.

TABLE XV.

SWITCH-RAILS AND ANGLES.

Frog. No.	Length of Switch-rail, S. Actual Feet.	Length of Switch-rail, S. Theoretical Feet.	Switch Angle, *s*.
4	11.0	11.46	2° 36′ 19″
5	11.0	11.46	2 36 19
6	11.0	11.46	2 36 19
7	16.5	17.19	1 44 11
8	16.5	17.19	1 44 11
9	16.5	17.19	1 44 11
10	16.5	17.19	1 44 11
12	22.0	22.92	1 18 08
16	33.0	34.38	0 52 05
18	33.0	34.38	0 52 05
20	33.0	34.38	0 52 05
24	33.0	34.38	0 52 05

129. The Practical Turnout.—The practical turnout from a straight track is shown in Fig. 78, the four principal lines representing the gauge-lines of the rails. The longer turnout rail consists of the circular lead-curve, B C, the straight switch-point rail, A B, and the straight frog-wing, C P, both being tangent to the lead-curve.

In addition to the definitions in ¶108, Fig. 66, let the following symbols be assumed:

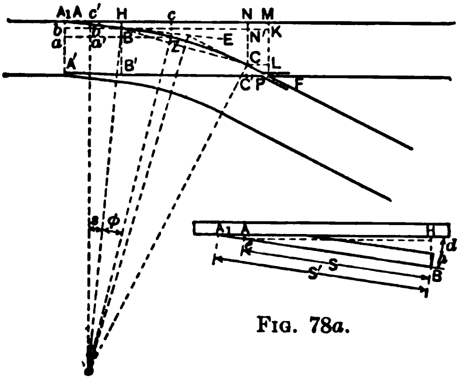


FIG. 78a.

FIG. 78.

S′ = the theoretical length of switch-rail;

S = the actual length of switch-rail;

s = switch-rail angle = c' O B = H A_1 B, Fig. 78, or $d\ e$ B, Fig. 78a.

k = length of toe wing-rail of frog = P C = P C′, Fig. 78.

In Fig. 78, A_1 is the theoretical point of switch-rail, B is the heel of switch-rail, C is the toe of frog, and P is the theoretical point of frog. In the triangle H A_1 B.

$$\sin HA_1B = \frac{HB}{A_1B}, \text{ or}$$

$$\sin s = \frac{h}{S'}, \quad (62)$$

Since the A. R. E. A. recommends that the thickness of the point be ¼ inch, then taking h and S in feet, we have

$$\sin s = \frac{h - 0.021}{S} \quad (62')$$

130. To Find the Long Chord B C.—In Fig. 78, continue the tangents A_1 B and C P until they meet at I, draw the line O I, and P M normal to the main track, and project B to K and C to L, then the angle K B C = I B C + K B I = $\frac{1}{2}(F-s)+s=\frac{1}{2}(F+s)$, and the angle E I C = B O C = F − s. Then in the triangle N′B C

$$BC = \frac{N'C}{\sin KBC} = \frac{MP - MK - LP}{\sin KBC}, \text{ or}$$

$$BC = \frac{G - S' \sin s - k \sin F}{\sin \frac{1}{2}(F + s)} = \frac{G - h - k \sin F}{\sin \frac{1}{2}(F + s)} \quad (63)$$

131. To Find the Actual Lead l.—In Fig. 78, project C to N, then the theoretical lead l_1 is

$$l_1 = A_1M = A_1H + HN + NM \quad (a)$$

From the triangle A_1 H B,

$$A_1H = S' \cos s \quad (b)$$

From the triangle N′ B C,

$$HN = BN' = BC \cos KBC,$$

substituting B C from (63) and K B C = $\frac{1}{2}(F+s)$,

$$HN = \frac{(G - S' \sin s - k \sin F) \cos \frac{1}{2}(F + s)}{\sin \frac{1}{2}(F+s)} \quad (c)$$

From the triangle P C L,

$$MN = k \cos F \quad (d):$$

Substituting (*b*), (*c*), and (*d*) in (*a*),

$$l_1 = S' \cos s + \frac{(G - S' \sin s - k \sin F) \cos \frac{1}{2}(F + s)}{\sin \frac{1}{2}(F + s)} + k \cos F, \text{ or}$$

$$l_1 = \frac{\left\{\begin{array}{l} S' \cos s \sin \frac{1}{2}(F+s) + G \cos \frac{1}{2}(F+s) - S' \sin s \cos \frac{1}{2}(F+s) \\ \quad - k \sin F \cos \frac{1}{2}(F+s) + k \cos F \sin \frac{1}{2}(F+s) \end{array}\right.}{\sin \frac{1}{2}(F+s)}$$

Rearranging this becomes,

$$l_1 = \frac{S' \cos s \sin \frac{1}{2}(F + s) - S' \sin s \cos \frac{1}{2}(F + s)}{\sin \frac{1}{2}(F + s)}$$

$$- \frac{k \sin F \cos \frac{1}{2}(F + s) - k \cos F \sin \frac{1}{2}(F + s)}{\sin \frac{1}{2}(F + s)} + \frac{G \cos \frac{1}{2}(F + s)}{\sin \frac{1}{2}(F + s)}.$$

Simplifying,

$$l_1 = \frac{S' \sin(\frac{1}{2}F + \frac{1}{2}s - s)}{\sin \frac{1}{2}(F + s)} - \frac{k \sin (F - \frac{1}{2}F - \frac{1}{2}s)}{\sin \frac{1}{2}(F + s)} + G \cot \frac{1}{2}(F+s), \text{ or}$$

$$l_1 = (S'-k) \frac{\sin \frac{1}{2}(F - s)}{\sin \frac{1}{2}(F + s)} + G \cot \frac{1}{2}(F + s) \quad (64)$$

From Fig. 77*a*,

$$A_1A = 0.021 \cot s,$$

and since,

$$l = l_1 - A_1A,$$

$$l = (S' - k) \frac{\sin \frac{1}{2}(F - s)}{\sin \frac{1}{2}(F + s)} + G \cot \frac{1}{2}(F + s) - 0.021 \cot s \quad (64')$$

132. Required the Radius R.—In the triangle Q O C,

$$OC = \frac{CQ}{\sin QOC} = \frac{\frac{1}{2}BC}{\sin QOC},$$

substituting $\frac{1}{2}$ B C from (63),

$$R + \frac{1}{2}G = \frac{G - h - k \sin F}{2 \sin \frac{1}{2}(F + s) \sin \frac{1}{2}(F - s)}, \text{ or}$$

$$R = \frac{G - h - k \sin F}{2 \sin \frac{1}{2}(F + s) \sin \frac{1}{2}(F - s)} - \frac{G}{2} \quad (65)$$

and substituting from (61) and from trigonometry $2 \sin \frac{1}{2}(F+s) \sin \frac{1}{2}(F-s) = \cos s - \cos F$, there results,

$$R = \frac{G - h - k \sin F}{\cos s - \cos F} - \frac{G}{2} \quad (66)$$

The degree of the curve can be obtained from $\sin \frac{1}{2} D = \frac{50}{R}$.

133. Length of Lead-curve Rail B C.—In Fig. 78

$$\text{Arc BC} = \frac{2 \cdot \pi (R + \frac{1}{2}G)(F - s)^\circ}{360^\circ} \quad (67)$$

The length of the rail B′ C′ is

$$B'C' = HN = AM - AH - NM, \text{ or}$$

$$B'C' = l - k - s \quad (68)$$

134. To Find the Coordinates of Any Point on the Lead-curve.—In Fig. 78, let $A_1 c = x$ and $c Z = y$ be the coordinates of any point Z on the lead-curve B C, from the theoretical point of switch A_1; draw the radius O c' normal to A M, and O Z, making the variable angle ϕ with O B; project the point Z to c and a, and the point B to H and b, then

$$x = A_1c = A_1c' + c'c = A_1H - c'H + c'c = A_1H - c'H + a'Z, \text{ or}$$

$$x = S' \cos s - (R + \tfrac{1}{2}G) \sin s + (R + \tfrac{1}{2}G) \sin (s + \phi) \quad (69), \text{ and}$$

$$y = cZ = a'c' = HB + Ob' - Oa', \text{ or}$$

$$y = h + (R + \tfrac{1}{2}G) \cos s - (R + \tfrac{1}{2}G) \cos (s + \phi) \quad (70)$$

135. Practical Turnout to Straight Parallel Track.—It is required to find the radius of the connecting curve and the distance along the main rail between the point of switch and the end of the connecting curve, the frog-number, N, the distance between centers of track, *p*, and the length of the heel-wing of the frog, *k'*, being given. In Fig. 79, project B to M and N, then in the right triangle O_1 B M, since,

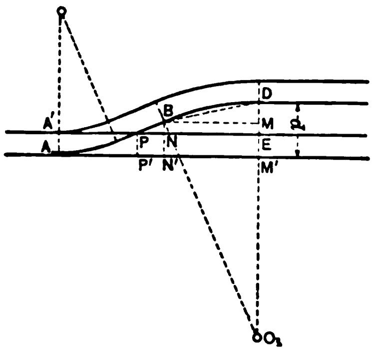


FIG. 79.

$O_1 B = R_1 - \frac{1}{2}G$, and $O_1 M = R_1 + \frac{1}{2} G - p + k' \sin F$, we have

$$O_1B = \frac{O_1M}{\cos BO_1M}, \text{ or}$$

$$R_1 - \tfrac{1}{2}G = \frac{R_1 + \frac{1}{2}G - p + k' \sin F}{\cos F},$$

from which,

$$R_1 = \frac{p - \frac{1}{2}G - \frac{1}{2}G \cos F - k' \sin F}{1 - \cos F} \quad (71)$$

And A being the actual point of switch,

$$AM' = AN' + BM = AP' + P'N' + N'M', \text{ or}$$

$$AM' = l + k' \cos F + (R - \tfrac{1}{2}G) \sin F \quad (72)$$

PROBLEM 20.—In a practical No. 8 turnout from straight track, with a heel-distance of 6¼ inches, a 20-foot switch-rail and k being 4.75 feet, compute the angle s and the lead.

PROBLEM 21. With the data in Prob. 20, compute the length of the lead-curve rail and the straight rail B′ C′.

PROBLEM 22. With the data in Prob. 20, compute the radius of the turnout curve.

PROBLEM 23. In a practical No. 8 turnout from straight track to a parallel track, compute the radius of the curve from the heel of the frog to the parallel track, the distance between tracks being 13 feet center to center, and k' being 8.75 feet.

ARTICLE XIII.

CROSSOVERS. SWITCH ATTACHMENTS.

136. Definition of Crossovers.—A crossover is an arrangement (Fig. 80) of two turnouts facing each other from adjacent tracks by means of which a train may pass from one track to a parallel track. They are necessary at block signals, so that a train may run over the left-hand track in case of obstructions on the other track, and also at stations and sidings and in yards for shifting purposes. It is usual to place crossovers along a railroad at intervals of not more than three miles, or at all points where orders from the train dispatcher at headquarters can be delivered to the conductor of the train. In case of damage or obstruction to the track, a train may be run around the obstruction by using the reverse track between crossovers. This is done through the operators in the stations or towers along the line.

A crossover is usually designated by the number of frogs, for instance if No. 8 frogs are used, it is called a No. 8 crossover.

137. Crossover between Straight Parallel Tracks.—Given the Frog-numbers and the Distance between the Centers of Tracks:

To find the distance B M between the frogs, measured along the main rail; in Fig. 80, prolong the line N C to

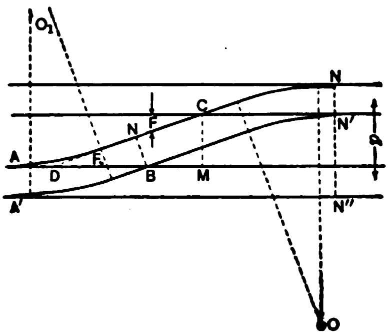


FIG. 80.

D, project the point B to N, and C to M. In the right triangle B D N,

$$\sin BDN = \frac{BN}{DB}, \text{ or}$$

$$DB = \frac{G}{\sin F} \quad (a)$$

In the right triangle D C M,

$$\tan CDM = \frac{CM}{DM}, \text{ or}$$

$$DM = \frac{CM}{\tan CDM} = (p - G) \cot F \quad (b)$$

In Fig. 80,

$$BM = DM - DB \quad (c)$$

substituting (*a*) and (*b*) in (*c*),

$$BM = (p - G) \cot F - G \operatorname{cosec} F \quad (73)$$

$$A'N'' = 2l + BN \quad (74)$$

$$BC = \sqrt{\overline{BM}^2 + \overline{CM}^2} = \sqrt{\overline{BM}^2 + (p - G)^2} \quad (75)$$

138. Example and Table.—Suppose it is required to lay a crossover with No. 8 frogs (No. 8 crossover) between parallel straight tracks 13 feet between centers: Then $N = 8$, $p = 13.00$ feet, $F = 7° \ 09' \ 10''$ (Table XIV), and $G = 4$ feet $8\frac{1}{2}$ inches, and from (73), Fig. 80,

$$BM = (p - G) \cot F - G \operatorname{cosec} F, \text{ or}$$

$$BM = (13.00 - 4.7803) \cot 7° \, 09' \, 10'' - 4.7803 \operatorname{cosec} 7° \, 09' \, 10'' = 28.261 \text{ feet.}$$

This result was obtained by using 7-place logarithms and using $G = 4.7803$ and $F = 7° \ 09' \ 10''$. If 5-place logarithms are used, $G = 4.708$ and $F = 7° \ 09'$, the result will be 28.28 feet; this is not a large difference, but is sufficient to warrant the more exact method.

From (75),

$$BC = \sqrt{\overline{BM}^2 + (p - G)^2}, \text{ or}$$

$$BC = \sqrt{\overline{28.261}^2 + \overline{8.292}^2} = 29.43 \text{ feet.}$$

In Table XVI are given frog-distances for different inter-track distances and standard gauge.

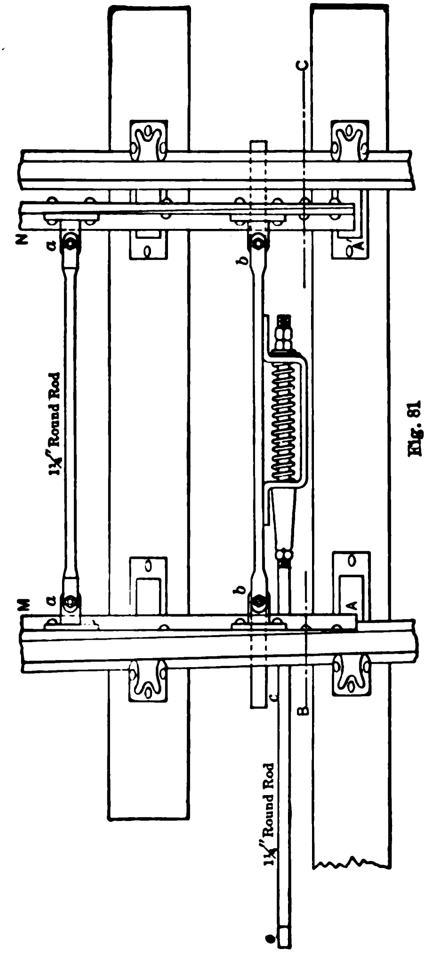
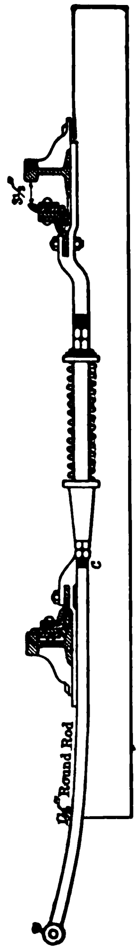


Fig. 81



SECTION B-C

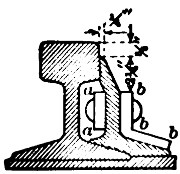
FIG. 82.

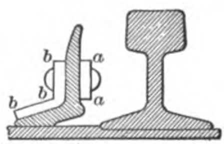
TABLE XVI.

CROSSOVER FROG DISTANCES.

Frog. No.	Center to Center of Tracks. Frog-distance along Main Rail.			Distance between Theoretical Points of Frog.		
	12′ 0″	12′ 2″	13′ 0″	12′ 0″	12′ 2″	13′ 0″
5	12.32	13.14	17.27	14.85	15.54	19.16
6	15.00	15.99	20.96	17.14	18.02	22.54
7	17.66	18.82	24.62	19.51	20.56	25.98
8	20.29	21.62	28.26	21.92	23.16	29.45
9	22.92	24.41	31.89	24.37	25.78	32.95
10	25.52	27.18	35.49	26.83	28.42	36.44

139. Reinforced Switch-point Rails. — Switch-point rails are made plain or reinforced. The plain





SECTION A-A′

FIG. 83. FIG. 84.

switch-point rails are formed by planing both sides of the head and one side of the flange of the rail so that the face of the rail that forms the gauge of the turnout will be in proper position when the switch rail is held against the main rail by the switch rods. In Figs. 81 and 82 are shown the plan and elevation of about three and one-half feet of a pair of switch-point rails and their attachments. In Figs. 83 and 84 are shown sections of the main rails and the switch-point rails at the points A and A′, Fig. 81. If the reinforcing bars *a a* and reinforcing angles *b b b* were omitted from Figs. 83 and 84 the plain switch-point rails would be left. Short switch-point rails are not usually reinforced, but long points always are. The reinforcing consists of the bars *a a* and the angles *b b b* riveted to the point-rails.

140. Switch Rods.—Switch-point rails are connected and held in position by one or more rods *a a* and *b b*, Fig. 81, the end rod being connected to the lever or device *c c*, Figs. 81 and 82, by which the switch is thrown. Switch rods are of two general types, viz., plain and adjustable, but there are many forms of each. Plain switch rods are most generally used and must be made to suit the design of the switch; the dimensions of switch rods depend upon the gauge, the weight of rail, the length of the switch-point rails, and the distance from the point of switch at which they are placed. The plain switch rod *a a*, Fig. 81, is bolted to clips which are riveted to the reinforced points.

Adjustable rods are made in two pieces which screw into a socket or joint at the center of the rod, by means of which slight variations in the length of the rod may be made. If switch rods are properly designed, there is no necessity for adjustment. Switch rods on account of their exposed position are very liable to become bent, thus shortening the distance between the switch rails, but it will be easier to take out the plain bar, straighten it, and put it back, than it will to attempt to adjust the difference due to the bending by means of a screw arrangement that has probably become badly rusted.

The end switch rod passes under the rails and is attached to the switch stand, and must have a spring arrangement that will allow the wheel flanges to force their way through the heel of the switch, when the point switch is set the wrong way. These springs are usually attached to the part of the rod that is between the rails, although there are some switch stand devices that have the spring in the stand.

141. Switch Stands.—A switch stand should have the following three essential points for satisfactory operation: First, a true throw with as little lost motion as possible; second, a safe locking device so that it cannot be misplaced through carelessness; and, third, a sure indication of its position, by target in daytime and lamp at night. A true throw is especially important for a stub switch, since the stub switch, having no spring, depends entirely upon the position of the lever, while in a point switch the spring will take up a small amount of lost motion.

In the early days of railroading, when the stub switch was in universal use, the most common form of upright switch stand was called the "harp" pattern. It consisted of a straight lever held upright in a harp-shaped frame, the target being attached to the upper end and the connecting rod to the lower end of the lever. The principle of the device was very simple, and furnished a cheap and reliable means for throwing and holding the switch rails. During the daytime it showed plainly the position of the switch; when the lever stood in a vertical position it indicated main line, and a side, or slanting, position indicated that it was set for the turnout. A switch light could not be readily attached, consequently the harp switch stand went almost entirely out of use when night signals became necessary. A few of these stands with a lamp attachment may still be found.

142. Low Switch Stands.—There are a great many varieties and patterns of switch stands. In Fig. 85 are shown three varieties of the Ramapo patent safety switch stands. The target is shaped and painted so that it shows clearly whether or not the switch is open, and this is also indicated by the lamp that is placed on the top of the stand by means of the attachment shown at the top of the vertical bar. The switch can also be locked in the position desired. Switch stands are used in yards and in connection with side tracks that are not much used. In case of an important switch or turnout from the main track a semaphore or banjo signal is used.

In the Ramapo switch stands, Fig. 85, the signal and switch rails are attached to the same switch rod. It is imperative that the signal and switch work in unison, as the engineman is guided solely by the target or signal, as it would be impossible to distinguish the position of the switch rails even when running within the speed limits allowed in yards.

143. Guard Rails.—Guard rails are always placed opposite a frog, as shown in Fig. 63, on both the turnout and main rails. They are usually from twelve to fifteen feet in length and are shaped in different ways. In one extreme they are curved throughout their entire length and are so placed that the center of the arc is directly opposite the point of frog; and in the other extreme, six or eight feet of the center of the guard rail is straight, and the ends are gently curved so that the wheel flanges are gradually crowded toward the main rail and allow a minimum amount of side motion for a distance equal to the straight part of the guard rail.

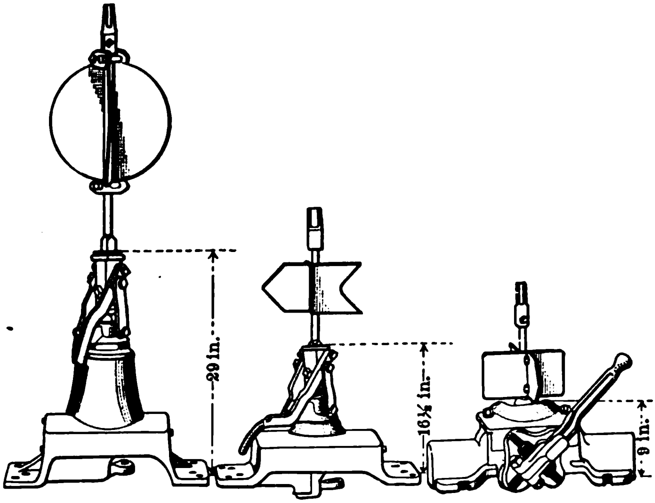


FIG. 85.

Arguments are advanced in favor of both extremes, but the general usage is between the two. In the guard rail shown in Fig. 86 the straight part is three feet long, and the guard rail is so placed that two feet of the straight part is ahead of the point directly opposite the point of frog and one foot of the straight part is behind it, thus making eight feet of guard rail ahead and seven feet behind the point of frog, the total length of the guard rail being fifteen feet. There is a clear flange-way, or distance between gauge of main rail and outside of head of

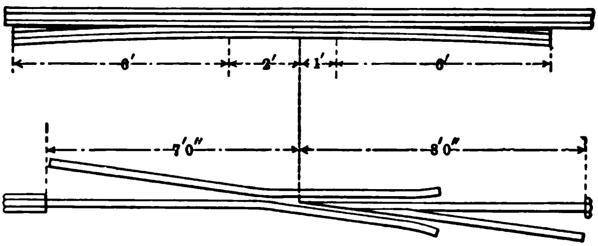


FIG. 86.

guard rail, of $1\frac{3}{4}$ inches along the straight part of the guard rail, and four inches at the ends. The inner flange of the guard rail is planed off so that the proper flange-way can be obtained without interfering with the spiking of the main rail. The guard rail is held in place by tie plates, rail braces, and spikes not shown in the figure. Only the heads of the rails in the frog are indicated in Fig. 86.

144. Foot-guards.—Foot-guards are devices placed between all rails which come so close together that a trackman may get his foot caught between them, such as between guard rails and the main rail, switch-point rails and the main rail, and other parts of the frog or switch with similar spaces. A large number of railroad employees are injured in this way every year, particularly in yards. In cutting, drilling, and making up a train very quick work must be done, the men jumping from moving cars without much time to look out for proper footing. If a man gets his foot caught in one of these traps under these circumstances, he is very liable to have a foot cut off or be killed before the car or train can be stopped. In some States legislation has been passed requiring proper safeguards to be used, and in all cases railroad officials should see that they are used. Wooden blocks, metal guards, and gravel or cinder filling are employed. Frogs frequently have cast-iron fillers bolted in during manufacture. The most difficult part to safeguard is the switch-point rail. A piece of iron or steel bar 1½ inches wide and ¼ inch thick, bent as shown in Fig. 87, and bolted to the webs of the rails, makes a light and efficient foot-guard.

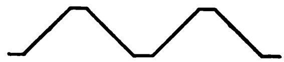


FIG. 87.

145. Headblocks.—At the point of each switch are placed two pieces of timber called headblocks, as shown in Figs. 81 and 88. The headblocks should be the same thickness as the ties, seven inches, or at most not more than one inch thicker, eight to ten inches wide, and twelve to fifteen feet long. The point of switch comes directly over the first block, and the switch stand, or whatever device there may be for throwing the switch and the signal, is fastened to the outer ends of the headblocks. Headblocks are necessary to insure that the rods and attachments that connect the switch-rails to the switch stand cannot become deranged through the shifting of the track. In some cases, such as where a simple ground lever is used for throwing the switch, only one block is used. It is better that headblocks be sawed, but they may be hewed if they give a true surface. In case of only one block being used, it is sometimes specified that it shall be seven inches thick, fourteen to sixteen inches wide, and twelve to fifteen feet long depending upon the standards of the particular railroad.

146. Switch-Timbers.—In order that the ties may extend the same distance outside the rails, it is necessary that the ties for a switch be made longer than the regulation tie. These ties of special length are called switch-timbers. When the regular ties are $8\frac{1}{2}$ feet long and the gauge is 4 feet 8 inches, the end of the tie is $20\frac{3}{4}$ inches from the gauge line. A switch may be laid roughly with ordinary ties by placing a tie under the main track and the next tie under the turnout track, alternately. This gives an unequal bearing for the different rails, necessitates an excessive amount of timber, and is used only when proper switch-timbers cannot be obtained.

A set of switch-timbers for a No. 6 turnout is shown in

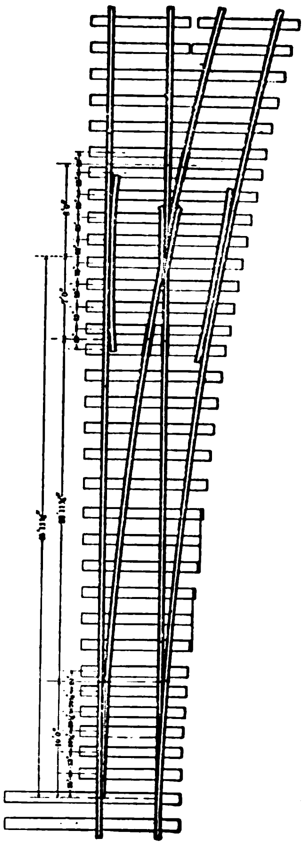


Fig. 88.

Fig. 88. The lower ends of the timbers follow a curve parallel to the curve of the turnout and 20¾ inches from the gauge of the outer rail, the timbers being cut to the nearest inch in length. Switch-timbers are placed under the turnout up to the point where the tracks are far enough apart to allow regular ties to be used, as shown to the right of Fig. 88. As soon as this point is reached the outer ends of the ties under the turnout are gradually placed closer together until the ties are normal, or radial, to the track.

On some railroads, instead of having each switch timber of different length with the center of their ends following the parallel, or concentric curve, two or more adjacent timbers are made the same length, provided the variation from the theoretic length is not too great. This method is indicated by the broken lines at the lower part of Fig. 88, three timbers being taken of equal length, the middle timber being the true length, and the ends of the timbers looking like a series of steps.

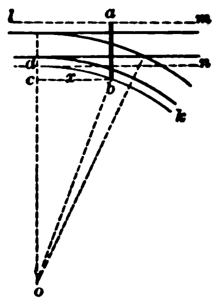


Fig. 89.

147. Length of Switch Timbers.—Switch timbers are placed at distances apart governed by the standard of the railroad. In Fig. 88 is shown the standard spacing of switch timbers for a No. 6 turnout on the Pennsylvania R. R., the timbers being placed closer together under the switch-rails and frog. The length of switch timbers may be determined by plotting the details of the turnout to a large scale, or by computing the length when the distance from the point of switch is known.

In Fig. 89, let *o* be the center of the turnout curve, draw *l m* and *d n* parallel to the main track and $8\frac{1}{2}$ feet apart representing the ends of regular ties, and the curve *d b k* at the corresponding distance from the turnout track. Then to determine the length of the switch timber *a b*, draw $bc = x$ parallel to the main track, and the line *o b*, and let the radius $od = r_1$, and r be the radius of the turnout. In the triangle *cob*, $\sin cob = \frac{x}{r_1}$, and in the triangle *dob*, $cd = r_1 \text{ vers } cob$, then

$$ab = 8\tfrac{1}{2} + cd \qquad (76).$$

In the above formula all the distances are in feet. The lengths of all the switch-timbers being determined, they

TABLE XVII.

BILL OF TIMBER.

NO. 6 TURNOUT. TIES 7″ × 10″.

No. of Pieces.	Length.	No. of Pieces.	Length.	No. of Pieces.	Length.
2	12′ 6″	1	10′ 1″	1	13′ 8″
1	8′ 7″	1	10′ 4″	1	14′ 0″
1	8′ 8″	1	10′ 7″	1	14′ 4″
1	8′ 9″	1	10′ 10″	1	14′ 7″
1	8′ 10″	1	11′ 1″	1	14′ 11″
1	8′ 11″	1	11′ 5″	1	15′ 3″
1	9′ 0″	1	11′ 9″	1	15′ 7″
1	9′ 2″	1	12′ 1″	1	15′ 11″
1	9′ 4″	1	12′ 4″	1	16′ 4″
1	9′ 6″	1	12′ 8″	1	16′ 8″
1	9′ 8″	1	13′ 0″	1	17′ 0″
1	9′ 10″	1	13′ 4″		

Total, 36 Pieces.

433′ 0″ lineal. 2526 feet B. M.

are compiled into a table called the *bill of timber*, there being a bill of timber for each style of turnout. In table XVII (page 151) is given the Pennsylvania R. R. bill of timber for a No. 6 turnout in which the turnout track is tangent from the heel of the frog, which requires more of the long timbers than where the turnout is curved beyond the heel of the frogs, as in Fig. 88, the first two pieces being the headblocks.

148. Derailing Switch.—A derailing switch is a device by which a train or car can be derailed when absolutely necessary. They are placed on sidings, as at *a b*, Fig. 90, to prevent a car from running on the main track from the siding, and the switch placed far enough back of the frog to prevent the train or car when ditched from interfering with the main line track. Derailing switches are also placed at the entrance to single-track railroad bridges, particularly drawbridges, and also at grade railroad crossings. In a grade railroad crossing, in most cases, when the tracks and signals are set for one railroad, the derailing switches on the other railroad are

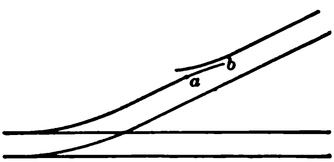


FIG. 90.

set so that a train can not run into the train having the right of way, it being invariably less dangerous to ditch one train than to run the two trains together. In Fig. 90, *a b* is a switch point controlled by a lever.

149. Interlocking Switches.—Interlocking devices are too many and complicated to give anything like a full discussion, therefore only a brief description of the manner of working an interlocked switch will be given here. When a train is to be run from the main line to a turnout, or vice versâ, the tracks being clear, the tower operator throws a lever which opens the switch and sets all necessary signals; by means of an interlocking device, this lever is prevented from being thrown back in its first position until the entire train has passed through the switch. The signals in the mean time are set so that another train can not run into the first train without disregarding the signals. The device that prevents the lever from being thrown back too soon usually consists of a long flat bar of iron which lies close to the outer face of the head of the rail, with its top flush with the head of the rail. This bar works on the pivot principle by means of small angle levers, and in passing from the position in which it lies when the switch is closed to its position when the switch is open, or vice versâ, it rises above the head of the rail and falls to a position level with the top of the rail. This bar, called a detector bar, is attached to the switch device in such a manner that it works automatically, and is of such length that there is always at least one wheel on it when a train is passing; the wheels hold it down, thus preventing the lever in the tower or any of the signals being changed until the entire train has passed.

PROBLEM 24. In a No. 6 crossover between parallel tracks, 13 feet center to center, compute the frog-distance along main rail, the distance between the theoretical points of frog, and the total length of crossover A′ N″, Fig. 80.

PROBLEM 25. Make the corresponding computations as in Problem 24, for a No. 8 crossover.

PROBLEM 26. Compute the length of switch-timber required at the frog-point in a No. 8 turnout.

ARTICLE XIV.

FROGS.

150. Rigid or Stiff Frogs.—Rigid frogs are so called in books and catalogs, but most trackmen call them stiff frogs. Frogs are of three general classes, viz., rigid frogs, springs frogs, and movable-point frogs. Stiff frogs are used in grade crossings and in turnouts and crossovers where both tracks are used equally, the speed always being reduced, as in yards. There are a number of forms of stiff frogs, differing in the manner in which the various parts are fastened together, viz., riveted, bolted, and yoked or keyed. All frogs, whether stiff or spring, are made of the same weight rail as the balance of the track. In Fig. 91 is shown a bolted frog. It is formed of pieces of rail cut and shaped to the proper form, held apart by rolled steel fillers, and firmly bolted together. The number of bolts depends upon the number of the frog and the general design, five to nine bolts $1\frac{1}{4}$ or $1\frac{3}{8}$ inches in diameter being used. One or more rivets are used in addition to the bolts, the rails M and N being riveted together, one rivet being shown in Fig. 91, and two other rivets near the section C D not being shown. In Figs. 92 and 93 are shown two sections of the frog, A B and C D respectively. Bolted frogs have the advantage that damaged

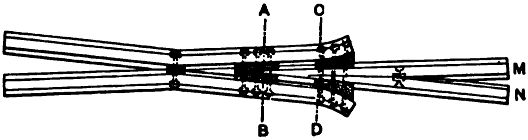


FIG. 91.

parts may be replaced, but the parts of the frog are more liable to work loose than in other forms.

Frogs are made and completed in the shop and are delivered ready to lay in the track; the trackmen then cut the track at the proper places and insert the frog.

151. Yoked Frogs.—Yoked frogs are known by one

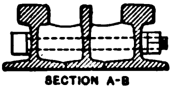


FIG. 92.

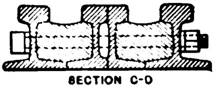


FIG. 93.

of three names, viz., yoked, clamped, or keyed frogs. The yoked stiff frog is similar in general outline to the bolted frog in Fig. 91, but instead of bolts it is held together by two or more yokes, or clamps. The yokes are made with a clear grip x, Fig. 94, depending upon the weight of the rail, the number of the frog, and their position in the frog. In the second sketch in Fig. 94 is shown the section, end-view, and dimensions of the clamp or yoke. The rails are placed in the yokes and fastened by means of steel wedges. In a frog with a large number three yokes should be used, taking the place of the three sets of bolts in Fig. 91. The yokes are made of wrought-iron or mild steel. Injured parts of a yoked frog may be more readily replaced than in a bolted frog, but the parts are more liable to work loose.

152. Riveted Frogs.—All frogs of the same number require the pieces of rail to have practically the same size and shape. Riveted frogs for light rails and light

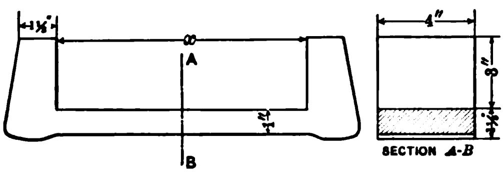


FIG. 94.

traffic are formed by riveting the bases of the rails to a large plate which extends under the greater part of the frog. The plate is rectangular in shape and is as wide as the widest part of the frog. No frog is put together for heavy rails and traffic by rivets alone, but consists of a combination of the bolted frog and the riveted frog described above, and is made by riveting a bolted frog to a rectangular base plate, by means of rivets through the flanges of the rails. These are called bolted plate frogs and are used under very heavy traffic where the bolts alone would not be strong enough. Bolted plate frogs last much longer than the other forms under the same conditions, but must be sent to the shop to be repaired.

153. Spring Frogs.—In stiff frogs there is a break in the continuity of both the main track and the turnout rails at the point of frog, there being a space over which the wheels must pass, the wheels being supported over this opening by a partial bearing on the wing rails of the frog, consequently a blow is struck by each wheel as it passes this point. These blows loosen and wear out the frog rapidly, besides necessitating a slow rate of speed. In the case of a turnout from the main track in which the main track is used considerably more than the turnout, a spring frog is used, the spring frog giving practically a continuous rail for the main track.

In Fig. 95 is shown the arrangement of the rails in a spring frog. The spring in the case S holds the movable wing rail *a b* firmly against the adjoining part of the frog so that the main rail *a c* is practically unbroken. When a train is passing from the turnout to the main track, the wheel flanges enter the heel of the frog at *b* and force the wing rail over, the spring not being stiff enough to prevent this action, but being stiff enough to force the wing rail back after the flanges have passed. In the same manner the wing rail is forced over when a train enters the turnout from the main track, the guard rails which are always placed on both the turnout and main track opposite the frog assisting in this action. A spring frog is more complicated in design than a stiff frog, not only on account of the movable parts and the spring, but also on account of the special tie plates and braces necessary for the proper working of the frog.

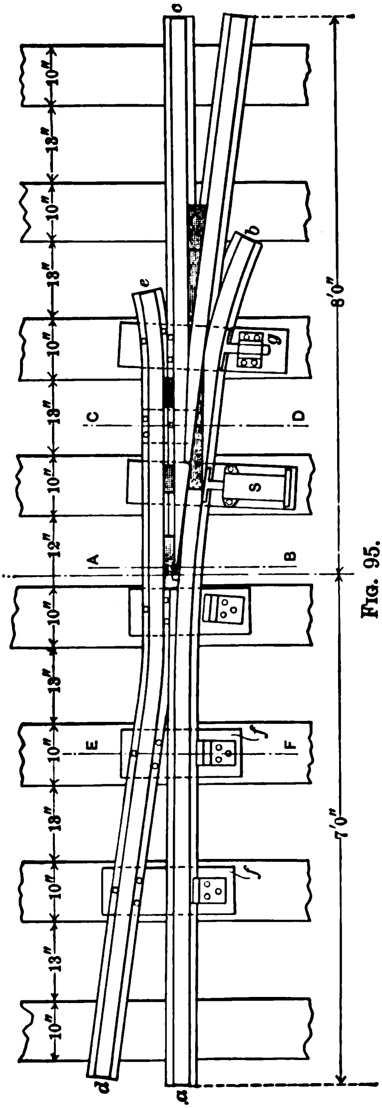
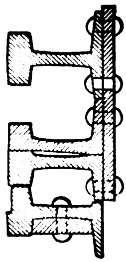
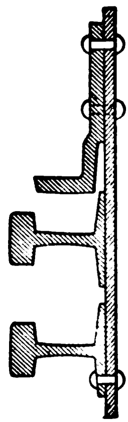


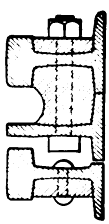
FIG. 95.



SECTION C-D
FIG. 96b.



SECTION E-F
FIG. 96c.



SECTION A-B
FIG. 96a.

The section through A B is shown in Fig. 96*a*. The fixed wing rail *d e* is bolted to the frog point rails through rolled steel fillers shown in the figure. In Figs. 96*a* and 96*b* is shown the reinforcing bar which is riveted to the web of the movable wing rail *a b*. The bar is not shown in Fig. 95, as the additional lines necessary to show it would add confusion to the figure. For the same reason the spikes, the bolts, and some of the rivets are not shown.

The movable wing rail *a b* slides over the tie plates and is braced when pushed over by the flanges by the braces *f f*, shown in Figs. 95 and 96*c*, the braces being riveted to the tie plate and shaped so that they fit snugly against the web of the rail or the reinforcing bar. The wing rail is further controlled by the arm *g*, which is riveted to the rail and moves through a socket riveted to the tie plate. In Fig. 96*b* is shown a section through C D.

154. Reinforced Frogs.—The metal of a frog is worn most at and near the point of the frog, this part being called the throat of the frog. The point of the frog is often strengthened by means of a manganese tip. The frog is made from standard rails and then about a foot in length of the point of the frog is shaped so that a tip of manganese steel can be fastened to it.

In Figs. 97, 97*a*, and 97*b* are shown the plan and details of a stiff frog reinforced with manganese steel. The rails of the frog are spread at the throat and a casting that reinforces both rails and the frog-point is inserted as shown in Fig. 97. In Fig. 97*a* is shown the plan of part of the frog-point, the elevation of the

MANARD ANVIL FACE FROG.

THE PENNSYLVANIA STEEL COMPANY.

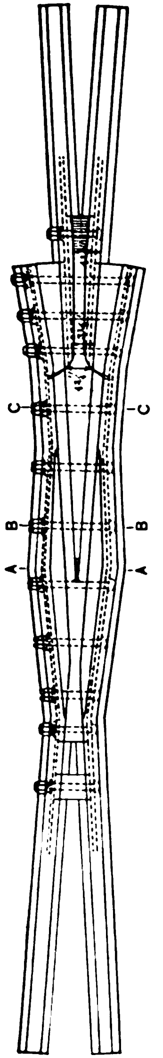


FIG. 97.

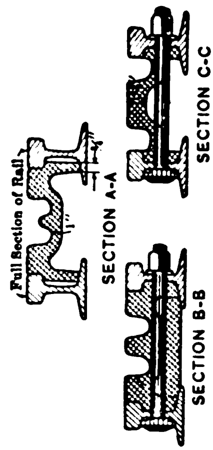


FIG. 97b.

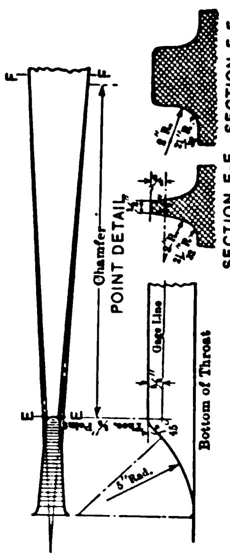


FIG. 97a.

point of frog and two sections. In Fig. 97*b* three sections of the frog are shown. This is called the "Manard Anvil Face Frog," and is patented and manufactured by the Pennsylvania Steel Company.

155. Crossing Frogs.—Crossing frogs are necessary where two tracks cross each other at grade. The details of the design of crossing frogs depend upon the amount of

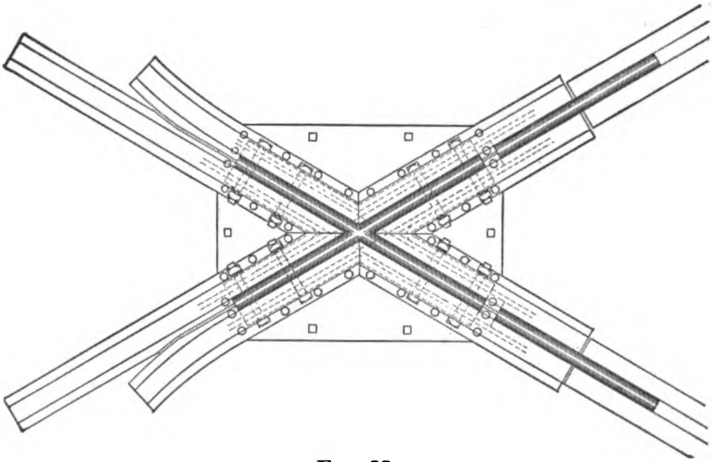


FIG. 98.

traffic and the crossing angle. A sixty-degree crossing frog manufactured by the Ramapo Iron Works is shown in Fig. 98, the figure representing the intersection of two rails, four of these frogs being necessary for the intersection of two single tracks. When the angle is greater than the angle of an ordinary turnout frog and the tracks are used equally, stiff frogs are used. Crossing frogs are subject to all the objections of an ordinary stiff frog, and the amount of pounding that they receive under heavy traffic makes them very difficult to maintain, and one year was a long life for them under fairly heavy traffic, when they were made out of the ordinary rail steel, but manganese steel frogs last several years.

A grade track crossing is one of the weakest spots in a railroad on account (1) of the danger, (2) interruption of traffic of both roads, and (3) difficulty of maintenance. In a few cases a grade-crossing is absolutely necessary on account of local conditions, topographic or otherwise. Formerly many were put in simply to save in the first cost of construction. In many instances railroads have gone to great expense and inconvenience to eliminate a grade-crossing, by substituting for it either an overhead or undergrade crossing. Laws are now in effect in most States which make it practically impossible to put in grade railroad crossings if either road objects.

156. Ordering Crossing Frogs.—Crossing frogs are ordered either from the shops of the railroad or from firms who make a specialty of manufacturing them, and the railroad must supply the following information: (1) gauge of track; (2) angle of crossing; (3) curvature, if any; (4) distance between centers of track, in case either road has more than one track; and also the following information for the drilling of splice-bars: (1) the distance from the end of rail to the center of first hole; (2) distance center to center of holes; base of rail to center of holes; and in addition to the above there must be sent a sample piece of the rail to be used, a full-size drawing of the rail section, or the number of the rail section in the rail manufacturer's catalog.

In addition to the above, it is now becoming customary for the railroad to specify that the steel in the rails used for the frogs shall have a certain composition of a higher grade than in the rails used on the balance of the track.

157. **Movable-point Frog.**—Where the angle between the crossing tracks is small, or a slip switch is necessary, a movable-point frog is often used. In Fig. 99 is shown a double slip switch and crossing, the lines representing the gauge of the rails. The track A A crosses the track B B by means of the stiff frogs F and F and the movable-

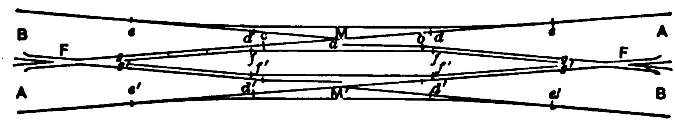


Fig. 99.

point frogs M and M′. The frog M consists of two switch points, *a b* and *a c*, which are controlled by separate levers attached to the companion points at M′. These points are shorter and stronger than the ordinary switch-point rails. In the figure the frogs are set for the track A A. By the proper manipulation of the switch-point rails *d e*, *d′ e′*, *f g*, *f′ g′* and the movable frogs trains may run from a track to either of the facing tracks.

A movable-point frog may be used in an ordinary turnout. In the McPherson patented safety switch and frog neither of the rails of the main track is cut. Movable-point frogs require a tower with interlocking devices to insure their proper action.

158. The Practical Turnout Frog.—The practical frog is constructed with the gauge lines of both rails straight; it can be used in the great majority of cases, even on curved secondary tracks (yards and sidings). The principal case where one gauge would probably have to be curved would be in a turnout or crossover in curved main track; fortunately such cases are the exception on important roads, and a special frog could be designed for each case.

159. Details and Data of Practical Frog.—A sketch of a stiff frog is shown in Fig. 100, in which

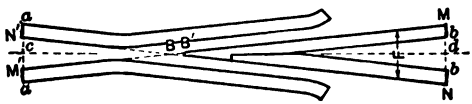


FIG. 100.

only the heads of rails are shown; M M′ and N N′ are the gauge lines intersecting at the theoretical point of frog, B, B M′ and B N′ are the toe wing-rails, *k*, and B M and B N are the heel wing-rails, *k*′. The practical point of frog is at B′, where the thickness is ½ inch, experience showing that when the point is too long and thin it soon is broken and battered off, consequently the Am. Ry. Eng. Assn. recommends a thickness of ½ inch. The total length, M M′, of the frog is governed by practical details, viz., there must be sufficient space between the ends of the wing-rails, M′ N′ and *b b*, to allow for the placing of the splice bars connecting the frog with the adjacent rails; the spaces M′ N′ and *b b* should be as nearly equal as possible, but may vary enough to prevent the wing-rails from being given in small decimals. The data in columns 4, 5, and 6, Table XVIII, are taken from the Manual of the Am. Eng. Ry. Assn.

In Fig. 100, in the triangle N′ B C,

$$N' c = N' B \sin N' B c, \text{ or}$$

$$\text{the toe spread} = 2N'c = N'M' = 2k \sin \tfrac{1}{2}F \quad (77)$$

and in the same way

$$\text{the heel spread} = 2k' \sin \tfrac{1}{2}F \quad (78)$$

TABLE XVIII.

FROG DATA.

Frog. No. N	Frog Angle, F.	Distance Theoretical to Actual Point.	Length.			Spread.	
			Point to Toe, k.	Point to Heel, k′.	Total.	Toe, w.	Heel, w′
		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
4	14° 15′ 00″	0.168	3.17	5.33	8.50	0.79	1.32
5	11 25 16	0.209	3.58	6.42	10.00	0.71	1.28
6	9 31 38	0.251	4.00	7.00	11.00	0.66	1.16
7	8 10 16	0.288	4.42	8.08	12.50	0.63	1.15
8	7 09 10	0.334	4.75	8.75	13.50	0.59	1.09
9	6 21 35	0.375	6.00	10.00	16.00	0.67	1.11
10	5 43 29	0.416	6.00	10.50	16.50	0.60	1.05
12	4 46 19	0.498	6.42	12.08	18.50	0.53	1.01
16	3 34 48	0.667	8.00	16.00	24.00	0.50	1.00
20	2 51 51	0.830	9.67	19.33	29.00	0.48	0.97
24	2 23 13	0.995	11.33	23.17	34.50	0.47	0.97

Substituting the data from columns 1, 2, 4, and 5 in the above formulas, columns 7 and 8, Table XVIII, are computed.

Referring to Fig. 100, the distances B B′, which are the distances between the theoretical and practical points of frog, were computed by proportioning the ½-inch thickness, the heel spread and the heel wing-rail length, and are given in column 3 of the Table.

160. Crossing-frogs for Straight Tracks.—When a single track crosses another track four crossing-frogs are required, and the four frogs are called a set of crossing-frogs. Let the four lines in Fig. 101 represent the gauge lines of two tracks crossing each other at the angle F, projecting the point A to E, then in the triangle A D E,

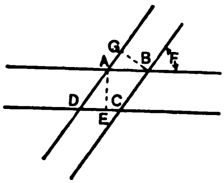


FIG. 101.

$$AD = BC = G \operatorname{cosec} F \quad (79)$$

If the gauges are equal, A D = B C = A B = D C, but if the gauge of the other track is G′, then from the triangle A B G,

$$AB = DC = G' \operatorname{cosec} F \quad (80)$$

161. Computing the Crossing-frogs for a Straight and a Curved Track.—It is necessary to know the angle between the tangent to the center line of the curve and the center line of the straight track, and the gauges, G_1 and G, of the tracks, since true curved crossings are very likely to be used on yard or shop industrial tracks. In Fig. 102, let O e = R, and $a\,b$ and $c\,e\,b$ be the center lines of the tracks, intersecting at e, and the angle $a\,e\,f$

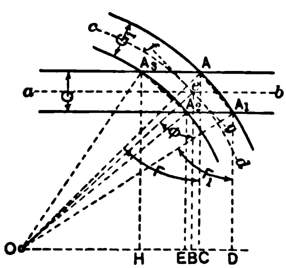


FIG. 102.

$=\phi$ be measured in the field, then it is required to find the frog-angles F, F_1, F_2, and F_3 at A, A_1, A_2, and A_3 respectively. Draw O *e* and O A, and project *e* to B and A to C on a line parallel to the straight track In the triangle A O C, the angle O A C = F, and A C = O A cos O A C = (R + ½ G_1) cos F; in the triangle *e* O B, the angle O *e* B = ϕ, and

$$eB = Oe \cos\phi = R\cos\phi,$$

but

$$AC = Be + \tfrac{1}{2}G,$$

substituting, we have

$$(R + \tfrac{1}{2}G_1)\cos F = R\cos\phi + \tfrac{1}{2}G,$$

$$\therefore\ \cos F = \frac{R\cos\phi + \frac{1}{2}G}{R + \frac{1}{2}G_1} \qquad (81)$$

To find F_1 at A_1, in Fig. 102, draw O A_1 and project A_1 to D, then in the triangle A_1 O D,

$$A_1D = (R + \tfrac{1}{2}G_1)\cos F_1, \text{ but}$$

$$A_1D = Be - \tfrac{1}{2}G;$$

equating the values of A_1 D,

$$(R + \tfrac{1}{2}G_1)\cos F_1 = R\cos\phi - \tfrac{1}{2}G,$$

$$\therefore\ \cos F_1 = \frac{R\cos\phi - \frac{1}{2}G}{R + \frac{1}{2}G_1} \qquad (82)$$

Similarly it can be shown that

$$\cos F_2 = \frac{R\cos\phi - \frac{1}{2}G}{R - \frac{1}{2}G_1} \qquad (83)$$

and

$$\cos F_3 = \frac{R\cos\phi + \frac{1}{2}G}{R - \frac{1}{2}G_1} \qquad (84)$$

To find the chord distance between frogs, in Fig. 102, draw the line $A A_1$, and a line from O to the middle of $A A_1$, then in the triangle $A O A_1$, the angle $A O A_1 = F_1 - F$, and

$$AA_1 = 2(R + \tfrac{1}{2}G) \sin \tfrac{1}{2}(F_1 - F) \quad (85)$$

and similarly,

$$A_2A_3 = 2(R - \tfrac{1}{2}G) \sin \tfrac{1}{2}(F_2 - F_3) \quad (86)$$

From the triangle $A O_1 D$,

$$OD = OA_1 \sin F_1 = (R + \tfrac{1}{2}G) \sin F_1;$$

and from the triangle $A_2 O E$,

$$OE = (R - \tfrac{1}{2}G) \sin F_2; \text{ but}$$

$$A_1A_2 = ED = OD - OE,$$

$$\therefore A_1A_2 = (R + \tfrac{1}{2}G) \sin F_1 - (R - \tfrac{1}{2}G) \sin F_2 \quad (87)$$

and in the same way

$$AA_3 = (R + \tfrac{1}{2}G) \sin F - (R - \tfrac{1}{2}G) \sin F_3 \quad (88)$$

162. Computing the Crossing-frogs for two Curved Tracks.—The Radii of the Curves, the Gauges, and the Intersection Angle being Given, to find the Angles of the Crossing-frogs and the Rail Lengths.

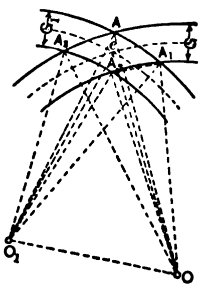


Fig. 103.

In Fig. 103, let O be the center of the curve of the track whose radius is R and gauge G, and O_1 the center of the curve of the crossing track whose radius is R_1 and gauge G_1, and the intersection angle $\phi = O_1 e O$. In the triangle $O_1 e O$, $O_1 e = R_1$, $O e = R$, and $O_1 e O = \phi$, then by trigonometry

$$\frac{Oe + O_1e}{Oe - O_1e} = \frac{\tan \frac{1}{2}(eO_1O + O_1Oe)}{\tan \frac{1}{2}(eO_1O - O_1Oe)} = \frac{R + R_1}{R - R_1} = \frac{\tan \frac{1}{2}(180° - \phi)}{\tan \frac{1}{2}(eO_1O - O_1Oe)}, \text{ or}$$

$$\tan \tfrac{1}{2}(eO_1O - O_1Oe) = \frac{R - R_1}{R + R_1} \cot \tfrac{1}{2}\phi \quad (89)$$

the angles at O_1 and O can be found, then by the law of sines,

$$O_1O = D = \frac{R_1 \sin \phi}{\sin O_1Oe} = \frac{R \sin \phi}{\sin eO_1O} \quad (90)$$

To find the frog angles in Fig. 103, draw the lines O_1 A and O A, then in the triangle O_1 A O, O_1 A O $=$F, O_1 A $=R_1+\frac{1}{2}$ G_1, O A $=R+\frac{1}{2}$ G, and O_1 O $=$D; letting $s=\frac{1}{2}(O_1 A+O A+O_1 O)$, we have from trigonometry,

$$\sin \tfrac{1}{2}F = \sqrt{\frac{[s - (R + \frac{1}{2}G)][s - (R_1 - \frac{1}{2}G_1)]}{(R+\frac{1}{2}G)(R_1+\frac{1}{2}G_1)}} \quad (91)$$

Similarly in the triangle O_1 A_1 O,

$$s = \tfrac{1}{2}[(R - \tfrac{1}{2}G) + (R_1 + \tfrac{1}{2}G_1) + D], \text{ and}$$

$$\sin \tfrac{1}{2}F_1 = \sqrt{\frac{[s - (R - \frac{1}{2}G)][s - (R_1 - \frac{1}{2}G_1)]}{(R - \frac{1}{2}G)(R_1 + \frac{1}{2}G_1)}} \quad (92)$$

Similarly in the triangle O_1 A_2 O,

$$s = \tfrac{1}{2}[(R - \tfrac{1}{2}G) + (R_1 - \tfrac{1}{2}G_1) + D], \text{ and}$$

$$\sin \tfrac{1}{2}F_2 = \sqrt{\frac{[s - (R_1 - \frac{1}{2}G)][s - (R_1 - \frac{1}{2}G_1)]}{(R - \frac{1}{2}G)(R_1 - \frac{1}{2}G_1)}} \quad (93)$$

And similarly in the triangle O_1 A_3 O,

$$s = \tfrac{1}{2}[(R + \tfrac{1}{2}G) + (R_1 - \tfrac{1}{2}G_1) + D], \text{ and}$$

$$\sin \tfrac{1}{2}F_3 = \sqrt{\frac{[s - (R + \frac{1}{2}G)][s - (R_1 - \frac{1}{2}G_1)]}{(R + \frac{1}{2}G)(R - \frac{1}{2}G_1)}} \quad (94)$$

163. Computing the Distances between Crossing-frogs for Two Curved Tracks.—Having the frog-angles from ¶ 162, and drawing the chord $A_1 A_2$ in Fig. 103, the triangle $OA_2 A_1$ is formed, in which $O A_2 = O A_1 = R - \frac{1}{2}G$, and the angle $A_2 O A_1$ is found as follows: In the triangle $A_1 O_1 O$, the three sides and the angle $O_1 A_1 O = F_1$, are known, and

$$\sin O_1OA_1 = \frac{O_1A_1}{OO_1} \sin O_1A_1O = \frac{R_1 + \frac{1}{2}G_1}{D} \sin F_1;$$

in the same way in the triangle $A_2 O_1 O$,

$$\sin O_1OA_2 = \frac{R_1 - \frac{1}{2}G_1}{D} \sin F_2;$$

and the angle $A_2 O A_1$ is known, since

$$A_2OA_1 = O_1OA_1 - O_1OA_2;$$

then from the triangle $A_2 O A_1$,

$$A_2A_1 = 2(R - \tfrac{1}{2}G) \sin \tfrac{1}{2}A_2OA_1 \quad (95)$$

In a similar manner $A A_1$, $A A_3$, and $A_3 A_2$ may be determined. The arc $A_2 A_1 =$

$$A_2A_1 = 2\pi(R - \tfrac{1}{2}G)\frac{(A_2OA_1)^\circ}{360^\circ} = (R - \tfrac{1}{2}G)\frac{(A_2OA_1)^\circ}{57.3} \quad (96)$$

The other rail lengths between frog-points may be determined in the same way.

Since crossing-frogs must be manufactured to suit the case, they are made with curved wings, as is also very often the case in a long turnout (large frog-number) from a curved main track to a third running track, and also in the accompanying crossover.

164. Crossing-slips.— A slip-switch crossing may be arranged with movable-point frogs at A_1 and A_3, Fig. 104, as at M and M′ in Fig. 99, or four ordinary frogs may be used as in Fig. 104; this will depend upon the frog-angles and the relative importance of the tracks, but in any case the intersection angle of the

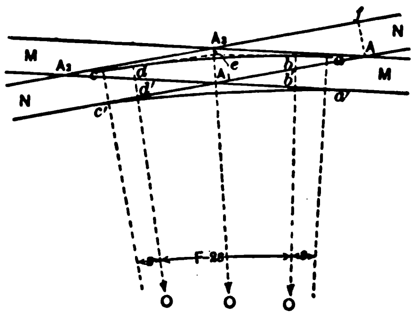


FIG. 104.

tracks must be small in order to give a sufficient distance $A A_2$ to allow the mechanical construction of the crossing. In Fig. 104, the crossing is such that regulation crossing-frogs are used at all four points; the points a and c of the switch-rails are assumed to be at the toe (or heel) of the frogs, which is the closest they can possibly be placed.

In Fig. 104, given the intersection angle F, compute the frog-number and the distance between frog-points $A A_1 = A_3 A_2 = A_2 A_1 = A_3 A$; then find the length of the wing-rail $A a = A_2 c$ of the frog; assume the length of the point-rails $c\,d = a\,b$, and then find the central angle $\phi = F - 2\,s$, the radius $(R + \frac{1}{2}G)$ and length of the rail $d\,b$.

Draw the normal line $A\,f$, then in the triangle $f\,A_3\,A$,

$$AA_3 = G \operatorname{cosec} F \quad (97)$$

$$N = \tfrac{1}{2} \cot \tfrac{1}{2} F \quad (98)$$

Assuming a toe-spread of w feet, from (77),

$$k = \tfrac{1}{2} w \operatorname{cosec} \tfrac{1}{2} F. \quad (99)$$

In order to get the switch-angle s, assume $S = a\,b$, then from (75),

$$\sin s = \frac{1}{2S} \quad (100)$$

Assuming c as the theoretical point of switch, in the triangle $c\,A_3\,e$, the angle $A_3\,c\,e = s$, $c\,A_3\,e = \frac{1}{2}(180 - F) = 90 - \frac{1}{2}F$, and $c\,e\,A_3 = 90 + (\frac{1}{2}F - s)$, then

$$c\,e : c\,A_3 :: \sin(90 - \tfrac{1}{2}F) : \sin(90 + (\tfrac{1}{2}F - s)),$$

or

$$ce = \frac{cA_3 \cos \frac{1}{2}F}{\cos(\frac{1}{2}F - s)} \quad (a)$$

but $d\,e = c\,e - c\,d$, and $c\,A_3 = A_2\,A_3 - k$, which, substituted in (a) give

$$de = \frac{(A_2A_3 - k)\cos \frac{1}{2}F}{\cos(\frac{1}{2}F - s)} - S' \quad (b)$$

in the triangle $O\,d\,e$, $\tan d\,O\,e = \frac{de}{Od}$, or $O\,d = d\,e \cot d\,O\,e$

$$R + \tfrac{1}{2}G = \left[\frac{(A_2A_3 - k)\cos \frac{1}{2}F}{\cos(\frac{1}{2}F - s)} - S'\right] \cot \tfrac{1}{2}(F - 2s),$$

combining and transposing,

$$R = \frac{(A_2A_3 - k) \cos \frac{1}{2}F}{\sin \frac{1}{2}(F - 2s)} - S' \cot \frac{1}{2}(F - 2s) - \frac{1}{2}G \quad (101)$$

and the arc

$$db = 2\pi R \frac{(F - 2s)^\circ}{360} = \frac{R(F - 2s)^\circ}{57.3} \quad (102)$$

Example 1.—Assume the intersection angle 14° 15′, then from (97) $A A_3 = G$ cosec $F = 4.7083$ cosec 14° 15′ $= 19.128$, $N = 4$, $w = 0.79$ from Table XVIII for a standard No. 4 frog, and $k = 3.17$; assume a point-rail of 11 feet; from Table XVI s is 2° 36′ 19″; then substituting in (101)

$$R = \frac{(19.128 - 3.167) \cos 7^\circ\ 07'\ 30''}{\sin \frac{1}{2}(9^\circ\ 02'\ 22'')} - 11.45 \cot \frac{1}{2}(9^\circ\ 02'\ 22'') - 2.354$$

$$= R = 200.98 - 144.85 - 2.35 = 53.78 \text{ feet.}$$

This shows that the crossing-angle assumed is entirely too large, the radius being barely sufficient for a trolley car.

Example 2.—Assume the same data as in the above example, excepting a point-rail of 8 feet, then from (100) s is found to be 3° 34′ 00″, and $R = 255.18 - 134.01 - 2.35 = 118.32$ feet, which is also too small.

Example 3.—Assuming the intersection angle as 2° 23′ 13″, $N = 24$, $k = 11.33$ feet, and $S = 33.00$ feet; then S' is found to be 34.33 feet, $s = 1^\circ\ 25'\ 57''$, $A_2 A_3 = 113.85$, and $R = 12{,}004.56$ feet, and $d b = 136.36$ feet.

Problem 27. A 3° curve crosses a straight track, making an intersection angle of 20° 31′ 30″, both gauges being standard. Compute the four frog-angles.

PROBLEM 28. A 3° curve crosses a 9° curve, making an intersection angle of 20° 31′ 30″. Compute the four frog-angles, both gauges being standard.

PROBLEM 29. Compute the rail lengths between frogs in Problem 28.

PROBLEM 30. Two straight tracks cross each other at an angle of 7° 09′, assuming the points of the 10-foot point-rails at 5 feet from the frog-points, compute the radius of the slip-switch turnout.

CHAPTER V.

SIDETRACKS, YARDS, TERMINALS, SIGNALS.

ARTICLE XV.

SIDETRACKS AND YARDS.

165. Passing Sidings.—Sidetracks may be divided into two general classes, viz., passing sidings and freight sidings. Passing sidings are tracks that are used to facilitate the running of trains. On a single-track railroad passing sidings are needed at more or less regular distances apart, so that trains may pass each other; the less the traffic, the farther apart the passing sidings. Originally these sidings were only long enough to allow the longest freight train to stand on them; as traffic increased these sidings were made long enough to hold two or more trains. Heavy traffic on single-track roads is frequently subjected to considerable delay. An instance of this was seen on a southern railroad some years ago, when two south-bound trains met three north-bound trains at a passing siding that would hold only one train. It took several hours to straighten them out, part of the delay being due to a very dark night.

166. Second and Third Tracks.—When traffic increases to such an extent that single-track and passing sidings are inadequate, the siding is extended until it is practically a double-track road in long stretches. In the same manner when it becomes necessary on double-track roads to have sidings in order to allow passenger trains to pass the slower freight trains going in the same direction, a third track is laid in such manner that the middle track is the siding. It is at the turnout at the ends of such tracks that the large numbered frogs (No. 15 to 24) are used, these frogs having such a small angle and the lead being so great that the siding can be entered at a speed of 30 miles per hour, which would be impossible without great danger of derailment over a frog with a small number.

On double-track railroads with heavy traffic there is usually a side track at each signal block, so that freight trains can be signaled and run out of the way of passenger trains. If there is no crossover within two or three miles of the block tower, one is usually laid at the tower. This enables trains to get from either track to the siding, and also to cross over and run the reverse track in case of one of the tracks being blocked by an accident.

Some railroads have such heavy passenger traffic that practically all freight trains, except way freights, are run as special trains at such times as will not interfere with the passenger trains. In cases of unusual passenger traffic, such as comes on roads centering in Washington, D. C., at the Presidents' inauguration, it is nothing unusual to have a freight take two or three days to run 100 miles. The train will be started from one end of the division and will run until flagged and sidetracked; as soon as there is a chance it will reach another block, and so on. As soon as the traffic warrants, these roads are changed to three- and four-track roads. This development is going on all over the United States at a greater rate than ever before, considering intervals of several years each. A reference to Table I will show the heavy proportionate increase in additional running tracks.

167. Freight Sidings.—When the freight handled at any station is more than can be loaded and unloaded from and to the platform, at least one siding is necessary. The simplest siding used for this purpose consists of a turnout and a track parallel to the main track, and long enough to hold one or more cars; this track may either turn back into the main track or have a bumper at the lower end. If, as is sometimes the case, a siding is built for the convenience of people at some distance from a regular siding, in this case there is very often no freight house, there being simply an uncovered platform, and in some cases there is no platform at all, teams driving close to the car to load and unload. When the railroad passes through a village or town, there is always a freight house with a siding long enough to accommodate the traffic, and probably sidings to coal dumps in addition.

168. Yards.—In towns and cities large enough to warrant several side tracks, these tracks are usually arranged in a system of tracks called a *yard*. Each manufacturing plant will have its individual sidings for handling freight in car-load lots, the general freight traffic being handled at the freight station of the railroad. An engine or engines must be provided to place the cars at the proper points for loading and unloading, to place the cars in the yard for shipment, and then to arrange them in trains to be forwarded in the proper direction.

A small yard is laid out along the general lines shown in Fig. 105. This sketch represents a yard alongside of the two main running tracks. D C is a crossover by which east-bound trains may pass over to the west-bound track and then to the *drilling track* A B, from which they can enter the *ladder track* B E. If the ends of the yards are symmetrical, a west-bound train will enter the yard at the east end; otherwise it will back in at A. A yard must be designed to suit the work required by the traffic, and only a few general points can be stated as common to

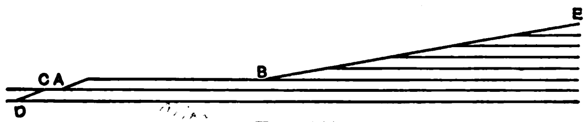


FIG. 105.

all conditions. In many yards the ladder track leaves the main track near the point B, and does not have the drilling track A B. One of the first principles in switching is to keep the main track as free as possible; if the track A B is not long enough to hold the longest train, it will be practically impossible to cut and drill the trains in the yard without backing on the main track. It is usually necessary to have a series of crossovers between the yard tracks.

169. Gravity Yards.—Cars are made up into trains by one of two general methods, viz., by being pushed, or kicked, into place, and by the aid of gravity. The first method must be used where the yard is level. The train is cut so that the desired car is on the end of the string, the engine pulls the cars out on the drilling track, and then pushes them rapidly on the track where the train is to be made up, the car is uncoupled, the engine stops, and the car is carried by its momentum to the desired spot, usually being controlled by a brakeman using the hand-brakes. This is repeated until all the cars are coupled into a train, and then the train is ready to be dispatched. The opposite is done with an incoming train with local freight; each car is drilled out and taken to the siding where it is to be unloaded.

Where the topography is such that the desired grade can be obtained, gravity yards may be constructed, the gradient sloping downward from the entering ladder track, there being a system of crossovers by which the cars may be run on to one track. In order that a car will start upon loosening the brakes a gradient of 0.8 to 1.0 per cent. is required; the rate of gradient required depends upon the temperature of the journals of the cars, the heavier gradient being required for the colder weather. In a strictly gravity yard, the work is done entirely by gravity, and consists in loosening the brakes and allowing the car to run to the desired point. There are no yards dependent entirely upon gravity, in the United States. The principal objection to gravity yards is the uncertainty of the action of the car at different temperatures; if the gradient is made steep enough to insure the car starting in the coldest weather, there is danger of the car getting beyond control in milder weather, necessitating special devices to prevent the car from running away, or rather for stopping it while running away.

170. Partial Gravity Yards.—Under normal conditions a gradient of 0.4 per cent is sufficient to just keep the car moving after it has been started. Some yards are built with a gradient of about -0.5 per cent. on the drilling track, and -0.25 to -0.4 on the standing tracks. By this method the engine pulls the car out on the drilling track and just starts it, the grade carrying it to the point desired. This method is far preferable to the level yard, and probably also to the strictly gravity yard, as there is practically no danger of a runaway. In *shunting, kicking,* or making a *flying switch,* it is very difficult to give the car just the right start, and the whole operation is much more dangerous for the train crew, and is illegal.

There are other methods of classifying a train, and also many ways of arranging a yard, which can not be shown here. The only way to get an adequate idea of the manner of arranging yards and terminals is to read the descriptions given in the engineering periodicals and study the accompanying conditions.

171. Terminals.—A terminal yard is placed at the end of each division of a railroad, and their proper design is a still broader question than that of a yard at an intermediate piont. It is essential that both passenger and freight stations be placed as near the center of a city as possible, particularly where there are competing roads. Most yards and terminal yards were started years ago, when the road had far less traffic, and there was in some cases too little attention paid to future needs. Tracks have been added from time to time, until finally there is not only no way of increasing the size of the yards without enormous expense for real estate, but the general design is not economical. An instance of what railroads are compelled to do in order to improve their facilities is shown in the work now in course of construction in and around New York city. It would not have paid to have attempted to anticipate all of this improvement twenty-five years ago, as the, at that time, useless expenditure would have put an unsupportable burden upon the various railroads, and the excess sum then expended would now, at compound interest, have amounted to an enormous sum of money.

The design of a terminal yard depends entirely upon the local conditions. In some terminals freight is mostly for local use or shipment, while in others the greater proportions must be forwarded to other points, the yard being used principally to classify through freight.

One of the principal features in which a terminal yard differs from an intermediate yard is that the engines must be housed, and fuel stored for them, and in some cases repairs are made to all the rolling stock. This requires many additional tracks that must be kept separate from the yard tracks, as well as proper buildings and fixtures for the purpose. In all yards there are facilities for at least as much repairing of cars as will allow the car to proceed, but at terminals there must be a fully equipped rolling stock "hospital."

172. Roundhouses.—Roundhouses are necessary for the proper care of locomotive engines at all points where it is necessary to have extra engines. An engine cannot be run continuously, it being laid off at certain intervals between runs, a continuous run being the length of the division of the railroad. Consequently there is always a roundhouse at each terminal yard, and also probably at large intermediate yards. When not in use, the fires are thoroughly cleaned and banked and the engine is run into the roundhouse, where it is thoroughly examined, wiped, and any small repairs and adjustments made. The general plan of a roundhouse and turntable is shown in Fig. 106. A track long enough to hold the largest locomotive and tender is arranged so that it can be turned on a pivot, and stopped and fastened by a clutch opposite any of the tracks radiating from it. A turntable is necessary in connection with a roundhouse, and also at the end of spur lines, in order to turn the engine for the return trip. The engines come from the yard on the track A B, and are run on to the turntable; the turntable is then turned until it is opposite the desired track, and the engine is run into the roundhouse.

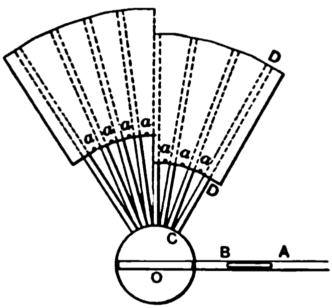


FIG. 106.

All the roundhouse tracks radiate from the center O of the turntable and turntable pit. The distance C D is sometimes made great enough to allow the engines to stand with the greater part of the engine outside of the roundhouse, and still have proper clearance at the turntable end of the tracks. In any case the distance C D must be great enough to allow proper clearance at the posts *a a* from which the doors are swung. If the distance C D is great enough, the ends of the adjacent rails of adjoining tracks may be placed at a distance apart equal to the width of the base of the rail plus $\frac{3}{4}$ inch (same as the throw) and ordinary rails are used. This is shown on the right side of Fig. 106. If the distance C D is too short for the above arrangement, frogs must be used, as shown on the left side of the figure.

173. Ash-pits and Coal-bins.—Ash-pits are necessary for the cleaning or dumping of the engine grates. They are usually placed on the track A B near the roundhouse. Ash-pits are also built in the roundhouse under each track. The proper arrangement of the ash-pit is one of the principal items in connection with the care of engines, the fires being cleaned after each trip in order to remove the clinkers. The clinkers and ashes are cooled with water and then loaded on cars for removal. The method of removing the material from the pits ranges all the way from shoveling into wheelbarrows to fairly elaborate mechanical devices. The greater proportion of the material from the ash-pits consists of clinker, and it is from this source that cinder ballast is obtained.

It is quite a problem to handle coal for locomotives economically. The simplest arrangement consists in hauling the coal on a high trestle and dumping it into bins; a low track is run alongside the bins, and the coal run into the tenders. In some cases the coal is put in the tender by means of cables and buckets, the cables being stretched across the track and at right angles to it.

Article XVI.

WATER-SUPPLY FOR LOCOMOTIVES.

174. Water for Locomotive Boilers.—There is no question that is of more importance to the item of engine repairs and operation than that of an ample supply of soft water. Water for this purpose should be free from all impurities that will affect the efficiency of the boiler tubes and the boiler in general. Hard water, containing a large percentage of lime, has in some cases decreased the life of locomotive boilers to one-half the time they would have lasted with soft water. In order to get an adequate supply of good water some railroads have bought up entire watersheds, built their own reservoirs, and, where necessary, installed pumping machinery. A large amount of water must be necessary in order to warrant the installation of a separate plant, and in ordinary cases it is more economical to buy water from a local plant, even if the water must be treated by a softening process before using.

Water is supplied to the locomotive tender in three principal ways: (1) from water-tanks; (2) from mains; and (3) from track troughs, or tanks.

175. Water-tanks.—It should be possible for an engine to take water at short intervals along the line, particularly at all regular stops. In country where the regular stopping-places are long distances apart, intermediate water-tanks must be maintained, and whenever possible the tanks should be placed just over a summit, so that gravity will assist the engine in starting the train. One of the most common methods is to pump the water from a well or stream to a tank. An iron pipe with the outer end curved downward at an angle of 90 degrees is attached to the lower part of the tank in such manner that it may be swung over the center of the track when filling the tender and swung parallel to the track and well out of the way when not in use. A piece of canvas or rubber hose is attached to the outer end of the pipe so that it can be run into the opening of the tender and prevent waste. The pipe is opened and closed by means of a valve, which is usually controlled by a wheel attachment.

The tanks are usually made of wood or steel. Wooden tanks are circular and made of staves held together by iron bands or hoops, and are supported by timber trestling or a masonry foundation. Steel tanks are circular in shape and made of boiler plates riveted together in the usual way. They are supported on steel towers or masonry foundations. The size of the tank will depend upon the amount of water required and the nature of the supply. If the rate of pumping is slow and a large amount of water is required in a short time, a larger tank will be required than when the rate of pumping can be varied and the demand is more uniformly distributed throughout the day. The capacity of tanks varies from 20,000 to 50,000 gallons.

176. Standpipes.—Standpipes are used when the water is furnished through a main, the standpipe being of sufficient height and having an arm, as described above, which is swung over the center of the track, the standpipe, or column, being simply a device to hold and control the arm at the proper elevation. The water is obtained from the town or city supply, the railroad company paying an annual rental for each column for all the water that may be used, or a water-meter may be attached. On roads having two or more tracks a standpipe is placed on the opposite side of the tracks from the company tank, and is connected with the tank by means of a pipe passing under the tracks.

Tanks and standpipes located at stations are placed as near as possible to where the engine stands while making a regular stop, in order that the engine may take water while the baggage is being shifted and passengers getting off and on the train, thus saving unnecessary delay.

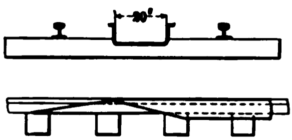


FIG. 107.

177. Track Tanks. — On tracks over which a great many through trains are run, arrangements are made by means of which the tank in the locomotive tender may be filled while the train is in motion. This is accomplished by means of a track tank or trough placed between the rails and kept filled with water, the general arrangement being shown in Fig. 107. The trough is about 7 inches deep and 20 inches wide in the clear, and is countersunk about 2 inches into the tie, which makes its top about the same elevation as the top of the rails. It is made of steel plates and braces, all the rivet heads on the inside of the trough being countersunk to present a smooth surface to the scoop. The ends of the trough are shaped as shown, the bottom being gradually inclined to the surface, and the ends being inclined in the same way, to insure against trouble in case the scoop is dropped too soon or not pulled up in time. The speed of the train forces the water up the scoop, which is lowered from the tender until its mouth is immersed in the water. In order to prevent the water from entering the tender with a velocity so great that it would injure the tender, the speed of the train is reduced a little and the scoop increases in size from the mouth toward the upper end, the velocity being decreased in proportion. The water is usually supplied from a tank, the supply being controlled by valves.

Article XVII.

SIGNALS.

178. Development of Signals.—Signals are devices by the aid of which the engineman and train crew may know whether or not they have a clear track. In the early days of single track and few trains this was accomplished entirely by flags, and before the invention of the telegraph the train was entirely in the hands of the train crew between stations. As traffic increased and the telegraph came into use it was possible for the chief operator to control all trains from one central point. By telegraphing ahead and setting a signal the train could be stopped for further orders. These signaling points were far apart. As the number of trains per day increased it was necessary to control them at shorter intervals, and this has increased until now on many railroads signals are placed a distance of one mile or less apart. There are several methods of signaling, the principal distinct types of which are the manual and the automatic.

179. Manual Signaling.—One of the earliest forms of the complete control of trains by signals was the "block tower" system. This system is still in use, but the details of operating the signals have been greatly improved. The early forms of the method consisted of towers spaced three or more miles apart. Each tower had two telegraph operators, a day- and a night-operator, and had one signal attached which could be placed in two positions, viz., at danger or at clear. When a train passed a block, the operator threw his signal to danger and kept it there until the operator at the next block ahead telegraphed that the train had passed his block, then the first operator threw his signal to clear. This was purely a manual system, the operator being able at any time to throw his signal to either position, depending entirely upon his information by telegraph. This method works all right as long as the operator does not become confused. Many accidents occurred from the carelessness or wrong interpretation of orders by the operator, in many cases the fault lying with the railroad officials, because through false economy or unusual circumstances the operator was held at his post for so long a time that he was temporarily mentally and physically incompetent. This led to the use of methods partly manual and partly automatic.

180. Manual-automatic Signaling.—In this method, after the operator has thrown his signal to danger, a mechanical contrivance acts in such a way that it is impossible for him to throw his signal to clear until the operator in the next tower has thrown his lever to danger. When the second operator throws his signal to danger, he automatically, by means of an electrical device, makes it possible for the first operator to work his lever so that he can throw his signal to clear. This method still leaves a possibility of danger, but it is far less than when no interlocking device is used. It is necessary to have towers and signals partly under manual control at all points where important switches must be thrown or at grade railroad crossings. The lever that operates the switch must be thrown by a man, but there are various automatic devices that guarantee the safety of the train while using the switch, ¶ 149.

181. Automatic Signaling.—In this system the signals are controlled entirely by automatic devices, and it is used for greater safety on stretches of track between block towers, the block towers in this case being placed only at points where an operator must work switches, etc. They are worked by means of electric circuits passing through the rails. This system, by means of placing the signals comparatively close together, allows a greater number of trains to be run with a minimum amount of danger, and is therefore economical on roads with very heavy passenger traffic, particularly at certain times of the day. It is much cheaper than putting block towers at the same distance apart, as the pay of the operator would be greater than the maintenance of the circuits. Automatic signals are entirely electric, or electro-pneumatic, the latter being compressed air controlled by electric devices.

182. Track Circuits.—When the track relay is energized by a current, it closes a local circuit and sets the signal at safety. The resistance of the relay is such that it requires nearly the whole current to work it and to keep the local current closed. Therefore, when there is any considerable loss of current from one rail to the other, the relay will not be sufficiently energized, the local current will be broken, and the signal will be set to danger.

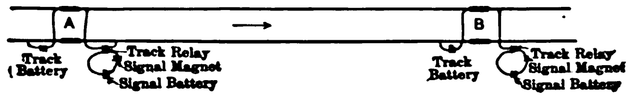


FIG. 108.

This diversion of current may be caused by the passage of a pair of wheels, the breakage of a rail, etc. Fig. 108 represents a track circuit, signals being located near A and B. A and B are insulated joints, all other joints being bonded, and the rails bonded together on each side of the insulated joints. When there is no train passing, the signal magnet is sufficiently energized to draw the signals to safety; when a train passes A, the current passes through the wheels and axle, causing the signal magnet to cease to act and the signal to set to danger. When the train passes B, the signal magnet at A again acts and draws the signal at A to safety, and sets the signal at B to danger. The signals are counterweighted so that they swing to danger when no force acts on them, and it takes a force to pull them to the position showing safety, consequently any break in the system causes the signals automatically to show danger.

183. Absolute Blocking.—Blocking is of two kinds, viz., absolute and permissive. In the absolute system, when a signal shows danger, or red, the train must come to a dead stop with no part of it beyond the signal, and wait until it gets a clear signal. In the days before the use of the *distant* signal it was quite a common occurrence for a train to round a curve and find a stop signal at such a short distance that it had to run some distance past the signal before it could stop, and then to back up until the whole train was on the proper side of the signal. This not only caused considerable delay, due to the time necessary to get up full speed after stopping, but also caused considerable expense in wear and damage to the track and train, consequently distant signals came into use.

184. Permissive Blocking.—In this method a train is allowed to proceed under control after the caution signal is displayed, and although the train must stop upon finding a danger signal, it is much less expensive to do so when running at a moderate rate of speed. A train running at 60 miles per hour can not be brought to a full stop in much less than 2000 feet unless the engineman resorts to methods that are very injurious to both his engine and the track. Consequently caution, or distant, signals are placed about 2000 feet before coming to each point where a full-stop signal is liable to be displayed, such as a block tower, etc. Sometimes on roads where only one signal is used a train may be allowed to proceed after the operator has issued a card allowing it to do so. The permissive method of blocking is shown in Fig. 109. The train B following the train A finds the signal as shown, the signals C stop all trains following B absolutely, until B has passed D. The top signal when horizontal shows danger, and a train must under no circumstances pass it; the lower signal when horizontal means caution, and the train B must proceed under control, knowing that there is a train in the second block, F E, ahead. When both signals are down, as at F, the track is clear for at least two blocks ahead, and the train A may pro-

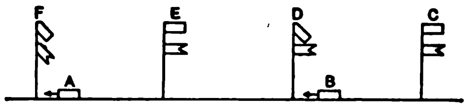


FIG. 109.

ceed at full speed. The lower, or caution, signal in this case is the distant signal, and on a road with heavy traffic the signals may be at a distance of about 2000 feet apart, or even less, particularly near curves. These signals are worked by a double arrangement of the circuits described in ¶ 182.

Signals are made in two forms, viz., semaphore and banjo.

185. Semaphore Signals.—Semaphore signals consist of an arm, shown in Fig. 110, which is fastened to an upright support by means of the pivot A. The arm consists of a light piece of board about five feet long, ten inches wide at the outer end, and seven or eight inches wide at the inner end, where it is fastened to a cast-iron arm plate. The arm plate contains the colored glass B, which gives the signal at night, and the whole arrangement is so balanced that the weight of the iron arm plate will hold the arm in a horizontal position, if left free to move about the pivot A. Home, or danger, signals have a square end to the arm, but in some cases distant, or caution, signals are notched on the outer end of the arm.

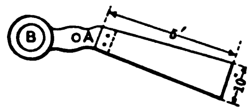


FIG. 110.

In daytime a horizontal position of the semaphore arm indicates danger and an inclined position indicates clear. At night the signals are indicated by colored lights. A lamp is fastened to the upright which holds the arms in such position that the glass B of the proper color comes directly over the lamp causing this color to show. When the signal is set at clear, only the color of the light from the lamp shows.

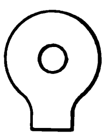


FIG. 111.

186. Banjo Signals.—Banjo signals consist of a flat box, shaped as shown in Fig. 111. A lamp is arranged in the box so that it shines through a lens of normal color when the signal is set to clear. There is a mechanism by means of which a glass of the proper color may be moved so that it will cover the light and show this color when so desired. These signals are mounted on uprights at about 25 feet from the ground in the same general way as semaphore signals. The outer part of the banjo face is painted white, the signal showing only in the center. Signals as far as possible are placed to the right of the track and away from all other lights so as to avoid confusion, with the signal facing the trains on the track it is to control. The backs of the signals are usually painted white with a red or black cross-stripe near the outer end of the semaphore arm, thus showing clearly to the engineman to which track the signal belongs. The faces of the signals toward the train show the colors which the railroad uses to indicate the condition of the track.

187. Color of Signals.—The colors in most common use for signals are as follows: (1) red, for danger and stop; (2) green, for caution and run under control; and (3) white or yellow, for clear. There seems to be a growing tendency to reverse (2) and (3) by using yellow for the caution signal and green for the clear signal. The face of the upper semaphore arm is painted red and has a red glass to cover the lamp. The face of the lower semaphore arm is painted green and has a green glass to cover the lamp, and is usually notched, or fish-tailed, on the outer end. The normal color of the lamp is usually white, but some roads have adopted yellow as the clear signal. The use of the yellow signal is increasing rapidly, since it is difficult to distinguish between a white signal light and an ordinary light, making it very easy to mistake an ordinary light for a signal. In case the red or green signal lens is broken out, the signal will show white instead of stop or caution, as it should show.

On double-track roads the lamps are made so that they can shine in only one direction, so that they cannot be confusing to a train going in the opposite direction. On single-track roads the lamps must shine in both directions. Signal lights must be placed at all switches, and show a caution signal when running into the point of a closed switch.

On January 1, 1908, automatic block signals were in use on 10,800 miles, and non-automatic block signals on 47,900 miles of railroad in the United States. Of the 10,800 miles of automatic signals, 2300 miles were disc (banjo) signals, and 8500 miles were semaphore signals. On January 1, 1914, on 186,000 miles of road (214,000 miles of track), there were 86,800 miles of road (113,000 miles of track) operated under block signal system, 26,600 miles of road having automatic; and 60,200 miles of road having non-automatic block signals. On 212,600 miles of road, train orders were transmitted by telegraph on 147,300 miles, and by telephone on 77,300 miles of road, the discrepancy in the total being due to some parts of a road being used by more than one company, thus causing duplication in the reports.

CHAPTER VI.

MAINTENANCE OF WAY.

Article XVIII.

ORGANIZATION OF MAINTENANCE OF WAY FORCES.

188. Divisions of a Railroad.—For the purpose of maintenance and operation, large railroad systems are divided into "grand divisions" and "divisions." A grand division usually consists of a trunk line several hundred miles long, together with all its branch lines, and is in charge of a general superintendent, who reports to a higher officer, usually the general manager of the system.

A grand division is usually divided into two or more divisions, each in charge of a superintendent. Divisions are made of such length that the mileage and work of the locomotives and trainmen will be the most economical, so that a round trip shall comprise a day's work. Trainmen and locomotives do not go off of their division, consequently the train crew changes and a new locomotive is attached to a through train at the end of each division. Divisions are in charge of a division superintendent, who reports to the general superintendent. The division superintendent is responsible for the operation and maintenance of his division.

189. Subdivisions.—The maintenance of track and all engineering structures of a railroad is called "maintenance of way," and is usually referred to as "M. W." The maintenance work on a division is in charge of a division engineer, called on some railroads "assistant engineer," who reports to the superintendent. Maintenance of way may be divided into three general headings, viz., track, signals, and structures. The signals of a division may be in charge of an assistant engineer of signals, who reports to the signal engineer, who has charge of the entire signal system of a railroad, or they may be in charge of a supervisor of signals, who reports to the assistant engineer.

The maintenance of structures, which includes all bridges, buildings, road crossings, fences, etc., is in charge of a master carpenter, who reports to the assistant engineer. In some cases the supervisor of signals reports to the master carpenter.

For the purpose of maintaining the track, the division is divided into a number of subdivisions, each in charge of a supervisor, who reports to the assistant engineer. On some railroads track maintenance is in charge of a roadmaster; in which case the track department may be entirely separate from the engineering department.

190. Sections.—Subdivisions are further divided into sections, each of which is in charge of a track foreman, who reports to the supervisor. The proper length of the section depends upon the amount of traffic, kind of ballast, condition of roadbed, number of tracks, and the general requirements as to excellence of track. On a single-track railroad with heavy traffic the sections should be about four miles long, while for light traffic they are sometimes ten miles long.

The amount of work necessary to keep a double-track road in good condition is less than double that required for a single-track line under the same general conditions. In both cases the same amount of work is required in maintaining ditches and fences and in keeping the grass cut and the part of the right-of-way not covered by the track in good shape. The surfacing of double track is less than twice that of single track, and is much safer, because the men need watch for a train from only one direction. For these reasons sections on double-track roads with heavy traffic should be about three miles long. In yards the sections are, of course, much shorter.

191. Track Gang.—The size of the track gang depends upon the same conditions as given above for the length of section; in fact, the size of the track gang depends upon the length of the section, the traffic, etc., and vice versâ. A rule sometimes stated is that there shall be a minimum of one man per mile of single track in addition to the foreman and trackwalker. As a usual thing very little track work can be done in winter, and to a certain extent, at least, the track will need a spring overhauling, which may require a gang of twelve or fifteen men. Crossties are renewed between spring and fall. It is customary to have at least a foreman, an assistant foreman, and not less than one additional man, making three men in all, permanently, and to take on men temporarily when needed. A permanent force is far more efficient than one that is composed principally of temporary men. Except in special cases, due to accident, railroad rails are laid in long stretches by the maintenance-of-way train gang and not by the regular track gang. Crossties, on the other hand, decay and wear out so irregularly that they are replaced at odd intervals by the regular track gang.

192. Track Foreman.—The track foreman has charge of all the maintenance work on his section, subject to the orders of the supervisor. He hires and discharges the other trackmen when so directed, receipts for all new tools and materials received, makes requisition for necessary tools and materials, directs and keeps the time of the men, has charge of all track-signalmen, and sends his time book to the supervisor at the end of the month so that the pay-roll can be made up. He has an assistant foreman, who takes the place of the foreman in his absence and also takes charge of part of the gang when it is necessary to divide it and work at different places, but does the work of an ordinary trackman when occasion requires. It takes long experience and training to make a good foreman; he is responsible for the surface and alinement of track, and must be thoroughly familiar with track work. He is also responsible for the safety of the men and also trains, and must see that a flagman is stationed so that the men will have plenty of time to get out of the way of approaching trains, and also so that the train may be stopped in case he has the track in such shape that it is unsafe, which must never happen, however, except when the foreman has received special orders to do so, these orders being given in special cases only.

193. Trackwalker.—The duties of a trackwalker and the number of trackwalkers per section depend upon the importance and amount of traffic passing over the track to be inspected. On a light traffic road where there is no liability to landslides, bridges to get out of order, and the weather is dry so that there can be no washouts, the trackwalker may be detailed from the track gang to walk over the track in the forenoon and rejoin the gang in the afternoon. But if there are dangerous spots on the section, or there is considerable rain, so that landslides may be expected, the trackwalker should patrol his section constantly, and during such times a night trackwalker should also be placed on the section; and if there is a particularly bad spot, such as a cut with slopes of doubtful stability, a special watchman should be stationed there.

The day trackwalker carries a wrench, a light hammer, a few extra bolts, nut locks and spikes, and a flag. He should carefully inspect the track, particularly all switch connections, and see that there are no signs of fire near a bridge. He should tighten up all loose bolts and drive down spikes that have worked up. An experienced trackwalker can in most cases tell at a glance whether or not a joint is loose; if he is in doubt, a tap with the hammer will show its condition. In winter he must keep snow and ice from packing hard about switches, frogs, guard rails, and crossings. In order to be an efficient trackwalker a man should have served on the track gang until he is thoroughly familiar with track work and has proved himself careful and reliable. The night trackwalker makes such inspection as is possible by lantern light, usually inspects the track ahead of the fast passenger trains, and carries torpedoes, in addition to his lantern, for signaling purposes.

ARTICLE XIX.

SECTION TOOLS AND OUTFIT.

194. Section Tool House.—In order to properly take care of the tools and outfit, there should be a tool house on each section. The manner of housing tools varies from a large box that can be locked, to an especially designed house in which the tools can be stored properly. The tool house should be large enough and so arranged that each kind of tool has its regular place, and there should be separate places for each kind of track material, such as bolts, splices, spikes, etc., otherwise tools will be thrown into a heap, possibly some of them broken, and there will be endless delay and confusion in finding the particular tool or track material required. The tool house should also be large enough to serve as a workshop and to allow the permanent men to make such repairs as possible to tools on days that are too stormy for outside work. At times it is necessary to hold the men at the tool house in readiness for anticipated trouble, such as heavy snow-storms, in which case it should be possible to heat the house by some simply constructed stove.

In some cases the tool house is a plain rectangular shed about 9 by 12 feet and 7 feet high, made of inch boards and covered with a pitched roof of corrugated iron, and without windows. A tool house of this description is poor economy, as it serves simply to pile the tools together and lock them up. In Fig. 112 are shown the outlines of the plan, elevation, and end view of a tool house. The A. R. E. A. recommends three sizes of tool houses, one for each class of railroad. The class A tool house is shown in Fig. 112, the dimensions being as shown; *m n* is the nearest rail of the track, and *a b* and *d c* are the hand-car rails.

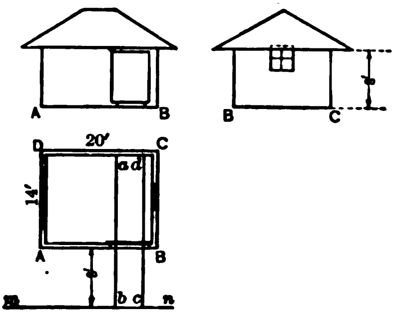


FIG. 112.

In a class B tool house the length A B is 18 feet, and the width B C is 12 feet; and in a class C tool house the width A B is 10 feet and the length B C is 14 feet, the height "to the square" being 8 feet in all cases, the ridge of the roof being 5′–2″, 4′–2″, and 4′–0″, respectively, above the square of the house. The runway *a b c d* is constructed of old rails or 3 by 4-inch timbers upon which the hand-car can be handled. The house in Fig. 112 is lighted, can be heated by a small stove, and has a small amount of room to be used as a work-shop.

195. Section Houses.—The headquarters of the track gang should be located with regard to both covering the section quickly and accessibility from the division headquarters. The most desirable location is at the center of the section near a telegraph office, and the tool house should also be so located. It is necessary that the foreman, at least, should reside at this point, so that he can receive orders at any hour of the day or night, and he should also be able to reach some of his men on hort notice. For this reason many railroads provide their section foreman with a residence, called the section house, at this point. It is not necessary to give plans of a section house. Each railroad has standard plans upon which such buildings are erected. In some sections of the country where there are few inhabitants and the different members of the track would otherwise live widely scattered, it will be economy for the railroad to provide houses for all the men. Often this arrangement is economical for both the company and the men. The railroad has the men where they are always ready for service and can charge them a rental which will pay the interest on the money invested, and the men get a better house for the money than they can rent in any other way.

196. Tools.—Each section should have enough tools to supply every man in the gang with an outfit for each kind of work that is required on the section, and enough extra tools to allow some to be away at the repair shop. At the supervisor's headquarters of the subdivision all track tools should be carried in stock, both to replace worn-out tools and also to equip an extra force in case of emergency, such as a washout or wreck. The following is taken from the standards of the N. Y. C. and H. R. R. R:

TABLE XIX.

Tools.	Yard.	Single Track.	Double Track.	Four Track.
Hammers, Spiking	6	4	4	4
" Nail	1	1	1	1
" Napping *	2	2	2	4
Bars, Claw	4	3	3	4
" Lining	7	6	8	8
" Pinch	1	1	1	1
" Tamping	8	6	8	8
Picks, Clay	10	4	6	8
" Tamping *	6	6	10	10
Shovels, Long Handle	2	2	2	2
" Scoop	6	2	2	2
" Snow	6	6	6	6
" Short Handle	6	6	6	6
Forks, Ballast *	6	6	8	10
Wrenches, Track	6	4	4	4
" Screw	2	1	1	1
Axes, Common	1	1	1	1
" Hand	2	2	2	2
Adzes	2	2	2	2
Signal, Flags Red	2	4	4	4
Signal, Flags Green	2	4	4	4
Signal, Flags White	2	2	2	2
" Lanterns	2	2	2	2

* Used with stone ballast.

In addition to the above, the following list of miscellaneous tools is needed on all sections, regardless of the kind of track or ballast:

1 Hand-car	2 Wheelbarrows
1 Push-car	4 Brooms
2 Track jacks	2 Oil-cans
2 Track gauges	2 Post-hole diggers
4 Rail tongs	1 Grindstone
2 Brush hooks	1 Switch key
Scythes and snaths	1 50-foot tape
1 Level board	1 Ditching line
1 Spike puller	1 Water pail and dipper
1 Sighting board	2 Hay-rakes
6 Track chisels	3 Grubbing hoes
1 Ratchet drill and 4 bits	1 Cross-cut saw
1 Sledge-hammer	1 Rail fork
1 Carpenter's kit	

The above table and list show the tools with which each track gang is supposed to be supplied; every article mentioned will be needed in the ordinary work of the track gang. In addition to the above tools there are a number which will be needed occasionally, but which are not absolutely necessary on each and every section, such as rail benders, etc. If the section has a rock cut with unstable slopes from which rock may slide on the track, a complete drilling and blasting outfit should also be added. These tools must all be stored in the section tool house, which shows the necessity for a tool house of ample size.

197. Spiking Hammers.—In Table XIX three kinds of hammers are given as necessary on each section, viz., spiking and nail hammers on all sections, and napping hammers in addition for stone ballast.

A spiking hammer, sometimes called a spike maul, is shown in Fig. 113, A. It is square in section near the center, octagonal (square with the corners beveled off) in section toward the ends, and circular on the ends, or striking faces. The hammer shown is $13\frac{1}{4}$ inches in length and 2 inches square at the center, one side of the hammer being $6\frac{3}{4}$ inches long and $\frac{7}{8}$ inch in diameter at the end for spiking in narrow confines, such as between the guard rail and the main rail, the other side of the hammer being $6\frac{1}{2}$ inches long and $1\frac{5}{8}$ inches in diameter at the end. The edges of the ends are beveled off so that the cross-section of the ends is circular, to prevent pieces from chipping from the spiking ends after considerable

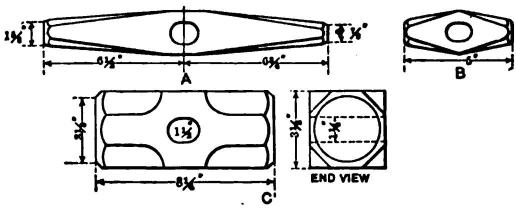


Fig. 113.

use. An oval-shaped hole, $1\frac{1}{4}$ by $\frac{7}{8}$ inches, extends entirely through the head, and a hickory handle, 3 feet 4 inches long, is fastened in it by means of a wedge. A spiking hammer of this size weighs ten pounds and is made of steel of such hardness on the ends as will best stand the work required. If it is too soft, it will batter out of shape; or if it is too hard, pieces of metal will break from the head—either fault quickly rendering the hammer useless.

The nail hammer mentioned is an ordinary carpenter's claw-hammer, and is used in repairing fences and all work in which nails of ordinary size are used.

198. Napping Hammers.—Napping hammers are used to break pieces of stone, or spalls, into the proper size for ballast. They should not be too heavy; the weight of the standard hammer shown in Fig. 113, B, is $3\frac{1}{2}$ pounds. It is symmetrical in form, 5 inches long, 2 inches square at the center, and circular ends $\frac{7}{8}$ inch in diameter. The cross-section toward the ends is octagonal, the same as in the spiking hammer. It is made of steel with the same requirements for hardness as a spiking hammer, and is attached to the same kind of handle.

199. Sledge Hammers.—A sledge-hammer, mentioned among the miscellaneous tools, is used for various purposes where a heavy hammer is necessary, such as breaking up large rocks and for cutting rails into special lengths with the aid of track chisels. Sledge-hammers are made in two general shapes and weigh from 6 to 30 pounds. The sledge-hammer shown in Fig. 113, C, is symmetrical in shape, $8\frac{1}{4}$ inches long, $3\frac{1}{2}$ inches square at the middle, $3\frac{1}{8}$ inches in diameter at the ends, octagonal in shape for intermediate sections, as shown in the end view, and weighs 25 pounds. The larger sledge-hammers have an oval hole, or eye, extending through the head, by means of which they are attached to the handle, which is usually 3 feet long. The other form of sledge-hammer has one-half of the head formed as shown in Fig. 113, C, but the other half of the head is shaped like a wedge, with a rounded blunt point, and is enough longer to give the same total weight to the hammer. This latter form is most convenient for breaking large rocks.

The sledge-hammer in general use usually weighs 12 or 14 pounds, has one of the two shapes described above, with the dimensions varied accordingly. They are made of steel with the same qualities as for spiking and napping hammers.

200. Claw Bars.—In Table XIX four classes of bars are given as essential on all sections, viz., claw, lining, pinch, and tamping bars.

A claw bar * is shown in Fig. 114. The claw is $4\frac{7}{8}$ inches long, $2\frac{7}{8}$ inches wide at the widest part, is curved

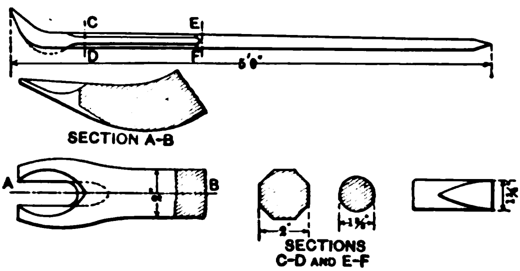


FIG. 114.

upward so that the point is $4\frac{3}{4}$ inches above the back of the bar, and has an opening $\frac{13}{16}$ inch wide and $2\frac{7}{8}$ inches long in the clear. The bar is two inches square for a distance of $2\frac{1}{8}$ inches, and in the next 2 inches changes to the octagonal form shown in section C D. The octagonal part is 14 inches long and then changes to the circular cross-section shown in section E F. The balance of the bar is circular in cross-section and tapers down to a diameter of $1\frac{1}{4}$ inches and has a wedge-shaped end $2\frac{1}{4}$ inches long. The total length of the bar is 5 feet, and it

* P. R. R. Standard claw bar.

weighs about 30 pounds. The bar described above is heavier than the bar used as a standard on some other railroads, the usual weight being about 25 pounds, the lower part being $1\frac{3}{4}$ inches square, and the other dimensions, except the length, being correspondingly less. Claw bars are made of steel. In some cases the back of the claw is made thicker, as indicated by the dotted line in Fig. 114, in which case they are called *goose-neck* bars.

In pulling a spike that holds firmly, it is customary to first strike the spike vertically on the head with a spiking hammer to destroy any bond between the spike and the tie due to rust. The bar is then held in a nearly vertical position and the claw forced around the head of the spike. It is often difficult to get the claw to take hold of the spike. Sometimes this can be aided by first using the other end of the bar, or by driving the claw and the head of the spike by hitting the back of the bar with a spiking hammer. After the claw takes hold the spike is drawn by pulling the bar into a horizontal position. Where there is much pulling to be done, it is sometimes economical to have a nearly straight claw bar with the other end square with which to start the spikes. The straight bar can be held in position and driven under the spike and then, by pulling the straight bar to a horizontal position, using a piece of wood or a spike as a fulcrum, the spike will be moved enough to allow the goose-necked bar to be used. Steel is usually relaid by the construction train force, which usually has one or more patent devices for pulling spikes.

201. Lining Bars.—Lining bars are used for throwing track into line laterally. They have a symmetrical pyramid or wedge-shaped end. This end of the bar is driven into the ballast, forming a fulcrum, the bar being in a slanting position resting against the base of the rail. A number of bars being properly placed, with one or two men to each bar, the word being given, all heave together and throw the track laterally. The ballast is first partially removed from around the ties. The lining bar shown in Fig. 115 is 5 feet 4 inches long, made of steel, and weighs 24 pounds. It has a square pyramid, or diamond, point, 2¾ inches long, the lower part of the bar is 1¼ inches square for 1⅓ feet, the middle of the bar is octagonal for 1¼ feet, and the upper 2½ feet of the bar is round and ⅞ inch in diameter at the end.

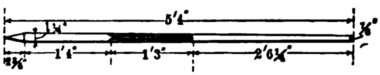


FIG. 115.

It is found that bars with points shaped as described above give the best hold; it is therefore more economical to have these special bars for lining track than to use some of the other bars, although pinch bars are sometimes used for lining track.

202. Pinch Bars.—There is hardly any part of track work in which pinch bars are not used; in some cases they give a better hold and make a better bar for lining purposes than the regular diamond-pointed lining bar. With the exception of the point, the pinch bar has the same general shape as the lining bar, is made of steel, and weighs 24 pounds. The point of the pinch bar, Fig. 116, is 2¼ inches long and wedge-shaped. The lower part of the bar is 1¼ inches square for a distance of 1 foot, the middle is 1⅛ inches octagonal for 1¼ feet, and the upper part is round, tapering down to a diameter of ⅞ of an inch at the end. Pinch bars are made with the straight chisel point shown, or with the point slightly curved up so as to give more of a fulcrum when prying.

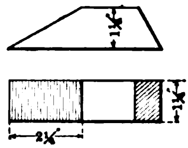


FIG. 116.

In proportioning any of the above bars they are made as short as consistent with good leverage and as light as possible and still withstand the force applied. Many different proportions are used, some being as short as 4¾ feet and weighing 20 pounds. While there should not be any unnecessary weight, it would not be economical to make them so light that they would bend under ordinary use.

203. Tamping Bars.—Tamping bars consist of a plain bar to which is fastened a rectangular piece of soft steel, and are used to tamp ballast under the ties.

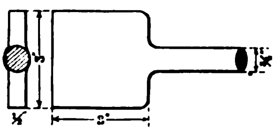


FIG. 117.

Tamping bars should not be too heavy, as a heavy bar would not only be hard to handle continuously, but will not do any better work than a bar of the proper weight. In Fig. 117 is shown one of the simplest forms of tamping bars. It consists of a piece of soft steel, 3 by 3 by ½ inch, welded to a 5-foot bar of ¾ inch round steel, the whole bar being 5¼ feet long and weighing about 10 pounds. There are a number of patented forms of tamping bars, the principal object being to give a better hand hold. The

¾-inch handle described above is so small that it is difficult to control the bar. Some railroads do not use tamping bars at all, dirt or gravel ballast being tamped with shovels, and stone ballast with tamping picks.

204. Picks.—Clay picks have one chisel point and one diamond point and are shaped as shown in Fig. 118. They are made of soft steel, and after they have become worn and dulled they are drawn out and reshaped by a blacksmith. The hole for the handle is larger on the convex side of the pick; the handle is held in place by having it fit snugly in the hole and by holding the handle in a vertical position with the pick head down and by

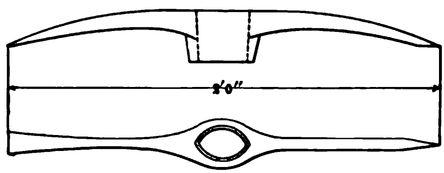


FIG. 118.

striking it a couple of sharp blows on some firm surface. To remove the handle from the pick for repairs, hold on to the pick and strike the handle a blow on a firm surface; this loosens the handle, and it is pulled through the eye of the pick.

A tamping pick is shaped like a clay pick except the chisel end is made shorter and the chisel is replaced by a rectangular piece of soft steel, 2 by ¾ inches in cross-section, similar to the end of a tamping bar.

205. Shovels.—Four kinds of shovels are mentioned in Table XIX, viz., long-handle, scoop, snow, and short-handle shovels. The long-handle shovel consists of a wooden handle 1½ inches in diameter, which is fastened to a steel blade in the same manner as the short-handle shovel in Fig. 119. The blades are made in two forms, viz., square, as shown in Fig. 119, and pointed, as in Fig. 120. The handle is straight, except near the blade, as shown in the figure; the curve in the lower part

FIG. 119.

of the handle causes the handle to set at such an angle to the blade that when the back of the blade lies horizontally on the ground, the upper end of the handle is at such a height from the ground that a man can throw his weight against the shovel when digging. The blades are about 12 inches long and 9½ or 10 inches wide. Long-

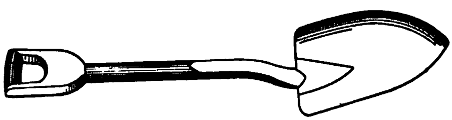


FIG. 120.

handle shovels are used in digging holes and narrow ditches.

Scoop shovels consist of a square-pointed blade about 12 inches wide, 13 or 14 inches long, and scoop shaped to a depth of 3 inches, the blade being attached to a short wooden handle with a grip on the end, as in Fig. 119. The end grip on the shovel handle, Fig. 119, has an opening large enough to allow the workman to place all four fingers through it. These grips are either made out of the same piece of wood as the rest of the handle, or consist of a malleable iron casting which is fastened to the straight part of the wooden handle. Scoop shovels are used to handle large quantities of light material, such as ashes, cinders, or snow.

Snow shovels are usually made of wood shod with iron, and are of so many sizes and descriptions and so familiar to all that no detailed description will be given.

Short-handle shovels are used more than any other track implement. They have a blade about 12 inches long and 9½ or 10 inches wide, and a short wooden handle with a grip on the end, and are slightly scoop shaped. The blades are either square pointed, Fig. 119, or round pointed, Fig. 120. The handle near the blade is curved in the same manner as in the long-handle shovel, and when the back of the blade is flat on the ground, the grip end of the handle is about 18 inches above the ground, which allows the workman to push it with the side of the leg at the height of the knee. The square-pointed short-handle shovel, Fig. 119, universally known among railroad men as a "No. 2 shovel," is one of the most used railroad implements; in construction work it divides honors with the clay pick. On track work it is not only used for all shoveling purposes, but also for tamping the track, more miles of track being tamped with the shovel than with tamping bars and picks.

Shovels wear out by the blade wearing thin and the metal breaking at the point of the blade. After the blade wears thin it will bend easily, even if it will not break, and it is a common sight to see a workman using the rail for an anvil and straightening the point of his shovel with a spiking hammer. Shovel handles are usually riveted fast to the blade, but there are a number of patent handles in which the parts may be replaced. Except in case of accident or carelessness, the handle will always outlast the blade, consequently it is not economical to use an expensive patent handle.

206. Ballast Forks.—A fourteen-tine ballast fork is shown in Fig. 121. The tines are $13\frac{1}{4}$ inches long, and at

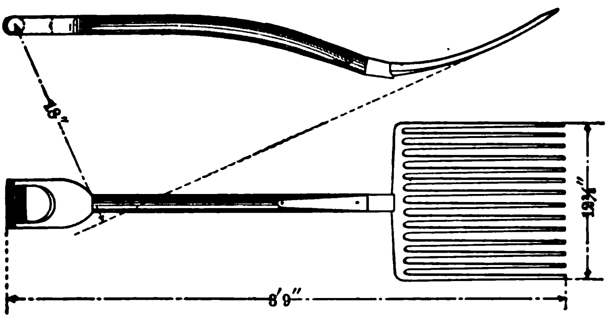


Fig. 121.

the point are $\frac{3}{16}$ of an inch wide and $\frac{5}{16}$ of an inch wide at the upper end, $\frac{3}{8}$ of a inch thick, and have wedge-shaped points. When the space between the points is $\frac{3}{4}$ of an inch, the total width is $12\frac{3}{8}$ inches. The handle is the same as the handle of a short-handle or scoop shovel. Under some circumstances ballast is handled with a No. 2 shovel, but when fine material and dirt are to be excluded, which is in most cases, a ballast fork is used.

207. Wrenches.—Two wrenches are given in the table, viz., track and screw wrenches. A screw wrench is one that can be adjusted to any size nut. They are of two general forms, viz., pipe-wrenches, for gripping round surfaces, and monkey-wrenches, for gripping nuts with plane surfaces. These forms of wrenches are used by trackmen only in special cases.

Track wrenches consist of a straight bar of $\frac{5}{8}$ by $1\frac{1}{4}$-inch steel, with one end upset and formed as in Fig. 122. When bolts of the same size are used in all the rail-joints on the section, the wrench has a grip on only one end; but if bolts of two different sizes are used, it is better to have each end of the wrench with a grip, so that the same

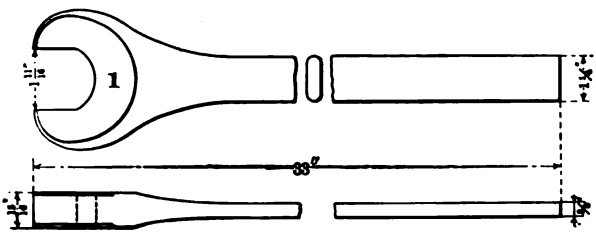


FIG. 122.

wrench will fit both sizes. The diameter of the bolt is stamped plainly on the head of the wrench; Fig. 122 shows a wrench for a 1-inch bolt, the grip being $1\frac{11}{16}$ inches for the nut. There is liable to be a slight variation in the size of nuts for bolts of the same size, and the grip of the wrench should be large enough to take hold of all the nuts for which it is intended. The wrench shown is 33 inches long and has the narrow edges rounded. In some cases the handle part of wrenches is made of round iron with the flat head welded on.

208. Axes.—Common axes and hand axes are known and recognized by everybody, and it is not necessary to describe them. They are not used often in track work, but when they are needed, nothing else will take their place.

An adze is the most convenient instrument for cutting horizontal surfaces, and is generally used by the track gang to trim the top of the tie so that it will give a good seat for the base of the rail, particularly in relaying rails on ties that are slightly worn. In case the old spike holes are plugged, the plug is driven with the axe or hand axe and is cut off level with the face of the tie with the adze. All three forms of axes are also used in making fences or in any kind of timber work.

209. Flags and Lanterns.—Signal flags consist of a rectangular piece of red, green, or white cloth or bunting nailed to a round stick about one inch in diameter and a few inches longer than the narrowest dimension of the flag, the shorter dimension being along the stick. A set of flags should be carried by each track gang. Track-work is dangerous and must be done without interfering with traffic as far as possible, but the gang must be protected by a flagman. When a red flag is displayed, the train must stop; if a green flag is shown, it must proceed under control, which is sometimes necessary when resurfacing track; a white flag means all clear.

The lanterns used on a section are usually red and white, and two, the number mentioned in the table, seem a very inadequate supply for a section. In case of a washout it is quite possible for both tracks to be out of service, in which case two red lanterns, one on each track, will be necessary.

210. Hand- and Push-cars.—Hand-cars consist of a platform mounted upon four wheels and driven by a rack and lever attached to two bars. These bars are as long as the car is wide and stand at right angles to the track; the bars are pumped by six men, three facing forward and three backward. Hand-cars must have an efficient brake, and have hand-holds at each corner of the car, so that they can be lifted to and from the track. The hand-car is used to carry the section gang and tools to and from their work.

Push-cars consist of a plain platform mounted on four

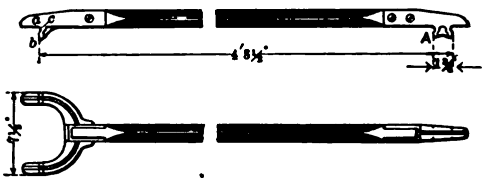


FIG. 123.

wheels, and are used to carry ties and rails to the point where they are to be laid in track. Both of these cars are essential on all sections, except that the hand-car is not necessary in yard work. The longer the section, the greater the necessity for a good hand-car.

211. Track Gauge.—The two essentials of a track gauge are—(1) that it shall be forked on one end, as shown in the plan, Fig. 123, and (2) that the projections shall fit against the gauge of the rail and give the required gauge of track. In the elevation, Fig. 123, three projections are shown: the outer projections give the gauge of track, and the projection A gives the proper spacing,

$1\frac{3}{4}$ inches, of guard rails from the main rail. The faces *a b* should be vertical for the A. S. C. E. section, and should have the direction of the side of the head of rail in use. The curve *c* is to prevent a flow of metal in the head of the rail from preventing its being put in true gauge. The forked end is to insure that the gauge will be placed normal to the rails. The ends of the gauge project just beyond the centers of the heads of the rails. Gauges constructed in a number of different ways are in use; the gauge shown in the figure consists of malleable iron ends with sockets into which is screwed a piece of round, kiln-dried white oak, $1\frac{1}{2}$ inches in diameter. The gauge is made as light in weight as is consistent with strength by making the cross-sections of the castings T- and U-shaped; sometimes hollow cylindrical sections are used.

In using the gauge one rail is spiked; the other rail is placed approximately in position; the gauge is laid on the rails; the loose rail is then thrown over until it is in true gauge, and is then spiked.

212. Track Jacks.—Track jacks are used to raise the track to the proper elevation when the track is being tamped into surface. The Barrett jack shown in Fig. 124 is used extensively. The point *c* and the part *e* are fastened to a solid bar which can be raised by pumping the part *d* and a ratchet attachment. In raising the part *ce* a wooden handle about 2 inches in diameter and three feet long is inserted into the socket *d*, and two men force the handle downward, the ratchet allowing the handle to be raised without resistance. While tamping, the handle is removed so that it will not interfere with the workmen.

The jack can be released, or lowered, by moving the clutch *f* on the side of the jack and forcing the handle upward, causing the part *ce* to be lowered. In some forms of this jack it is released by striking another form of clutch on the side of the jack with the wooden handle, whereupon the part *c e* falls immediately to its lowest position, the jack collapsing as soon as the clutch is struck. In jacking the track the point *c* is placed as low as possible, part of the ballast is removed so that the base *a b* will have a firm support and the point *c* will grip the base of the rail; the movable wooden handle is then inserted into the socket *d* and the track raised until the top of the rail is at the desired elevation.

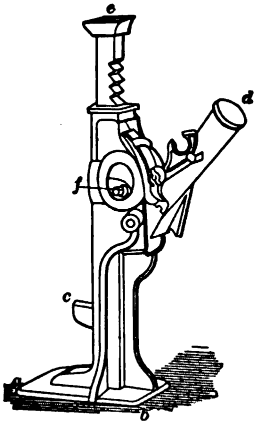


FIG. 124.

213. Rail Tongs.—Rail tongs are used in handling rails, one man taking hold of each handle of the tongs. They are made of 1⅛-inch round iron with the ends made rectangular in section and shaped as in Fig. 125, being fastened together by a ¾-inch rivet. The jaws of the tongs are opened and slipped over the head of the rail; when being carried, the weight of the rail causes the jaws to grip the rail. A 33-foot 100-pound

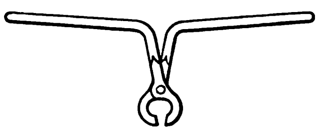


FIG. 125.

rail weighs 1100 pounds; therefore six pairs of tongs and twelve men will be required if the rail is to be moved more than a short distance; eight men could carry it a short distance, and four men could slide it along.

Tie tongs are similar to rail tongs except they are made of lighter iron and the jaws are larger, wider apart, and pointed so that they can be forced into opposite sides of the tie.

214. Brush Hooks and Scythes.—A brush hook (Fig. 126) consists of a sickle-shaped piece of steel about $\frac{3}{16}$ of an inch thick on the back and 2 inches wide, with a cutting-edge on the entire concave outline. It is fastened to an ordinary axe handle by means of two iron straps, about $\frac{1}{8}$ by $\frac{1}{2}$ inch in section, which pass around the handle and are bolted through the blade. More small brush can be cut with a brush hook in the same time and with greater ease than with any other implement. It is very useful in clearing up right-of-way and in trimming small branches from trees. Including blade and handle, it does not weigh more than three pounds.

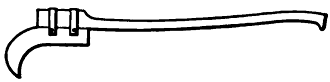


FIG. 126.

For section work scythes should be of two forms, viz., grass and brier scythes. The snath, or handle, is the same for both. The grass scythe is long and light and is not strong enough to cut anything tougher than grass or green weeds. The blade of the brier scythe is short and thick, and can be used to cut large weeds and even small bushes.

215. Level Boards.—The simplest form of level board, or track level, consists of a piece of plank $1\frac{1}{4}$ or $1\frac{1}{2}$ inches thick, and notched on one end, planed on all four sides, with the top and bottom faces exactly parallel and a level bubble set in the top edge. The depth *a e* of the board depends upon the degree of the curves on the section and the standards of the railroad. The notches *b c*, Fig. 127, are made $\frac{1}{4}$, $\frac{1}{2}$, or 1 inch deep. If the notches are made 1 inch deep, the distances *c d* may be made 3 or 4 inches long; but if they are made only $\frac{1}{4}$ of an inch deep, *c d* is made 2 inches long. The length *a b* must be at least 5 feet, so that the board can be used for level track. A hand hole is cut in the board at a lo-

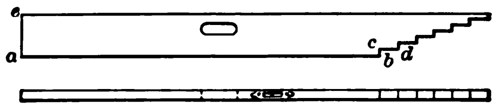


Fig. 127.

cation such that the board will balance when lifted and will carry in a horizontal position. Either soft or hard wood may be used, there being a number of arguments in favor of using soft wood, such as white pine, the argument against using soft wood being that the bearing surfaces wear out sooner. There are a number of elaborately designed track levels, the bearing surfaces being shod with metal, and the difference of level is obtained by means of a movable arm which moves in a vertical direction and is fastened by a set-screw. Unless handled very carefully, metal-shod boards are inclined to jar the bubble out of level.

216. Track Chisels and Punches.—A track chisel, or rail cutter, is shown in Fig. 128, A. It consists of a piece of crucible steel made in the shape of a hammer, and is fastened to a hammer handle. The cutting-edge is curved, $1\frac{1}{4}$ inches wide, and the thickness at the top of the bevel and the beveled edges make an equilateral triangle $\frac{3}{8}$ of an inch on the side. In cutting, a mark is made around the rail, the chisel is placed on the mark and struck with a sledge-hammer, the chisel is moved along slowly until there is a cut entirely around the rail, and this is repeated until the cut is deep enough to allow

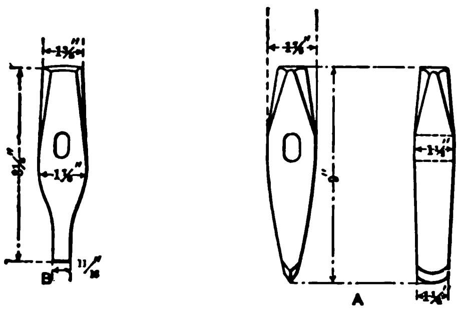


FIG. 128.

the rail to be broken in two. If a short piece is being cut from the rail, after the rail has been cut to a sufficient depth, a blow on the end of the rail will cause it to break. If the cut is near the center of the rail, it can be broken after a cut of sufficient depth has been made, by raising the rail and dropping it across a block raised above the general ground level.

Track punches, Fig. 128, B, are made of crucible steel and fastened to a hammer handle the same as a track chisel. The punch end is slightly larger at the extreme end than it is a distance back from the end, in order to prevent it from sticking fast when driven in. They are usually about $\frac{11}{16}$ of an inch square, and are used for removing old bolts and rivets, and in some cases they are used to force the holes in the rail and splice-bars into line, so that a bolt can be put in, particularly where rails of different sizes are being spliced by a special joint.

Track chisels and punches are used in case of emergency by the section gang, such as after a wreck, when the track must be fixed in the shortest possible time, or in laying a switch.

217. Rail Fork.—A rail fork is used in turning rails

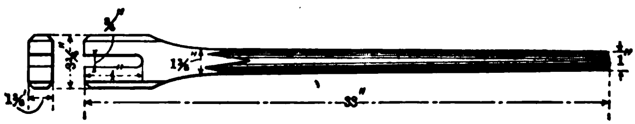


FIG. 129.

over. The prongs of the fork are slipped over the base of the rail. Rail forks are made out of mild steel; the general dimensions are as shown in Fig. 129; the slot is $\frac{3}{4}$ of an inch wide and 4 inches deep, the prongs are $1\frac{3}{8}$ inches thick, the lower part of the handle is $1\frac{3}{8}$-inch octagonal steel, and the balance of the handle is round, tapering down to 1-inch diameter at the end, the total length being 33 inches. Rail forks are not needed often, but they are very convenient and save a great deal of time in some cases, such as in cutting a rail, in which case the rail must be turned repeatedly.

218. Grubbing Hoe and Post-hole Digger.—A grubbing hoe, or maddock, is shown in Fig. 130; it consists of two blades whose cutting-edges are set at right angles to each other. The eye for the handle is larger on the outside and the handle is placed in the head in exactly the same manner as in a pick. It is made of wrought-iron with steel cutting-edges, and the cutting-edges are tempered so that they are not hard enough

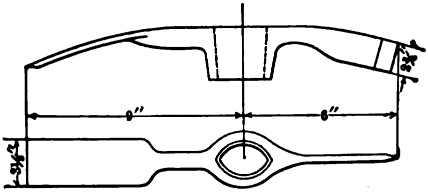


FIG. 130.

to break if a stone is struck in digging. The lower blade is about 3½ inches wide, and is curved at such an angle to the handle that when the workman holds the handle at an ordinary height, the end of the blade is horizontal, so that the surface of the ground can be skinned off. The

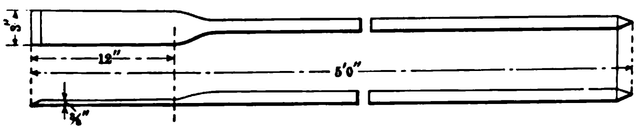


FIG. 131.

grubbing hoe is better than the clay pick for loosening material when the material is full of roots and does not contain too many stones, the upper edge being used as an axe to cut roots. Grubbing hoes may be bought in several sizes and weights, the head weighing from 4 to 6 pounds.

A post-hole digger, shown in Fig. 131, consists of a blade about 12 inches long, 3 inches wide, and $\frac{3}{8}$ of an inch thick, welded to a wrought-iron bar 5 feet long and 1 inch in diameter. About 3 inches of the end of the blade is made of steel and has a chisel edge so that the hole can be dug with vertical sides, and is tempered the same as the ends of picks and grubbing hoes. The upper end of the bar is pointed so that it can be used in loosening small stones that obstruct the digging. The whole bar is about 6 feet long and weighs 17 pounds. The post digger is proportioned for the sole purpose of digging holes, and is not strong enough to use as a crowbar.

219. Carpenter's Kit.—The carpenter's kit should consist of a tool-box containing at least the following tools: 1 auger, 1 brace, 2 brace-bits, 1 file, 1 nail hammer, 1 hatchet, 1 draw-knife, and 1 handsaw. These tools, together with a grindstone, form the necessary rainy-day repair outfit. Tools with tempered steel edges can be sharpened by grinding when the edges are not so badly worn that they must be drawn out and reshaped by a blacksmith, and the parts of stormy days in which the track gang cannot do regular work can be profitably spent in putting tools in good order. Extra hammer and pick handles are always kept in the section tool house, and the draw-knife will be found very useful in fitting them, particularly if there should be a bench vise in the outfit.

Descriptions of spike pullers and ratchet drills can be found among the advertisements of any engineering paper, and the rest of the miscellaneous tools mentioned in ¶ 196 are so well known that they need no description. If the members of the track gang are permanent, as they should be, they soon become proficient in handling all the tools in use on the section, and the number of tools going back and forth to headquarters for repairs is reduced to a minimum.

ARTICLE XX.

TRACK SIGNS.

220. Division Posts and Mile Posts.—Each railroad has its own standard track signs, and although they vary considerably, there is enough similarity in the different standards in use to enable one who is familiar with the meaning of signs along one railroad to understand those of another railroad. The principal sign that interests the general traveling public is the mile post, the other signs being for the guidance of the employees. Sign posts vary in detail design from a square wooden post to posts built of angle irons and iron plates and set in a concrete base.

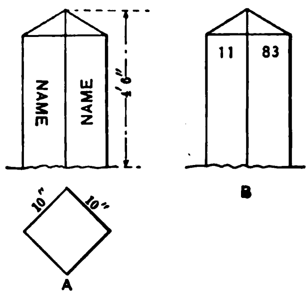


FIG. 132.

The simplest form of division post consists of the square wooden post shown in Fig. 132, A. It is ten inches square, has a pyramid top four inches high, is 7 feet long, and is planted 2½ feet in the ground, leaving 4½ feet above ground. The names of the adjacent divisions are painted on the post, as shown in the figure, in letters four or five inches high. Usually the post is painted white and the letters black, but sometimes they are painted black with white letters.

Mile posts are similar in form and dimensions to division posts, and are marked as shown in Fig. 132, B, the numbers representing the number of miles from each of the termini, the sum of the numbers being the length of the railroad in miles. Division and mile posts are set with a clearance of not less than eight feet from the gauge line of the outer rail in fills, and just beyond the ditch in cuts.

221. Subdivision, Section, and Yard Limit Posts. —In Fig. 133, A, is shown the general arrangement of the Pennsylvania Railroad "supervisor's division" and "section" signs. The numbers are placed on a cast-iron oval plate, $10\frac{1}{2}$ by $20\frac{3}{4}$ inches, mounted on a 3-inch wrought-iron pipe which is set in a stone or bed of concrete $2\frac{1}{2}$ feet square and 4 feet deep when necessary. The edges of the cast-iron plate are raised $\frac{1}{8}$ of an inch, the panels are sunk $\frac{1}{8}$ of an inch, and the figures are flush with the face of the plate. The post and plate are painted black and the numbers white. In Fig. 133, B, is shown the back of the plate, the diagonal strengthening ribs, and the socket into which the post fits. The upper plate in Fig. 133, A, shows the "supervisor's division number," referred to in previous paragraphs as "subdivisions," and the lower plate shows the section numbers. The post in the figure shows that supervisor No. 5 has sections number — to 65, and supervisor No. 6 has sections number 66 to —. For intermediate sections the sign post is similar to Fig. 133, A, without the top plate, the section sign being in both cases 5½ feet above the ground.

At yard limits a sign post of the dimensions shown in Fig. 133, C, is placed. It is made of cast-iron in the same general way as the section signs, is lettered as shown in the figure, and is placed eight feet above the ground.

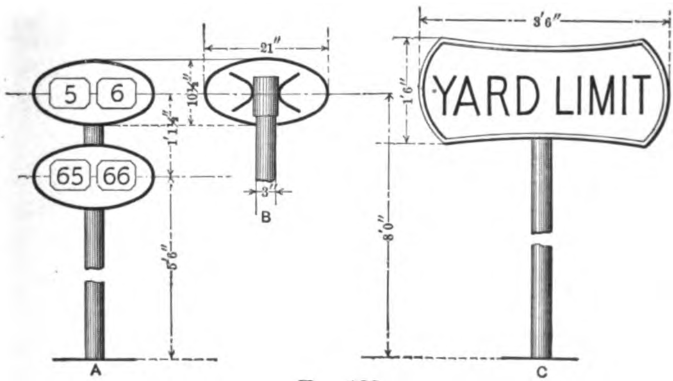


FIG. 133.

222. Whistle and Ring Posts.—These posts may be cast-iron or wood, as described, in ¶ 220, Fig. 132, excepting the top of the post is 5½ feet above the top of rail. On a whistle post a W 7½ inches high and on a ring post an R 7½ inches high is painted. They are painted according to the same rules mentioned in ¶ 220. These posts are set facing the approaching train at the distance before each grade crossing, station, etc., that will give the best warning.

223. Road Crossing Signs.—Railroads are compelled by law to erect signs giving warning at all road crossings, particularly grade crossings. Formerly these signs read as in Fig. 134, B, "Look out for the Locomotive," but at the present time the wording in Fig. 134, A, "Railroad Crossing, Stop, Look, and Listen," is in most general use, the old wording still being in force in some States. It has been said that the man who advised the use of the words, "Stop, Look, and Listen," received the highest price per word ever received by a writer. These signs are made in many different ways.

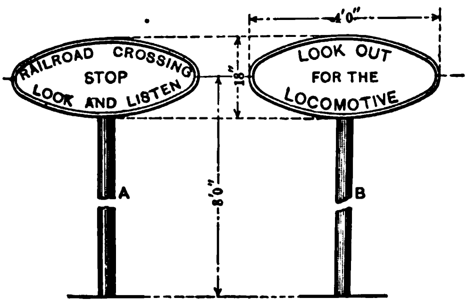


Fig. 134.

The standard Pennsylvania Railroad signs consist of an oval plate 18½ inches high and 4 feet wide, made of cast-iron, on the same general plan of the section sign plates, and mounted in the same way, the words *railroad, crossing, look, and,* and *listen* being 3 inches high, and *stop* 4 inches high, and in the other sign the words *for the* are 3 inches high and all the rest of the words are 4 inches high; the face of the letters and the border are painted white on a black ground, and the back of the sign and the post are painted black.

224. Trespass Signs.—It is customary for railroads to place trespass signs at certain points along its line. The general trespass sign usually reads, "Caution! do not walk nor trespass on the railroad." These signs are usually placed at all points where there is a break in the right-of-way fence. At each end of a bridge is placed a sign which reads, "Caution! do not walk nor trespass on this bridge." Each railroad has standard forms for these signs, the same way that they do for all other signs. At private crossings a sign is placed which reads, "Not a public crossing: all persons are warned not to trespass."

225. Property Corner-stones and Center Line Markers.—A property corner-stone is shown in Fig. 135. It consists of a rough block of granite about 10 by 10 by 34 inches. The top is dressed 6 inches square and 4 inches high, with the edges beveled off at an angle of 45 degrees, leaving the top face 5 inches square. In the top is made a triangular shaped cut forming a cross, the center of the cross being the exact property corner. These stones are set at all property corners, and also at all angle points in the property lines. In most cases a hole about one-half inch in diameter is drilled in the top of the stone instead of the cross to mark the exact corner.

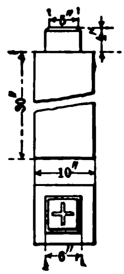


FIG. 135.

Center line markers should be placed every three or four hundred feet on a tangent and every hundred feet on curves, and also at each P C., P. C. C., and P. T., so that the track will not be gradually thrown out of true line. In most cases 3- by 3-inch white oak stakes are used, and in some cases stone monuments similar to Fig. 135 are set with the top flush with the top of the ballast. The Pennsylvania R. R. uses an iron center line marker, the outline of the cross-sections of which is square, with round re-entrant corners, three inches at the top and two and one-half inches at the bottom; its total length is three feet, the point being six inches long. The top has a cross one-half inch deep in it, similar to the top of the property stone cross in Fig. 135. These markers are driven on the center line of track, and enable the track foreman to keep his track in true line.

226. Road Crossings.—On account of the open space necessary along the gauge of rail, wheels of vehicles in crossing over the rails are very destructive to the roadway, and it is very difficult to construct a road crossing that will hold a good top surface. It has been found that the most serviceable roadway consists of a framework of planks filled in with ordinary ballast to within a short distance from the surface, and covered with a top dressing of fine crushed stone, preferably trap rock. The planks used are 12 inches wide, 4 inches thick, and as long as required. The plan and section of a road crossing are shown in Fig. 136, A and B. It consists of two planks outside of each rail, or outside of the outside rails when the railroad is double-track, one plank on the inside of each rail, and a piece of plank at each side of the road crossing between rails, forming a box. Usually a row of stone blocks is placed along the side of the outer planks as shown. Fig. 136, B, gives the elevation of this arrangement. The planks are spiked to the ties and the middle filled with broken stone, as described above.

The arrangement of the planks next the rail is shown in Fig. 137, A; the top surface of the outside plank is placed ¼ inch below the top of the rail, and the top of the

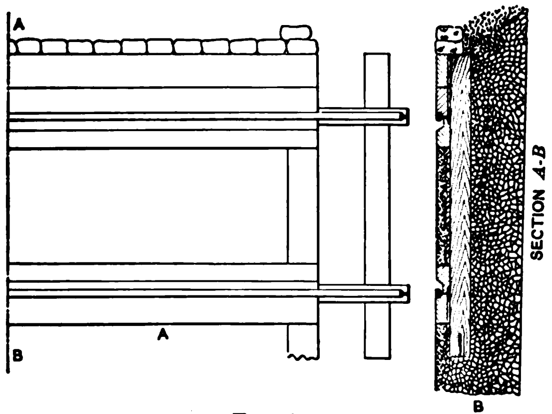


FIG. 136.

inside plank 1¼ inches below, as shown in the figure. The plank next to the gauge of rail is notched as shown, so that the flanges of the wheels will not be obstructed. In order to have the tops of the planks at the proper

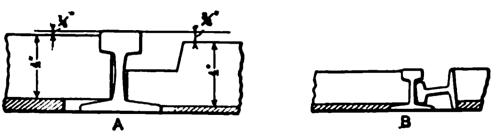


FIG. 137.

elevation, furring must be placed between the ties and the planks, the thickness of the furring depending upon the weigh, or height, of the rail.

Instead of the notch shown in Fig. 137, A, the space for the wheel flanges is sometimes obtained by placing an old rail on the inside of the track rail, as shown in Fig. 137, B, and the planks are laid against the base of the old rail.

Article XXI.

THE WORK TRAIN.

227. Function of Work Train.—The work train is used to distribute track material along the line at the various points where the material is needed for repairs or renewal, particularly ballast, ties, and rails. A work train is a necessity on a division handling heavy traffic, and is in active service most of the time, except possibly in the winter months. If a temporary trestle has been built on a new road on account of lack of proper material for the fill, the fill to replace the trestle is made by the work train and its force. On the older lines, where there are no temporary trestles to be filled, one of the principal uses made of the work train is in removing rails and ties and laying new ones. Where the ties or rails are to be replaced at intervals or in short stretches where they have become unserviceable, the work train distributes the material and the section gang does the laying, but where new ties or rails are to be laid for considerable distances, all the old ones being removed, it is more economical to do the work with the work train force. The above remarks apply more particularly to cross-ties, as rails are usually renewed in long continuous stretches.

228. Form of Train.—The number and kind of cars composing the work train depend partly upon the work to be done, and consist in all cases of an engine, caboose, and tool car, the balance of the train being made up of the cars necessary to handle the material for the particular piece of work. Rails are hauled on flat cars with low sides and the ties in gondola cars. If the track is being ballasted for the first time, cars with hoppers in them could be used, provided the discharge could be regulated, but when the ballast is for renewal purposes, it is hauled in gondola, flat, or special cars and deposited on each side of the track, as it would not be safe to deposit ballast between the rails of a track that is in service. It is expensive to distribute ballast from a gondola car, therefore in most cases the ballast is hauled on flat cars with movable sides, particularly when the haul is short.

The caboose should be large and furnished with as many conveniences as practicable. In most cases they are built for the purpose, but sometimes old-fashioned passenger coaches are fitted up as cabooses. The seats are usually along the sides of the car and arranged with lockers underneath in which the men may stow their dinner-pails, and there should also be lockers for necessary supplies and some of the tools. The caboose should contain a stove for heating purposes, a water-cooler, and a desk for the foreman. The platforms at the ends of the caboose should be large and roofed over, and the steps and grab-irons conveniently placed, as it is necessary for the men to be able to get on and off in the least possible time. It is usually provided with a large box or locker which is fastened underneath the center of the car, and in which ropes, chains, screw-jacks, snatch-blocks, rerailing frogs, etc., are kept.

229. The Tool Car.—A tool car consists of a flat car upon which large tool boxes are fastened. The tools in most common use, such as shovels, lining bars, tamping bars, etc., are kept in these boxes, which are provided with locks. The tool car is often provided with a grab-piece and a running-board on each side of the car, and for its entire length, so that the men can get aboard quickly and conveniently. The tool car is coupled just ahead of the caboose. The tool car and caboose should be attached to the work train at all times, and should carry a complete outfit of tools, so that a large force of men can be supplied with tools to do any kind of track work that may be required, and should also be outfitted for ordinary wrecking purposes.

230. The Engine.—A work train is not heavy and must make good time, consequently a passenger locomotive is best for the work train. Old passenger locomotives that are too light or too much worn for service on regular trains are generally used, but it is not economical to use an engine that is not in fair condition. It is necessary to work between regular trains without interfering with the regular train schedule, and at best a great deal of time is lost in getting to a siding until a regular train has passed and then back to the working point. The work train usually starts from division headquarters in the morning and returns at night, and if it has a passenger locomotive and is fully equipped with air-brakes, it can run on a passenger-train schedule and not be compelled to lay over in order to allow passenger trains going in the same direction to pass it.

231. The Work Train Crew.—The work train crew consists of the train crew and the work gang. The train crew consists of at least four men, viz., the conductor, engineer, fireman, and at least one brakeman or flagman. Some railroads place both the train crew and the working force in charge of one man and call him either conductor or foreman, and make him responsible for both running the train and handling the men. This is not an economical arrangement, particularly on roads with heavy traffic, especially as another flagman is required. The best arrangement is to have the train crew in charge of a conductor and the work gang in charge of a foreman. The conductor is responsible for the safe running of the train, receives and is governed by the orders of the train dispatcher, and sees that the train is properly protected by the flagman, and runs the train as requested by the foreman within the above limits.

The foreman distributes the materials and handles his working force free of all worry about running the train. He must keep his men employed as constantly as possible. Excepting in special cases, he knows the exact length of time he will be able to work uninterruptedly at a certain place, and also the length of time the train must stay on a siding. In case of a long lay-over, he should, if possible, provide work for his men adjacent to the siding; if nothing else, they can dress slopes and clean ditches and the right-of-way.

232. The Work Train Force.—The size of the working force for the work train depends upon the work to be done. The cost of running the train and wages of the train crew are relatively constant, and it is not economical to work short-handed. If the train is in constant service, a regular force is employed, as much more work can be done with an experienced force. If the train is not in constant service, it will be necessary to pick up inexperienced men when needed, in which case the efficiency of the force can be increased by using one or more men from the nearest section gang.

The cost of the work train per day for engine, fuel, and wages of train crew is about $30.00; consequently, where possible, a large working force should be used, as the greater the number of men, the less the proportionate expense of the train.

233. Distributing Ties.—If ties have been delivered to the railroad and piled to season at convenient points along the division, the work train may be run to the nearest supply and ties be loaded on the train by the working force. It will in many cases, however, be more economical to have cars loaded with ties placed on sidings near the place where they are to be used, where the work train can pick them up. In distributing the ties a great saving can be made by placing the ties at the right place. The section foreman should make a careful report to the supervisor, stating how many and where the ties are needed. This report should be forwarded to the assistant engineer by the supervisor, and the assistant engineer should instruct the foreman of the work train to distribute the ties accordingly, or the supervisor or his assistant should go with the train and see that the proper distribution is made. In many cases the train can be run slowly and the ties distributed while it is moving, care being taken not to throw them too far from the track, particularly on high fills, where they are liable to slide to the bottom. Careless work on the part of the train workmen will cause a great amount of work and loss of time to the section gang, as it will cause a great deal of push-car work to get the ties to the right place. The distribution may be governed by chalk marks on telegraph poles or fences; it would also be well to have the section foreman accompany the train.

234. Handling Rails.—The work train force have two problems in handling rails, viz., unloading new rails and loading old rails. Rails are usually unloaded by dropping them from the side of the car, by sliding them off with skids, or by means of derricks. There are also several methods and devices for unloading rails by dragging them from the rear car of the train by means of a drag rope and truck, etc. The details of unloading the rails depend to a great extent upon the kind of car they are loaded on. The rail may be slid to the top of the side of the car by means of skids and dropped, or slid by means of another set of skids on to the ground or ballast. If care is taken that both ends of the rail strike the ballast at the same time, there is very little danger of injuring the rail in either case; but even when skids are used, the rail may be ruined by having one end hit the ground considerably before the other. Rails may be unloaded from both sides of the car at the same time, but frequently on double-track roads all the rails are unloaded on the inside and allowed to lie between the tracks.

In loading old rails, the rail is picked up, raised above the side of the car, and thrown broadside into the car. It is a dangerous proceeding for inexperienced men, but there is practically no danger with experienced men. A sufficient number of men to raise the rail at arm's length with ease should be used; they stoop over and take hold of the head of the rail, straighten up, then raise the rail above their heads, step forward, and throw it upon the car. An 80-pound rail 33 feet long weighs 880 pounds; there is not room for more than about sixteen men to take hold of it, and each man must lift 55 pounds.

235. Handling Ballast.—The handling of the various kinds of ballast until it is loaded on the cars at the supply points is described in detail in Chapter II, Article II. The ballast is then hauled to the division headquarters and placed on sidings, and each day the work train takes as many cars of ballast as can be distributed during the day. Ballast can be handled in three ways, depending upon the amount of work to be done, as follows: It can be distributed along a long stretch of track and then tamped, or it can be distributed along a short distance and tamped and then over another short distance, etc., all the work being done by the work train force; or it can be distributed by the work train and tamped by the section gangs.

236. Filling a Temporary Trestle.—At least two trains are required for each steam shovel when the site of a temporary trestle is being filled, and the size of the trains, distance hauled, and the method of operation should be such that the shovel is in continuous operation and one train working all the time that the other train is being loaded. The excavated material is loaded on flat cars with sides fastened with hinges, so that the sides can be dropped before unloading, or in one of the many forms of patented side-dumping cars. The material is unloaded from flat cars either by hand or with a plow. There are a number of patented plows which in general consist of a heavy framework which holds a moldboard in a diagonal position across the car, and is guided by some device on the side of the car opposite to the side from which the material is unloaded. In the simplest form of plow the moldboard consists of a plank shod with boiler-iron and held in position by a triangular framework. The train is hauled to the fill and fastened by brakes or blocks so that it cannot move; the engine is cut loose from the train and drags the plow ahead by means of a rope. In some cases the plow is built so that its point follows the center of the car and throws the material both ways. The economy of using a plow depends upon the kind of material that is being handled, it being cheaper to unload some kinds of material by hand.

237. Wrecking.—When a wreck occurs, it is the duty of the employees of the railroad to report it promptly to headquarters. The train dispatcher and the wrecking crew are notified immediately. The train dispatcher takes all precautions necessary to safeguard all trains, and the wrecking crew and outfit are hurried to the scene of accident. In case of accident to a passenger train in which persons are injured, a relief train is also hurried forward. The wreck train is kept at division headquarters and is usually under the charge of the track department or the master mechanic of the shops. Each railroad has its own method, depending upon the nature of the work likely to be required. One railroad may be so located and constructed that in case of a wreck most of the damage will be to rolling stock and the injury to the track will be of minor importance. On railroads in mountainous country subject to landslides most of the injury may be to the track. In any case it is the duty of the wrecking force to get the track in operation as soon as possible.

238. The Wreck Train.—Where there is a construction train in constant use on a division, and it carries the equipment mentioned in ¶ 228, the only additional outfit necessary is a derrick car and a sufficient supply of hydraulic and other heavy jacks. As soon as the shop force knows the nature of the wreck, the necessary equipment can be obtained from the shops. It is the duty of the nearest section gang and the work train to proceed to any serious wreck immediately, the wrecking crew and train arriving as soon as possible. When there is no regular work train, the wreck train must carry all the tools and appliances previously mentioned, and are usually kept loaded on a car and ready for instant service. A telegraphing outfit is also carried, so that reports can be made promptly to headquarters, either to report that the track is clear or to ask for additional equipment.

239. The Wrecking Crew.—On most railroads the wreck train is in charge of at least two men, a foreman and an assistant, who are constantly on duty, and whose duty it is to see that the train is ready for service on short notice. The wrecking crew is made up of as many experienced men as can be obtained, including shop men. On account of the various gangs and crews whose duty it is to help clear up a wreck, it is important that there shall be a rule defining who shall take charge of the wreck, in order to prevent a conflict of authority. The wreckage can be handled best by the shop men, and the track work by the track department, as both bosses and men will be best acquainted with the work in hand.

Every wreck train should be supplied with a "first aid to the injured" outfit, as it may be indispensable in caring for those injured in the wreck or for members of the crew injured while engaged in clearing the wreck. All train men should be instructed in applying simple remedies, and particularly in bandaging wounds, as a compress or bandage applied immediately may save life.

240. Snow-plows.—Excepting in the lower Mississippi and Gulf States and portions of the southwest, considerable trouble is experienced in all parts of the United States in keeping the tracks free from snow in winter. This problem is so serious that in some parts of the northwestern States snow-sheds and even tunnels are built to prevent snow from completely stopping train service temporarily. Snow-plows are of three general types, viz., attachments that are placed on the locomotive, push plows, and especially designed machines. The first-mentioned type, attachments to the front of the locomotive, is all that is required in a large part of the country, but in sections noted for heavy snow-falls the machine snow-plow is used.

When the snow is not deep and is light, an attachment to the locomotive pilot is all that is necessary to keep the track clear. There are a number of pilot snow-plows; one of the attachments consists of two boiler-plate moldboards which are fastened to the sides of the pilot so that they present a vertical sharp edge to the snow. These moldboards are slightly concave, so that the snow slides both ways from the point, which is over the center of the track. An arrangement of this kind is only effective in keeping the track open, and would be of no use in opening a track that has become snow-bound. The fight to keep the tracks open should begin as soon as the snow begins to fall, particularly if there are indications of a heavy storm. If the above simple device can be kept moving during the storm, every train removes a part of the snow, and it will not be possible for the snow to block trains; but if nothing is done until the snow has become deep, with the accompanying drifting and packing that take place, or the storm is so heavy that it stalls trains between stations, then the machine plows are required to open the road. Snow nearly always causes delay, but only in exceptional cases does it completely stop heavy traffic.

241. Push and Machine Plows.—Push snow-plows consist of a specially designed car the end of which is so shaped that the snow is plowed from the track when the plow is pushed along by locomotives. On a single-track railroad the plow is shaped so that the snow is thrown both ways from the center of the track, but on double-track roads it is shaped so that all the snow is thrown to the outer side, so that the snow from one track will not be thrown on the other track.

The machine snow-plow in most common use is the "rotary" snow-plow. It consists of an especially designed engine which resembles a freight car to some extent, with a vertical revolving wheel on the front end, the wheel consisting of blades that are so arranged that they cut away the snow, the snow being thrown to either side of the track from the top of the case holding the rotary cutting wheel. The case or hood is made of steel plates, with cutting-edges at the sides and bottom. The wheel makes about 200 revolutions per minute, will cut through a large drift of packed snow, and will throw the snow from 50 to 150 feet from the track, depending upon the condition of the snow and the speed. The rotary snow-plow will clear the track at the rate of 6 miles per hour in heavy snow, and 12 to 15 miles per hour in light snow. Rotary snow-plows are expensive in first cost and operation, and are economical only on railroads where the snow forms drifts of such depth that the simple forms of snow-plows will not work.

ARTICLE XXII.

MISCELLANEOUS.

242. Bumpers.—Car stops, bumping blocks, or bumpers, are devices to prevent cars from running off the end of a track, and are made in a great many forms, varying from a bank of earth to an elaborately designed and patented device. The first requisite of a bumper is that it will stop the car; the secondary one is that the car shall not be injured. Where there is plenty of space for it, a bank of earth makes a very effective car stop. The bank should be cut to a nearly vertical face, the track laid up to this face, and then the excavated earth should be replaced so that bank facing the track should have a natural earth slope. If a car strikes the slope at a reasonable velocity, the wheels cut through the earth and encounter an increasing resistance as they get further into the bank, and the car will be brought to a stop without the wheels leaving the rails. If the car

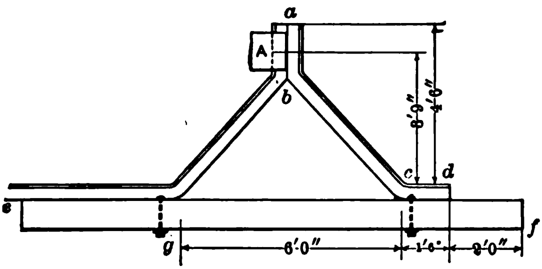


FIG. 138.

is traveling at an excessive rate when it strikes the bumper, the truck that strikes the bumper may be derailed, but nothing will be broken.

The design of a bumper depends upon its location, the strongest and best forms being used in places where the car must be stopped regardless of the damage that may be done to the car. This is the case where a track ends at the building line of a street, where loss of life might result if a car were to run into the street. A simple and effective bumper is shown in Fig. 138; it is made by turning the ends of the rails up, as shown in Fig.

138, until they are about 4½ feet above the top of rail; two pieces of rail are bent so that the parts *a b* and *c d* are 18 inches long and vertical and horizontal respectively; these pieces are riveted or bolted together at *a b* and are strapped or bolted to the stringer *e f* at *c* and *g*. Both rails of the track are arranged as shown in the figure and described above, and a 12- by 12-inch timber, A, is bolted to the rails transversely to the track with its center 3¾ feet above the top of the rail.

243. Gauge of Track.—In the early days of railroading in the United States a number of different widths of gauge were used, and were divided into two general classes, viz., broad gauge and narrow gauge. This made it necessary to transfer all freight at the junctions of two roads of different gauge, and caused so much delay and expense that the same gauge was adopted by all railroads. This is called "standard gauge," and is 4 feet 8½ inches, some railroads using 4 feet 9 inches, and a car can be shipped to any railroad point in the United States. There are a number of different gauges in use in other countries, a broad gauge in common use being 5 feet, and a narrow gauge which is used extensively is 1 meter. Narrow-gauge roads are usually built where construction is both difficult and expensive, but even then it is of doubtful economy.

244. Widening Gauge on Curves.—On account of the length of the wheel-base of large locomotives it is customary on some railroads to widen the gauge on curves. The gauge of the wheel flanges is made 4 feet 8⅛ inches, which gives a play of ⅜ of an inch on standard gauge when the rails and flanges are not worn. The wheel flanges soon become worn, which gives a play of more than $\frac{3}{8}$ of an inch, therefore on curves of a radius of 955 feet or more there is no necessity for widening the gauge. There is, however, a difference of opinion, and some railroads widen the gauge a proportionate amount on curves. The New York, Lake Erie, and Western Railroad uses the following rule:*

Degree of Curve.	Radius in Feet.	Gauge.	Amount of Widening in Inches.
0 to 3	to 1910	4 ft. $8\frac{1}{2}$ ins.	0
3 to 5	1910 to 1146	4 " $8\frac{5}{8}$ "	$\frac{1}{8}$
5 to 7	1146 to 819	4 " $8\frac{3}{4}$ "	$\frac{1}{4}$
7 to 9	819 to 637	4 " $8\frac{7}{8}$ "	$\frac{3}{8}$
9 to 11	637 to 521	4 " 9 "	$\frac{1}{2}$

245. Clearances.—It is customary for each railroad company to issue "dimension books," which give the size of the largest object that will pass through the smallest tunnel, bridge, or opening on the railroad. These data are very important to firms that manufacture large objects. Where the weight does not prohibit, parts of structures are put together in the shops in as large portions as possible, the limiting feature being the possibility of shipping it to its destination. In many cases it has been necessary to ship large objects by roundabout routes on account of an old-time small opening on the direct route. These dimension books give, first, the dimensions governing the size of the object that can be shipped over the entire system of the railroad, and, second, those of each division. As soon as the smallest of these openings is rebuilt and enlarged, a new dimension book is issued. These data are tabulated

* Standards and Rules, American Railways, Roadmaster and Foreman.

in three columns: First, "Height above top of rail"; second, the corresponding "width of lading on open cars must not exceed"; and, third, the location of this limiting point on the railroad. The distances in the first column vary by increments of 3 inches.

246. Track Clearances.—The principal clearance on double-, or more, track roads is the inter-track distance. The longer the car and the sharper the curve, the greater the required distance between tracks, fast Pullman trains requiring the greatest clearance. The distance between centers of tracks is 13 feet 0 inches on main line, and 12 feet 0 inches in yards, on the more important railroads, although less distances than these are in use.

It is the duty of the section foreman to see that no material is piled along the main track at a less distance than five feet from the nearest rail, and that it is piled in such manner that it cannot fall toward the track.

The clearances, both side and overhead, of all bridges and tunnels are governed by the standards of the railroad, the side clearance seldom being less than 4 feet 2 inches from gauge of rail, and the headroom less than 20 feet from the top of rail.

247. Bridge Warning.—When the clearance is not great enough to allow a man to stand on top of a freight car without danger of striking the overhead structure, 22 feet or more above the top of rail, bridge warnings are erected. For single-track railroads bridge warnings are built about as shown in Fig. 139, which consists of a post L M supporting an arm O *a* by means of the brace N P and the guy L *a*. The suspended parts consist of pieces of rope *b c* three feet long, which are suspended from the arm O *a* by heavy wires 2½ feet long. The ropes are six inches apart and cover a space eight feet wide, and project six inches below the level *e f* of the lowest part of the overhead structure. The warnings are placed about one hundred feet on each side of the structure, and the trainman must stoop immediately after the ropes strike him. The suspended ropes are designed so that they will hang in place and give certain warning without inflicting injury. When there are two tracks or more, posts are planted outside the tracks and an arrangement similar to the above is suspended over each track from a wire stretched between the posts.

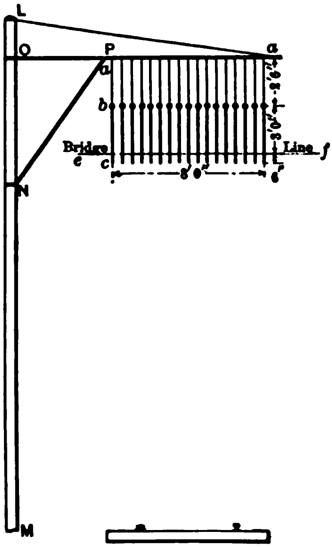


FIG. 139.

248. Telegraph Line.—A thoroughly maintained telegraph line is essential to the operation of a railroad. The telegraph line is either built and maintained by a company subject to agreement with the railroad, or by a special department of the railroad. When the width of right-of-way permits, the telegraph poles must be placed far enough from the track to prevent obstructing the track if blown down in a storm. The maintenance of the telegraph line is in charge of a foreman and a gang of experienced men who make all repairs, trim branches of trees so that they cannot strike the wires, and keep the line in good working order.

It is the duty of the section gang to pay strict attention to the telegraph wires, make any small repairs within their ability, and to report all defects promptly to the proper authority.

Telegraph poles are numbered consecutively by large, clear, painted numbers. The numbering is always according to some system by which the location of the pole is known from the number, and furnishes one of the best methods of locating a particular point in the track.

249. Bridge Watchman.*—Bridges should be inspected after the passage of each train, and at shorter intervals if trains are too far apart. A supply of water must be kept on the bridge, and the watchman should follow each train and be prepared to extinguish fire promptly. Hot cinders are constantly falling from the engine and form a constant source of danger to all frame track structures. The piers and abutments should be kept clean, and all combustible material removed to a safe distance from the bridge. The watchman should frequently examine all the timber and ironwork of the bridge and report promptly any decay or defect. He should also note the speed of passing trains and report any violation of the speed limit, and also prevent all unauthorized persons from crossing the bridge. When the bridge watchman is not occupied with the above

* Roadmaster and Foreman.

duties, he is kept busy at such other duties as the section foreman may direct.

250. Policing.—Policing is a term used by railroad men to express the keeping of the right-of-way in good order, and consists in keeping the grass and weeds cut, ditches in good shape, and material piled in the proper manner. Section foremen are responsible for keeping everything between the right-of-way fences, including thc fences themselves, in proper shape and condition. All old cross-ties taken from the track must be gathered daily, if practicable, and piled or disposed of in such manner as directed by the supervisor, and may be used for fence-posts, firewood, or burned, depending upon their condition. All old bolts, nuts, spikes, and similar material dropping from cars should be collected and removed to the tool house.

After grass and weeds have been cut they should be raked together and burned. Whenever fires occur on the tracks or adjoining grounds, they must be promptly extinguished, and if caused by a locomotive, the number of the train must be reported to the supervisor.

To sum up, the foreman must see that everything on his section is up to regulations, in good condition, and presents a neat appearance.

Article XXIII.

TRACK INSPECTION.

251. The Supervisor.—The duties of the supervisor, or roadmaster, may be divided into two classes, viz., office and inspection work. The office work to a great extent consists of details of a recurring nature, and there should be an experienced office force to handle them. The office force should be in charge of an experienced clerk, thoroughly familiar with all the details of the track work of a subdivision, and the routine office work should be handled in such a manner that the supervisor, while thoroughly familiar with what is taking place in the office, should be compelled to give personal attention only to the larger and more important matters, and the facts in these should be prepared by the office force in such a manner that the supervisor can dispose of them intelligently in the shortest possible time. This arrangement will allow the supervisor to be out on his subdivision the greater part of the time, and give him the opportunity to keep thoroughly posted as to the condition of his subdivision by actual observation. There is no universal rule governing the actual number of times the supervisor must inspect his division, except that he must get over his division often enough to be thoroughly familiar with the condition of all parts of it at all times.

252. Inspection by the Supervisor.—The supervisor may obtain data as to the condition of the track by riding on the engine of a fast train, by riding on the rear car of a train, and by walking over the line. It is necessary to inspect in all three of these ways in order to get the best results.

The most important method of inspection is by walking over the line, the section foreman accompanying the supervisor over his own section. This gives the supervisor a chance to become thoroughly familiar with every foot of the track, to become thoroughly acquainted with the foreman and familiar with his method of work. It also gives opportunity to give detail instruction to the foreman and to make any necessary changes in his methods, with the result that the amount of work done will be increased and the grade of the work will be improved.

When the track has been inspected and defects remedied as far as can be seen, it is customary for the supervisor to make a trip over his division on the engine of a fast passenger train, the degree of smoothness with which the engine rides being the principal test as to the condition of the track. The location and probable nature of a defect are noted, and steps taken to remedy the defect.

Inspecting the track from the rear car of a train is the easiest method, and is the best way to form an idea of the general appearance of the right-of-way and to make a casual inspection, but care must be taken that too much dependence is not placed in this method on account of the ease with which it can be done. If there is not time to walk over the line, it is better to make the trip on a track velocipede. The more walking done by the supervisor, the better the discipline and work of the section gangs, particularly if the men do not know just when he will be along. All workmen keep their eye on the "boss," and the more they see him, the better they will work.

253. Details of Inspection.—"Roadmaster and Foreman" divide track inspection into five classes and ten parts as follows:

Class A:	1,	Alinement.
	2,	Surface.
Class B:	3,	Joints.
	4,	Spikes.
Class C:	5,	Switches.
	6,	Frogs.
Class D:	7,	Ballast.
	8,	Sleepers.
Class E:	9,	Ditches.
	10,	Cleanliness.

254. Alinement and Surface.—On tangents the rails should lie in perfectly straight lines as projected on a horizontal plane, or sighted by a plumb line, and symmetrically located with respect to the center line markers; and on curves the rails should be concentric with the curve indicated by the center line markers and symmetrically placed with respect to the markers. Foremen have no trouble in alining track on tangent and a uniform grade, but they must pay strict attention to the center line markers both in hollows and on humps where the grade breaks. At the P. C. and P. T. of a simple curve trackmen almost invariably and unconsciously form a short transition curve in endeavoring to prevent the change from tangent to curve or vice versâ from appearing abrupt; nothing but a well-marked center line will prevent this from becoming excessive.

Track is said to be in true surface when the top of the rail forms a straight line on tangents when projected on a vertical plane, and has the proper curvature on easement curves, and when the corresponding point on the companion rail of the track has the same elevation on tangent, or the proper difference of elevation on curves.

255. Joints and Spikes.—The splice-bars, rails, and bolts should be kept screwed up so that the joint can be kept in alinement and surface the same as the rest of the track; and the proper space should be maintained between the ends of rails so that the track will neither be pushed out of line in hot weather nor leave a space that will cause the joint to be pounded out of surface in cold weather.

At least one spike is required on each side of the rail on every tie, and joints should be double spiked. Spikes should hold the rail firmly against the tie and should be kept driven down so that no movement between the tie and rail can occur. If the spikes become loose, additional spikes should be driven.

256. Switches and Frogs.—Switches should receive constant attention, and all parts kept in proper condition and adjustment. The headblocks should be tamped firm, the switch stand in thorough working condition, and the target painted. Damaged parts should be replaced before they cause injury to adjacent parts.

Frogs are the most costly and most vulnerable part of a switch, and must be made to last as long as possible, but must be replaced as soon as they are unfit for the service required; this does not mean that they are totally unfit for use, as a frog that is unfit for main track may be plenty good enough for yard use, where it will not have to stand much service.

257. Ballast, Sleepers, Ditches, and Cleanliness.—Ballast, ditches, and cleanliness, or policing, have been discussed in previous articles. Sleepers, or ties, are spaced and lined according to the rules of the individual railroad. It is claimed that they will wear best if sorted and laid in uniform sizes. Decayed and badly cut ties should be promptly removed. Even where ties are of uniform size and apparently similar in all respects, some will wear out considerably before others even when laid in the same stretch of track.

258. General Inspection.—It is customary, particularly on Eastern railroads, to have an "annual inspection," when the principal officers of the road inspect the entire system. Prizes are awarded to the division, subdivision, and section having the best track, attention being paid to all the principal points in ¶ 253. Efforts are made by every supervisor and foreman to have the best piece of track, the winners not only receiving a cash prize, but a far greater benefit from the increased chances of promotion.

CHAPTER VII.

RAILROAD CONSTRUCTION.

Article XXIV.

THE ENGINEER CORPS.

259. The Preliminary and Location Corps.—On preliminary and location the field engineer corps is composed of three parties, viz., the transit, level, and topography party, all in charge of the assistant engineer. The transit party consists of the transitman, head-chainman, back- (or rear-) chainman, one or more axemen, and the back-flagman. The level party consists of the levelman and level-rodman; and the topography party consists of the topographer and two tapemen. The relative rank of the members of the party is well established for all but the topographer, and, leaving out the topographer, they rank in the following order: (1) assistant engineer; (2) transit man; (3) level man. The relative rank of the topographer depends upon the notions of the chief engineer. By some chief engineers the topographer is made practically independent of the rest of the field corps and reports directly to the office, and in other instances may rank anywhere from just below the assistant engineer to junior to the levelman. In all well-regulated field corps, in addition to the assistant engineer, the transitman, levelman, and topographer should be theoretically trained engineers; and in many cases the head-chainman and level-rodman are young graduates, thus giving a party that will never be at a loss for instrument-men.

260. The Residency.—The line to be built is divided into sections from about six to twelve miles in length, depending upon whether the work is heavy or light, and these sections are called *residencies*. The name probably comes from the fact that each of the sections is in charge of a corps of engineers who reside on the work. The resident corps, commonly called *residency party*, consists of three or more men, the chief of whom is universally called the *resident engineer;* the titles of the balance of the party are, however, subject to considerable variation, as shown in the following arrangement of parties:

Resident Engineer	Resident Engineer	Resident Engineer
Transitman	Assistant Engineer	Instrument-man
Levelman	Rodman	Axeman
Rodman	Axeman	

The size of the party depends upon the nature of the work and the custom of the railroad, but they all agree in having at least two men who can handle instruments. In addition to the above members, an *inspector* is added when there is masonry of importance to be built.

The residency headquarters should be on the line, and where accommodations cannot otherwise be obtained, a camp, more or less temporary in construction, must be maintained. The headquarters should not only contain living quarters for the engineers, but also a complete office outfit.

Other things being equal, the residency headquarters should be located near the center of the residency, so that all parts of the work may be reached in the shortest possible time; but in some cases it will be more convenient to locate it at one end of the residency, in order to be more accessible from division headquarters.

261. Duties of the Residency Party.—As soon as the residency party is appointed and located it must secure complete notes of the survey of their part of the line, including a copy of the transit and level notes, and the map. There should be a copy of the profile for each instrument-man and one for the office. The line must be referenced as described in ¶ 262 before any grading is done. The referencing is usually done by the location party, but it may be necessary for the residency party to reference additional points.

After the residency headquarters is fixed up and the copy of the necessary data obtained, the first work of the party is the setting of slope-stakes. Slope-stakes are necessary before any excavation work can be done. As the first duty of the contractor is to clear and grub the right-of-way, it is usually possible to set the slope-stakes on the parts of the line that are comparatively clear, and slope-stake the balance of the line after the clearing and grubbing have been finished.

262. Referencing the Final Location.—After all necessary lines have been run, topography taken, the line adjusted in every detail, the line that is shown to be the best possible through the territory in question is adopted and called the final location, the line being rerun to take out all *equations* and give continuous stations. The last field work to be done by the location party is to thoroughly reference all the principal *hubs*, or transit points, on the line. This is necessary in order to relocate the line in either of the two following cases: (1) in case construction should not follow immediately after location, and the line be partly obliterated; or (2) in order to replace the line when part of it has been dug up or covered over in the course of construction.

In some cases it requires considerable ingenuity on the part of the instrument-man to reference a point so that the point may be relocated. In Fig. 140 is shown one

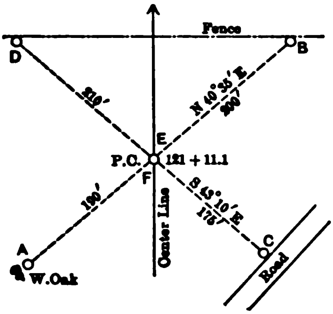


FIG. 140.

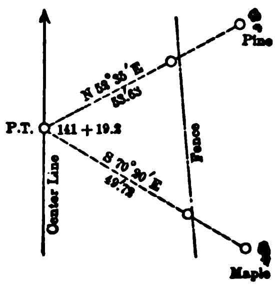


FIG. 141.

of the most complete methods of referencing a point, the point being the P. C. sta. 121 + 11.1, the line running in the direction indicated by the arrow. The lines A B and D C should cross each other at an angle as near 90 degrees as possible, which gives the most definite intersection. The points A, B, C, and D must be placed so that they are in no danger of being knocked out, so that the transit can be set up over at least one point on each line, and also so that they can be readily found, properly marked guard stakes being set near them, and notches cut in the fence. The bearings and distances are taken, as they may aid considerably in relocating a point, particularly if the survey is old.

263. To Relocate a Point.—Suppose we have the notes and sketch in Fig. 140 and the point 121 + 11.1 has been destroyed; the general method of relocating it would be as follows: By means of the sketch and data the points A, B, C, and D are located; set the transit up over B, sight to A, and place stakes and tacks at E and F on each side of the line D C, then set up at C and sight to D, locating the point O where the line of sight C D crosses a string stretched between E and F; this intersection will be the required point 121 + 11.1.

Another method of referencing is shown in Fig. 141. One of the most important points to keep in mind in all work of this kind is to take notes as complete as possible. It only takes a few minutes' additional time to read the magnetic bearings and make a complete sketch, but poor notes may cause the loss of a much greater length of time in relocating.

264. Slope-stakes and Cross-sections.—Slope-stakes are stakes set at the points where the slopes of the cut or fill cut the original ground surface. Cross-sections record the differences of elevation of the ground surface at corresponding distances out from the center line and normal to the center line. If the cross-sections are taken in order to determine the difference in the amounts of cut and fill in a proposed shift of the line, the length of the cross-section is determined by the distance the line may be shifted. If the line is finally located, the slope-stakes may be set and the cross-section taken at the same time, and if the slopes are uniform from the center stake to each of the slope-stakes, no intermediate cross-section notes are necessary in order to plot the cross-section. In Table XX is shown a convenient method of keeping slope-stake and cross-section notes in a transit book. The cross-section notes should be plotted in a cross-section book made of cross-section paper, with ten divisions to the inch. In Fig. 142 is shown the cross-section of sta. 183 as it appears in the cross-section book. The areas and volumes are also recorded in the cross-section book, with the corresponding cross-sections.

TABLE XX.

Sta.	Ground.	Grade	End Areas, Sq. Ft.	Cut, Cu. Yds.	Fill, Cu. Yds.	L	C	R
183	388.5	381.8	173.8	488.5		$\frac{+5.7}{14.7}$ $\frac{+6.1}{9.0}$	+6.7	$\frac{+7.8}{9.0}$ $\frac{+8.6}{17.6}$
182	387.4	381.3	90.0			$\frac{+2.9}{11.9}$	+6.1	$\frac{+6.1}{15.1}$

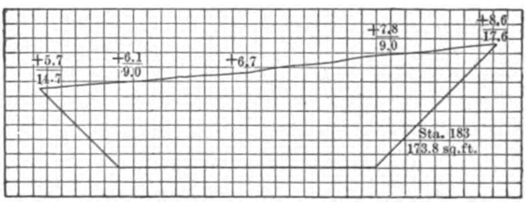


FIG. 142.

Cross-sections are designated according to the number of elevations it is necessary to take in order to show the irregularity of the ground, viz., if the ground is level, it is called a *level section;* if the ground sloped uniformly from c to l and from c to r, Fig. 143, it would only be necessary to record levels at c, l, and r, and it would be called a *three-level* section. The section in Fig. 142 is called a *five-level* section.

265. Setting Slope-stakes.—Slope-stakes are set at l and r, Fig. 143, in order to show the distance from

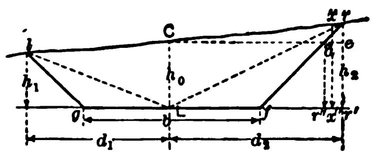


FIG. 143.

the center stake C at which the grading commences The method of setting slope-stakes can be shown in five minutes in the field and in an hour a party of green men can make good progress, but it is an almost hopeless task to make a clear explanation in writing. The man in charge of the slope-stake party must have a copy of the profile in order to get his elevations, and must know the width of subgrade and the side-slopes. In Fig. 143 is a single-track cut, the width of base b being 18 feet and the earth side-slopes 1 to 1, and it is required to locate the slope-stakes l and r. From the profile we have the elevation of C given as 388.5 and L as 381.8. Since the slope is 1 to 1, $fr'' = a\ r''$;

if the ground were level, the slope-stake would be at a, where $C\,a = L\,f + f\,r'' = L\,f + a\,r''$; but the ground rises from C towards r, $r\,r'$ is greater than $a\,r''$ and C L, and a trial point must be taken at some point x farther out from C. The point x is found to be 8.0 feet above L, therefore $L\,x''$ should equal $L\,f + f\,x''$, or $9.0 + 8.0 = 17.0$ feet, but measurement shows x to be only 16.7 feet out, consequently points farther out must be tried until a point is found where the computed and measured distances agree within 0.1 of a foot. In this case it was found at 17.6 feet out, where the difference in level between L and r was 8.6 feet, Fig. 142. *Slope-stakes can only be set by trial*, as above, and all attempts to place the simple computations into the shape of formulas simply help to muddle the beginner.

266. Computation of Cross-section Areas.—The area of a level section is obtained from a table by knowing the center cut or fill. The area of an irregular section such as shown in Fig. 142, is found by drawing vertical lines which divide the section into triangles and trapezoids the areas of which are computed from the dimensions found in the cross-section notes as recorded in Table XX, the method being very simple when the section is plotted on cross-section paper.

In the three-level section in Fig. 143, let the center height be h_0, and the side heights be h_1 and h_2, and d_1 and d_2 be the distances out of the slope-stakes l and r respectively; the area of the triangle $C\,l\,L$ is $\frac{1}{2}\,h_0 \times d_1$, the area of the triangle $C\,r\,L$ is $\frac{1}{2}\,h_0 \times d_2$, the area of $L\,l\,g$ is $\frac{1}{2}\,b \times \frac{1}{2}\,h_1$, and the area of $L\,r\,f$ is

$\frac{1}{2}b \times \frac{1}{2}h_2$; the area of the cross-section is the sum of the areas of these four triangles, or

$$A = \tfrac{1}{2}h_0 \cdot d_1 + \tfrac{1}{2}h_0 \cdot d_2 + \tfrac{1}{2}b \cdot \tfrac{1}{2}h_1 + \tfrac{1}{2}b \cdot \tfrac{1}{2}h_2, \text{ or}$$

$$A = \tfrac{1}{2}h_0(d_1 + d_2) + \tfrac{1}{4}b(h_1 + h_2) \quad (103)$$

From which we have the following rule:

The area of a three-level section is equal to the product of the center height times one-half the sum of the distances out, plus the product of one-half the base times one-half the sum of the side heights.

The advantage of this rule is that all the data excepting the width of roadbed are recorded in the cross-section notes as shown in Table XX, sta. 182, the center height h_0 being 6.1, the side heights being 2.9 and 6.1, and the distances out being 11.9 and 15.1.

267. Clearing and Grubbing.—The contractor is required to cut all timber on the entire width of the right-of-way and grub out the stumps for the specified width before any other work is done on the wooded portion of the line. The logs and stumps must be moved completely off the right-of-way or burned before any filling is done by the contractor, excepting when the timber is worth saving it may be piled on a part of the right-of-way where there is no danger of the logs getting into the fill, when the Resident Engineer gives special orders to that effect. In some cases on flat ground where the stumps are not too close together and the tops of the stumps are at least two feet below subgrade, they are not grubbed up. In all cases all loose stumps must be destroyed immediately. When the material in a cut must be excavated in a manner that does not first require the grubbing of the stumps and it is more economical to leave them until the excavation is made, great care must be taken by the residency party to see that the stumps do not get into the fill.

268. Situation Plans.—Plans for all openings larger than a box culvert, where masonry is to be used, are usually worked up at division headquarters. In order to supply the necessary data for this purpose the residency party must, as soon as practicable, make up situation plans and forward them to headquarters. If, for instance, a situation plan is to be made for a bridge over a stream, a topographical map of the ground and stream covered by the bridge abutments and piers is drawn to a scale of 20 feet to 1 inch, showing the elevation of the banks and of the bottom of the stream by one-foot contours, and also the depth to solid rock at points where piers and abutments are to be built. If the bridge is too long to show to this scale, a plan showing the general outline and data may be drawn to a scale of 50 or 100 feet to 1 inch, and a situation plan made for the site of each abutment and pier to the scale of 20 or possibly 10 feet to 1 inch. With the aid of the situation plan the detail plans for the construction of the masonry can be drawn. These plans are sent to the resident engineer, who stakes them out, and through his inspector supervises the work.

269. Monthly Estimates.—It is the duty of the residency party to furnish monthly estimates of the work completed at the time of taking the estimate. The measurements are made as close to the end of the month

TABLE

RAILROAD..........

Resident Engineer's Monthly Estimate

Clearing and Grubbing. Miles.				Earth Excavation.—Cu. Yds.				Loose Rock Cubic	
Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

First-class Masonry—Cubic Yards.				Second-class Masonry—Cubic Yards.				Culvert Cubic	
Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

Piling—Lineal Feet.				Foundation Timber—1000 Ft B. M.				Trestle Tim- 1000	
Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

XXI.

..........BRANCH

No......., Section No......., ...191..

EXCAVATION—Yards.		SOLID ROCK EXCAVATION—Cubic Yards.				EMBANKMENT—Cubic Yards			
Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

MASONRY—Yards.		PAVING—Cubic Yards.							
Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

BER Ft. B. M.									
Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month	Station.	Total to Date.	Last Estimate.	Est. for Month
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

....Resident Engineer.

as possible, and must be forwarded to division headquarters not later than the last day of the month. In order to furnish these estimates cross-sections must be

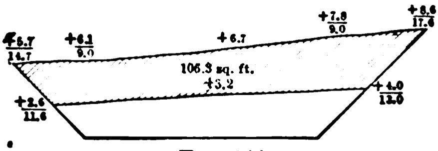


FIG. 144.

run over all the line where work is in progress. After the slope-stakes are set the notes are plotted in the book especially designed for the purpose (¶ 264). When the monthly cross-sections are taken, they are plotted over the original section at that point, and the area of the excavated shaded portion in Fig. 144 is determined, and from these areas the total amount excavated is computed. The portion of the line where embankments are being made is measured and plotted in the same way. The last estimate, minus the previous monthly estimate, gives the number of cubic yards of material excavated or filled during the month, and forms the basis upon which a part payment, 85 or 90 per cent., is made to the contractor. Monthly estimates are made on all work done by the contractor—clearing and grubbing, excavation, masonry, trestling completed, and borrow. Overhaul is usually left until a portion of the line is completed. The blank form of monthly report is shown in Table XXI.

270. Progress Profiles.—As soon as the monthly estimates are finished, the residency party plots up two progress profiles, one for their own information and one for division headquarters, the latter being sent back and forth for the purpose. The general idea of a progress profile is shown in Fig. 145. The portion A excavated

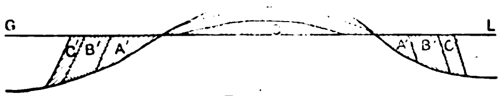


Fig. 145.

in the first month is deposited in the embankments A′, for the second month from B to B′, and so on, until the cut is finished. Information as to the state of completeness of all other work, such as culverts, etc., is also placed on the progress profile. The progress profile enables the engineer to judge whether or not the work is being pushed at a rate that will finish it within the specified time. If it shows the contractor to be too slow in his method of working, the contractor is ordered to put on more force. The work done in each month is shown by tinting that portion of the profile with a color corresponding to the month; as, for example, the following:

January	Cobalt Blue
February	Vermilion
March	Chrome Yellow
April	Venetian Red
May	Sepia
June	Olive Green
July	Van Dyke Brown
August	Antwerp Blue
September	Chrome Orange
October	Payne's Gray
November	Scarlet Lake
December	Burnt Sienna

The progress profile gives the quickest and surest way of estimating the condition of the work at any particular time.

CHAPTER VIII.

THE SUBGRADE.

ARTICLE XXV.

ROADBED IN FILLS.

271. The Subgrade.—The permanent way of the railroad consists of the foundation, the ballast, and the track. The foundation consists of the cuts, embankments, trestles, bridges, etc. The finished surface of the foundation is called the subgrade, being the surface upon which the ballast is to rest. This surface, often called the *roadbed*, consists of the bottom of the cuts and the tops of the fills, and is finished so that its plane is parallel to and a certain distance below the plane of the base of the rail. The cuts and fills are often referred to as the *grading*. The term grading is more appropriate while the work of excavating and filling is going on. The main function of the subgrade is to support the ballast which supports the ties, rails, and trains. In order to have a good track the subgrade must be of a character that will not hold water, and be of such shape that the water will run off its surface readily. If the fills have been properly made, no stumps, logs, etc., having been placed in the fills, and their surfaces properly shaped, they will always give a good support to the ballast. If poor material has been allowed to be placed in the fill and wet spots develop, these spots must be attended to before the ballast is placed on it. This can often be done by dumping the proper material in the place, the mixture making a good material. Sometimes it is necessary to excavate all the poor material and replace it with good material.

The roadbed must sustain not only the weight brought upon it, but also the forces of nature, such as frost and erosion. Despite this fact, very often very little care or forethought is given to the formation of an embankment. The material cheapest to handle is dumped or dragged

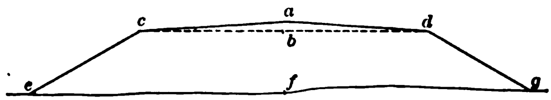


FIG. 146.

into the fill in the quickest and easiest way possible, with the result that the embankment will settle or cause trouble long after it should have attained a stable condition.

272. Shape of Subgrade.—The stakes *f*, Fig. 146, on the center line are set when the final location is run; before any grading is done the slope stakes *e* and *g* are set at right angles to the center line on tangents and radially on curves. After an embankment has settled it is dressed to a true shape, the tops of slope *c* and *d* are made sharp and true, and the lines through these points are straight and parallel to the center line, the slopes *e c* and *d g* are trimmed to a uniform surface, and the subgrade *c a d* is also made uniform and even. When the embankment is trimmed as described above, it makes an excellent appearance, and the extra work necessary to so finish it is not great.

Usually the top of the subgrade is finished perfectly flat, but it is a grave mistake to do so, as water falling upon it will not run off, but will soak in, causing the ballast to settle into the subgrade, necessitating extra expense in maintaining the track in surface and alignment, and in some cases causing sections of the embankment to slide down the slope. The top of the subgrade should always slope away from the center *a*, as shown in Fig. 146. The slope *a d* should not be less than ¼ inch in 1 foot, giving a rise *a b* of 2 inches for an embankment 16 feet wide. In some cases this slope is made 1 inch in 1 foot, making *a b* 8 inches. A sufficient slope will cause all rain water to run off immediately, and after a crust has formed practically no water will soak into the embankment.

273. Classification of Railways.—The A. R. E. A. classifies railways into three classes as follows:

"Class A includes all districts of a railway having more than one main track, or those districts of a railway having a single main track with a traffic that equals or exceeds the following:

"Freight car mileage passing over district per year per mile, 150,000; or, Passenger car mileage per year per mile of district, 10,000; with maximum speed of passenger trains of 50 miles per hour.

"Class B includes all districts of a railway having a single main track with a traffic that is less than the minimum prescribed for class A, and that equals or exceeds the following:

"Freight car mileage passing over district per year per mile, 50,000; or passenger car mileage per year per mile of district, 5,000; with maximum speed of passenger trains of 40 miles per hour."

"Class C includes all districts of a railway not meeting the traffic requirements of Classes A or B."

274. Width of Embankments.—The width of a railway embankment depends upon the depth of ballast

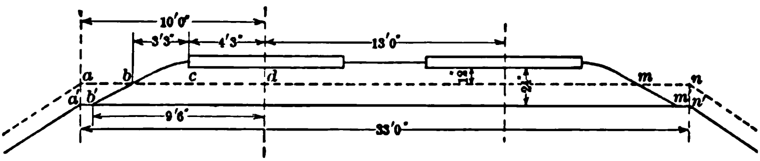


Fig. 147.

and the class of track. In Class A, double track, the width of embankment is usually 33 feet, and single track is 20 feet wide. In Class B the width of embankment is usually 16 feet, and in Class C it is 14 feet.

In Fig. 147 the subgrade and the cross-section of the ballast for a Class A track are shown. The minimum depth of ballast allowed on a Class A track is 12 inches below the bottom of the tie, and it has been found that under very heavy traffic it is better to have 24 inches of stone ballast between the bottom of the tie and the subgrade. In Fig. 147 *a n* shows the subgrade for 12 inches of ballast, and that the shoulders *a b* and *m n* are 2′–6″ wide on a 33-foot roadbed: the line *a′ n′* shows the subgrade for 24 inches of ballast and the shoulders $a' b'$ and $m' n'$ are only 6 inches wide.

In Fig. 148 $a\,n$ shows the 14-foot roadbed and the cross-section of 6 inches of ballast below the tie, the shoulders $a\,b$ and $m\,n$ being 15 inches wide: If the traffic of this Class C track increased to Class B, it would be necessary to widen the roadbed before 12 inches of ballast could be placed.

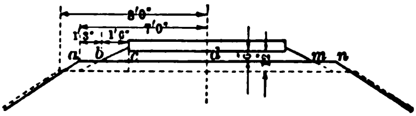


FIG. 148.

The effect of having built the subgrade too narrow is frequently seen, and in many cases ballast has been wasted down the slopes of the fill.

The usual slope in fill is 1 on 1½; rock may run a little less, and clay a little more. Only in exceptional cases is a fill made of one uniform material, consequently slope-stakes are set for the above slope.

275. Side-hill Fill.—When a fill is made on a steep hillside, care must be taken to prevent the fill from sliding both at the time it is made and later. The original surface should be roughened up and all leaves, soil, etc., removed, so that the new material will thoroughly bond with the original surface in order to prevent a distinct cleavage between the two, it being necessary in some cases to cut rough steps, as shown in Fig. 149. All stumps should be grubbed out; otherwise

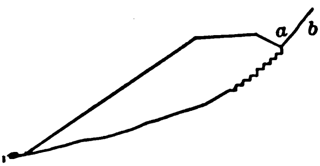


FIG. 149.

after they decay the embankment is liable to slip down. A berm ditch should be constructed at *b*, Fig. 149, so that the least possible amount of water reaches the toe of slope *a* and soaks along the old surface, thus causing the fill to slip. In considering the above precautions a little time may be lost and some extra expense incurred, but it will be practically nothing compared to the time and money lost by a slip after the track is laid and in operation.

Article XXVI.

ROADBED IN CUTS.

276. Roadbed in Cuts.—The roadbed in cuts is made at least 4 feet wider than fills, in order to allow for a ditch on each side. It is more of a problem to design a properly shaped cross-section in cut than in fill. If the cut is short, the amount of water that falls on the slide slopes and the roadbed will be small and the ditch that can be placed in the additional width of 2 feet on each side will be ample to take care of it. If the cut is long and deep, the ditches must be made larger, particularly toward the lower end of the cut. If the cutting is in rock, there will be no trouble, provided it is taken out deep enough to allow for ballast. If the cutting is in earth, care must be taken to provide a dry subgrade; this can be done by the methods given for fills in ¶ 271, and by subdrainage. These methods are more liable to be necessary in cuts than in fills. A common source of trouble in cuts is due to springs which keep the subgrade soft and in poor shape. Springs must be drained off off by means of subdrains, or some method that will prevent them from interfering with the formation of a dry and firm roadbed. This will be discussed later under the headings berm ditches and ditches.

277. Cross-section of Cuts.—The width of roadbed in cuts varies from 18 to 24 feet for single-track, and

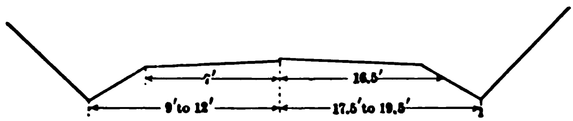


FIG. 150.

from 35 to 39 feet for double-track. In Fig. 150 is shown the shape of cross-sections in cut in use on some roads, the dimensions to the right being for double-track, and the left for single track. The main part of the roadbed has a slope of ½ inch in 1 foot and then a slope of 4 to 6 inches in 1 foot into the ditch. The side slopes of the cut should be the same as the angle of repose of the material. The usual earth slope in cut is 1 on 1, and in solid rock 4 on 1. If the earth is unstable, it is sometimes necessary to have side slopes of 1 on 1½ or even 1 on 2.

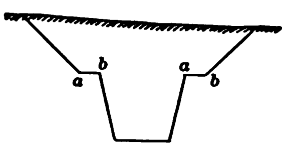


FIG. 151.

If the cut is through both earth and solid rock, the cross-section is as shown in Fig. 151, the earth and rock having the usual slopes, and there should be a berm *a b* at least 4 feet wide at the top of the rock, to insure that no earth will slide on the track, and also to allow for a berm ditch.

278. Side-hill Cuts.—When the slope upon which a side-hill cut is located is steep and part of the section is in fill, great care must be taken in order to prevent the fill from slipping. The same precautions are necessary as in a side-hill fill, ¶ 275. In Fig. 152 is shown a section in cut and fill, the center line stake being at C, A being the cut and B the fill. In many cases it is necessary to place a wall E of dry rubble or a crib-work in order to hold the fill, and it is frequently found necessary to shift the line so that all or a greater part of the section is in cut, particularly if the line is along a stream and high water is liable to reach the toe of slope, both on account of the danger of part of the slope being washed away and also on account of the fill being unstable when wet. A slope of this kind is usually protected by means of rip-rapping with large pieces of rock.

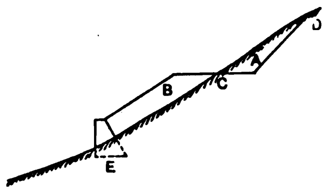


Fig. 152.

ARTICLE XXVII.

DITCHES.

279. Function of Ditches.—Properly constructed and located ditches and drainage are absolutely essential for the proper maintenance of roadbed and track. When the roadbed is free from water, the track can be kept in true surface and line with much less expense. The danger of the upheaval of the track by frost is also avoided. Proper ditches and drainage are economical because they make the track safer and greatly lessen the cost of maintaining the track. Ditches should be considered a part of the original construction of the road and made at the same time, and in some cases before the cuts and fills are made. It is more economical to keep the water out of earthwork than it is to delay the digging of ditches until after the earthwork has been even partially saturated. It takes constant care on the part of the track gang to keep ditches clear and in good shape.

280. Ditches in Cuts.—In cuts the ditches must carry the water that falls upon the slopes and the roadbed. When a cut is short and the grade slopes both ways from the center of the cut, ditches shaped as in Fig. 150 will be ample. The size of a ditch depends upon the area drained and the material in the cut. They must be large enough to carry off the heaviest rainfall and prevent the water in the ditch from rising to the height of the lowest part of the ballast. If the material in the cut is liable to erode easily, it will be necessary to pave the ditch. If the cut is long, a ditch several feet deep may be needed toward the end of the cut, and it may be necessary to protect it with stonework to keep it from washing out, and also to deflect the water so that it will not affect the adjacent fill.

281. Berm Ditch and Slope of Ditches.—It is important that no more water should run down a slope than actually falls on the slope. In order to prevent this it is customary to dig a *berm ditch* on the higher side of the cut, as shown at D in Fig. 152. The berm ditch intercepts all water coming down the hillside and prevents it from running down the slope of the cut. If this water were allowed to run down the slope of the cut, it would certainly wash gullies in the slope and obstruct the track ditches with the eroded material, and might even wash material on the track, necessitating constant vigilance to prevent wrecking a train. There would also be danger of landslides.

282. Ditches along Fills.—Ditches are necessary along fills, particularly to take care of the water from the adjacent cut. On the upstream side of fills there is a tendency of the water to run toward the fill and strike the bottom of the fill and then run along the toe of slope until it reaches the culvert. This tendency should be prevented by a suitable ditch, otherwise the water will have a tendency to seep under the embankment along the original ground surface, which may cause trouble, and, in addition, if the volume of water is considerable, it will wash the toe of slope. Suitable ditches should therefore be constructed parallel to the toe of slope, leaving a berm of sufficient width, and running from the cut on each end of the fill to the culvert or other opening through the fill.

ARTICLE XXVIII.

CUTS AND FILLS.

283. Definitions.—*Cut*, or *excavation*, is the term applied to the material above the grade line G L, Figs. 145, 156, 157, and 158, which must be removed in order to form the roadbed of the railroad.

Fill, or *embankment*, is the term applied to the material that must be deposited in the hollows below the grade line in order to form the roadbed, or subgrade.

When the material is excavated from the cut, it is carried each way from the center of the cut and deposited in the adjacent fills. When the cut is not sufficient to complete the fills, it is necessary to obtain additional material for the purpose, and this additional material is called *borrow*. If the cuts should give more material than is required to complete the fills, the excess material is called *waste*.

The line G L, Fig. 145, drawn on the profile representing the elevation and longitudinal slope of the finished roadbed, is called the *grade*, or *gradient*, grade being used in the United States and gradient in England. In a finished track the grade line represents the elevation of the base of rail, or top of tie, but during construction the grade line on the profile should really be called the subgrade line, since it represents the elevation to which the subgrade is to be built, as is the case with the line G L in Figs. 145, 156, 157, 158, and others. Grades are expressed in percentage of rise and fall; if a grade rises 0.3 foot in 100 feet, it is called a + 0.3 per cent. grade, and if it falls 0.5 foot in 100 feet, it is called a − 0.5 per cent. grade.

The *subgrade* is the top of the foundation upon which the ballast rests, and is the surface represented on the profile by a line parallel to and a certain distance below the grade line. The distance between the grade and the subgrade is governed by the depth of ballast that is to be used, and may vary from 7 inches, the thickness of a tie, to 2 feet 7 inches, the greatest depth of ballast that is likely to be used; this distance between the grade and the subgrade must be decided before any construction work is done. The main duty of the residency engineers is to see that the excavations and embankments are made in the proper manner and finished to the proper surface together with all masonry, etc., necessary thereto, and to furnish an accurate estimate of the quantities and cost.

284. **Classification.**—Contracts for the completion of the subgrade are let in three ways, viz., (1) without classification; (2) with classification; and (3) by force account. In a minority of cases work is let without classification. This consists in agreeing on a fixed price per cubic yard of excavation for all the excavation on the line, no variation in price being made for different kinds of material. The contractor goes over the line, examines the material, and with the aid of a profile that is furnished him estimates the average price at which he can complete the work at a profit and at the same time bid lower than competing contractors. A very small percentage of railroad work has been done in this way, owing to the great uncertainty and chance of loss, but with improved excavating machinery and outfit it is probable that a greater percentage of railroad work will be done in this way in the future, particularly where the new line lies near other work that has been completed and a fairly accurate estimate of the cost can be made.

When work is let with classification, it is divided into three and sometimes four classes, viz., earth, loose rock, and solid rock, or earth, hardpan, loose rock, and solid rock, the contractor agreeing to do each class of excavation at a specified price per cubic yard, the amount of each class of material being measured as it is excavated.

285. Earth.—Each railroad has its own arbitrary rules for dividing the excavated material into the different classes, and the classification on some railroads varies materially from the classification on other railroads, but this causes no hardship to the contractor because he is furnished a copy of the specifications before bidding.

Earth includes loam, clay, sand, gravel, decomposed rock and slate, and boulders not greater than one cubic foot. Earth is often defined as "any material that can be plowed by a two-horse plow and scraped," some railroads specifying a four-horse plow.

The principal operations in excavating earth are loosening, loading, hauling, and spreading. In addition to the men, teams, and implements necessary to do this, there are expenses due to keeping the roadway over which the material is hauled in repair, repairs to implements, etc., and superintendence. In ordinary earthy materials, if the fills are not too long, the cheapest method is to use plows to loosen the material, and drag- or wheel-scrapers to carry and spread it. The most expensive method is loading the material into wagons by hand and hauling it into the fills; this method is necessary when the haul is long.

Earth excavation usually costs from 15 to 20 cents per cubic yard. The cost of all excavation depends upon the amount of work to be done, because the first cost of the necessary outfit, or even of moving the outfit to the job, will be less in proportion the greater the amount of work to be done.

286. Hardpan.—Hardpan has been defined as "the more or less firmly consolidated detrital material which sometimes underlies a superficial covering of soil," and also as "any bed of mingled clay and sand or pebbles, if firmly compacted." It sometimes closely resembles conglomerate rock in general appearance. When material of this formation can be plowed with a four-horse plow, it is usually classed as earth; but when it cannot be plowed, it is classed either as hardpan or as loose rock, depending upon the specifications.

287. Loose Rock.—"Loose rock shall include shale, slate, coal, soft friable sandstone, cemented gravel, or conglomerate rock; stratified limestone in layers of six inches or less, separated by strata of clay; masses of boulders or detached rocks, free from earth, in which the average size of the boulders or detached rocks is not less than one cubic foot, nor more than one cubic yard; and masses of earth mixed with loose stone and boulders of one cubic foot or more average size, wherein the proportion of rock to the whole mass is more than one-half." The railroad that has the above specification does not have hardpan in its specifications, but the hardpan is covered by the phrase "cemented gravel."

288. Solid Rock.—Two specifications for solid rock are as follows: "Solid rock will include all rock in place, which rings under the hammer, in masses of more than one cubic yard, with the exception of stratified limestone described in the specifications for loose rock." And, "solid rock shall include all rock occurring in masses which, in the judgment of the engineer, may be best removed by blasting." It is very difficult to write a specification for solid rock which will fit all parts of a line without variation. In the first specification the clause "rings under the hammer" is very severe, and in the second specification the phrase "may be best removed by blasting" should never be used, as a judicious use of powder may assist materially in excavating any material, even some forms of earth. To classify rock equitably requires sound judgment on the part of the engineer, and is a pregnant cause of dispute between the engineer and the contractor.

Earth, loose rock, and solid rock are often found in the same cut, and the residency party is kept busy running cross-sections and resetting slope-stakes. In this case the cross-section of the finished cut will be as in Fig. 153, the slopes A E and B F being 1 on 1, or 1 on 1½, and G K and H L 4 on 1, depending upon the material. First, the slope-stakes A and B are set, the earth is cleared off to the loose rock C D, and the cross-section C D is run and the amount of earth computed; then the loose rock is removed down to the solid rock E F, the cross-section E F run, and the amount of loose rock computed; then the slope-stakes G and H are set, and

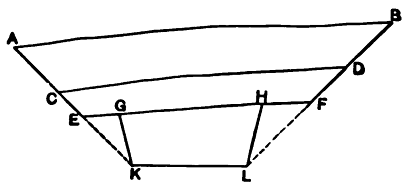


FIG. 153.

the solid rock excavated and computed. The berms E G and H F should be at least four feet wide.

289. Fills or Embankments.—Other things being equal, the grade is so placed on the profile that the cuts and fills balance, or just enough material is excavated to make the embankments. It is obligatory on the part of the contractor to excavate the cuts at the contracted price per cubic yard and haul the excavated material and make the fill without additional charge, provided the haul is not greater than a specified distance. The contractor must also place the material in the fill in the specified manner. This may be specified in any one of a number of ways, viz., spread the earth in layers and drive over it as much as possible, thus compacting it. Usually the contractor is allowed to dump the material into the fill in the manner most economical to him, provided, of course, there is no good reason to the contrary, and then add additional material, if necessary, after the embankment has settled.

290. Borrow and Waste.—As stated in ¶ 283, borrow is the term applied to the material necessary to finish the fill when the cut is insufficient. If there is rock in the excavations, it is usually more economical to borrow to make the fills, than it is to lower the grade line so that the cuts and fills will balance, particularly if earth borrow is convenient. As the contractor is paid only for excavation, there should be no waste except where absolutely unavoidable. Waste may be necessary in order to get the required grade and alinement over the line as a whole. Waste is usually deposited along the side of a fill, so that later it may be used for an additional track.

291. Borrow Pits.—A borrow pit is the hole from which borrow has been taken; it is staked out by the engineer and cross-sections taken over the ground before any borrow is taken out. The contractor is required to leave the pit as symmetrical as possible, so that its measurement will be simplified, and is paid for the number of cubic yards removed. In case of leaving an irregularly shaped hole difficult to measure, if the engineer so decides, the contractor may be compelled to accept the yardage found in the fill after settlement, thus losing the amount of shrinkage. If the cuts adjacent to the fill are earth, it may be specified that the borrow shall be made from the cuts, the additional width being used later for an additional track. Borrow pits, Fig. 154, are always located as near the embankment as possible to save haul; where they run parallel to the embankment, the top of the slope of the borrow pit B should not come closer to the toe of slope of the embankment A than 10 or 12 feet, and if the embankment is likely to be widened for another track, the berm A B should be wide enough to leave the 10 or 12 feet after the embankment has been widened.

292. Shrinkage.—When earth is excavated and dumped loosely, it makes, while in the loose state, a greater bulk than it occupied before excavation. But after it has settled and compacted it makes a less bulk, usually, than it occupied before excavation; this is termed *shrinkage*. Different earthy materials shrink by different amounts; some materials will make as much fill as they originally occupied, but on the average earth is considered to shrink 10 per cent. The length of time it takes earth to shrink the full amount (to a stable volume)

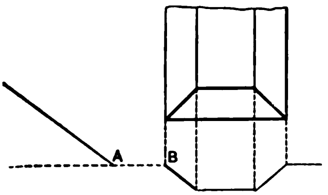


FIG. 154.

depends principally upon the amount of compacting it gets while being placed in the fill and the amount of water that gets into it while in a loose state. When embankments are made by dumping in loose material, they are usually made high enough to allow them to shrink the full amount and still be on grade, Fig. 155. The work is not accepted and measured by the engineer until, in his judgment, it has become solid. The railroad company is on the safe side in this matter, as the 10 or 15 per ct. of the estimate which is held back is not paid until the entire road is completed, and by that time all the fills have had sufficient time and rain to become solid.

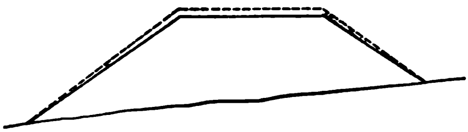


FIG. 155.

293. Swell of Rock.—Solid rock when evcavated and placed in a fill always increases in volume; the amount of increase of volume, or swell, depending upon the sizes into which it is broken. If stone is broken into small pieces of uniform size, the broken stone may contain as high as 50 per cent. of voids, or the original solid rock would make double the amount when placed in the fill. If the pieces vary in size, the percentage of voids will be less, so it seems reasonable to assume that solid rock will swell 40 per cent. It is very difficult in some cases to estimate the amount of fill a rock cut will make, particularly a side hill cut along a stream. The contractor is paid to make the excavation, and his endeavor is to get the material out of the cut in the quickest and easiest way, and it takes eternal vigilance on the part of the resident engineer to keep the contractor from blowing a large portion of the material into the stream by the use of excessive charges of powder. In some cases the contractor will deliberately blow the material away and make good the deficiency in the fill by borrow at his own expense, provided, of course, the engineer compels him to replace the wasted material.

294. Sections.—Before the work is let to the contractors, in fact, when the cost of the line is estimated, the line is divided into sections about one mile long, but they sometimes vary in length from 4000 to 7000 feet. The sections are so placed that, as far as possible, the cuts will balance the fills. Fig. 156 shows section 4; every yard of excavation between the section posts should go into the fills in this section. The profile which is given the contractor when he goes over the line to get data upon which to base his bid has these sections marked on

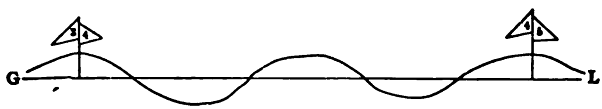


FIG. 156.

it, together with the probable quantities, so that he can estimate the amount of overhaul, if any, and the number of teams, etc., required; he then bids for the work in certain sections. Although there is always a clause in the contract allowing the chief engineer to make changes in the plans at any time, it would cause trouble to change section limits after the contract has been let, if the contractor thought "he was being ruined" by the change, as he is very liable to claim.

295. Overhaul.—It is always stipulated in the contract that the excavated material shall be hauled a certain distance without extra charge; this distance, called *free-haul,* is usually 500 feet, but in some cases it is greater. Assuming the free-haul to be 500 feet, when the material must be hauled more than 500 feet, the excess of distance over 500 feet is called *overhaul,* and is paid for at the rate of one or one and one-half cents per cubic yard per 100 feet of overhaul, in addition to the contracted price per cubic yard for excavation.

There are two methods of computing the distance and amount of overhaul, both of which are in general use. In Fig. 157 the excavation B F is to be placed in the embankment B C; let g and g' be the centers of gravity of the volumes F D and E C respectively, and let them be projected on the grade line at G and G′. The

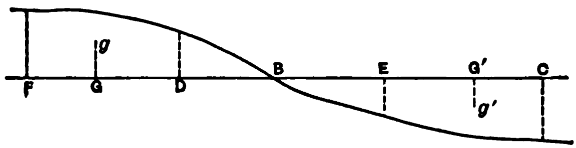


FIG 157.

first method is to excavate the part B D and make the fill B E so that the distance D E equals the free-haul. Then the mass F D is hauled to E C, and the distance of overhaul will be G G′—D E, and the amount of the overhaul will be the product of the volume F D, the distance of overhaul and the price of the overhaul per yard per hundred feet. For example, if the volume of F D is 800 cubic yards, the distance of overhaul 320 feet, and the rate one cent per yard, then the cost of the overhaul will be

$$800 \times 3.20 \times .01 = \$25.60.$$

In the second method the cut B F, Fig. 158, is hauled into the fill B C, and g and g' are the centers of gravity of the cut and fill respectively; then the overhaul is G G′— 500 and this is applied to the entire volume B F. This method, in the example which follows in ¶ 298, is not so favorable to the contractor as the first method.

Overhaul is computed for each fill, and overhaul in one fill is not counterbalanced by a short haul in another fill, even if both fills are in the same section.

296. Method of Computing Overhaul.—While it is not necessary to determine the centers of gravity, with extreme precision, in general, it will not be sufficiently accurate to take the centers of gravity of the plane figures

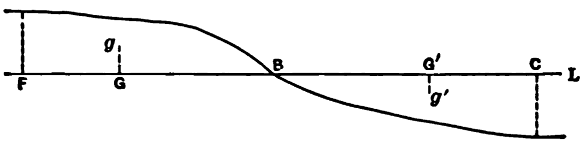


FIG. 158.

shown in Figs. 157 and 158 as the centers of gravity of the volumes represented, on account of the volumes increasing more rapidly then the first power of the height of the cut or fill. The center of gravity is usually computed by the algebraic method, or by moments.

Only the total volume of a cut or fill is written on the profile, but in the cross-section book the volumes between the adjacent cross-sections are recorded. These sections are never more than 100 feet apart, and are less than 100 feet apart if the ground is rough, so the total volume of a cut or fill is divided into a number of small volumes, or prismoids. In most cases there will be no appreciable error in the final result if the center of gravity of each of the prismoids is considered to be half-way between its end sections. In order to compute the center of gravity of the cut (or fill), assume some point as B, Fig. 158; then the sum of the products of each small volume by the distance of its center of gravity from B in feet, divided by the total volume B F, will give the distance B G in feet. In the same way B G′ is computed, and then the total distance between the centers

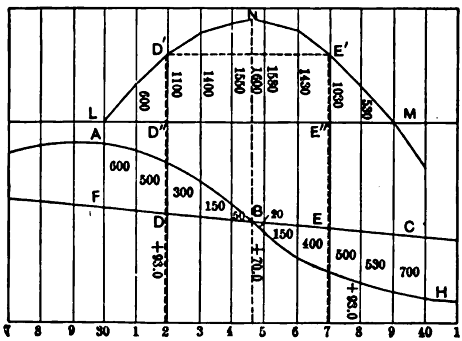


Fig. 159.

of gravity is G G′ = B G + B G′, and the distance of overhaul is G G′ minus the free-haul.

297. The Mass Diagram.—The amount of overhaul may be computed graphically by means of the *mass diagram* shown in Fig. 159. The line A B H represents the profile of the portion of the line between stations 30 and 40, F C the grade line, and B, sta. 34 + 70.0, the point of zero cut and fill. The portion of the cut to the left of sta. 30 is carried to the left, and all the cut to the right of sta. 30 goes to make the fill B C H. In order to construct the mass diagram a table similar to table XXII is compiled. The volumes of the prismoids in the second and third columns are taken from the cross-section book; the quantities in the fourth column are obtained by adding the quantities in the second and third columns algebraically, cuts being considered positive and fills negative. The quantities in the second and third columns are also written on the profile in the parts corresponding to the respective prismoids, 600 being the number of cubic yards between stas. 30 and 31, etc.

TABLE XXII.

Sta.	Cut, Cu. Yds.	Fill, Cu. Yds.	Ordinate, Cu. Yds.
30	0	..	0
31	600	..	+ 600
32	500	..	+ 1100
33	300	..	+ 1400
34	150	..	+ 1550
34 + 70	50	..	+ 1600
35	..	20	+ 1580
36	..	150	+ 1430
37	..	400	+ 1030
38	..	500	+ 530
39	..	530	0
40	..	700	— 700

To construct the mass diagram L D′ N E′ M draw the indefinite horizontal line L M, and on the ordinate through each station plot the corresponding value from the fourth column of table XXII to any convenient scale, and connect the upper ends of the ordinates by the line L D′ N E′ M. The point M where the curve cuts the line L M shows the limit of the fill that can be made from the cut. In the data assumed in the above illustration, the number of cubic yards in the prismoids, the beginning of the cut, and the end of the fill were taken in round numbers, so that the method could be the more easily understood. The shrinkage and swell were also ignored.

298. Overhaul from the Mass Diagram.—The area of each trapezoid in the mass diagram represents the volume of the corresponding prismoid moved 100 feet, therefore the area of the mass diagram represents the total volume moved 100 feet, and the area of the mass diagram divided by the total volume of cut equals the total distance hauled, or the distance between the centers of gravity of the cut and fill, in hundreds of feet. Assuming the volumes of the prismoids to be proportional to the areas of the trapezoids, the total haul is found as follows:

$$\frac{300 + 850 + 1250 + 1475 + 1102 + 477 + 1505 + 1230 + 780 + 265}{1600} = 5.77, \text{ or } 577 \text{ feet.}$$

The area of the mass diagram can also be obtained with a planimeter.

To compute the overhaul according to the first method in ¶ 295 (Fig. 157) in Fig. 159, draw the horizontal line D′ E′ at such an elevation that the distance D′ E′ intercepted between the points where the line cuts the curve is equal to the free-haul, and project the points D′ and E′ to D and E respectively; then the points D and E show the limits of free-haul; the volumes B D, B E, and D′ N E′ are equal, and correspond to the part that is moved free before any overhaul is allowed; the volume of the rectangle D′ E′ E″ D″ is also hauled free, and the sum of the volumes L D″ D′ and E′ E″ M is the volume upon which overhaul must be paid, or 2192 cubic yards hauled 100 feet. The cost of the overhaul by the two methods at one cent per yard per 100 feet is as follows:

By the first method............. $1600 \times .77 \times .01 =$ \$12.32
By the second method.......... $2192 \times .01 =$ \$21.92.

299. Practical Application of Mass Diagram.—In practice, the volume upon which overhaul is allowed is measured in the fill after it has settled; therefore the overhaul is not usually computed until just before final acceptance of the work. This in some cases, however, is not possible, as, for instance, when the fill is being made from excavated material and borrow at the same time. In such cases the quantities are taken from the cross-section book, corrected for shrinkage or swell, tabulated as in table XXIII, and the overhaul computed. In this case earth is assumed to shrink 10 per cent., loose rock to remain constant, and solid rock to swell 40 per cent., the corrections being shown in brackets in the second and fourth columns. The mass diagram for the quantities in table XXIII shows that the cut will make the fills up to sta. 39 + 34. The limit of the fill can also be found by proportioning between the ordinates in the seventh column opposite stas. 39 and 40. In this case the total cut is found to be 1836 cu. yds., the overhaul 106 feet, and the cost of the overhaul at one cent per yard per 100 feet by the first method will be:

$$1836 \times 1.06 \times .01 = \$19.46.$$

The above shows only one feature of the mass diagram. If a mass diagram be constructed for one or more sections (miles), a study can be made of the balancing of the cuts and fills, the borrow or waste, as well as the overhaul, and the advisability of raising or lowering the grade, or shifting the line.

TABLE XXIII.

Sta.	Cut in Cu. Yds.			Correct'd Yardage.	Fills, Cu. Yds.	Ordinates.
	Earth.	Loose Rock.	Solid Rock.			
30......	0	0	0	0		0
31......	331 — (33)	0 ..	269 + (108)	+674	..	674
32......	176 — (18)	50	274 + (110)	+ 592	..	1266
33......	149 — (15)	39	112 + (45)	+ 330	..	1596
34......	61 — (6)	0	99 + (40)	+195	..	1791
34 + 70.	50 — (5)	0	0	+ 45	..	1836
35......	..	..	..	..	— 20	1816
36......	..	..	..	..	— 150	1666
37......	..	..	..	..	— 400	1266
38......	..	..	..	..	— 500	766
39......	..	..	..	..	— 530	236
39 + 34.	..	..	..	..	..	0
40......	..	..	..	..	— 700	— 464

300. The Cost of Excavation.—In railroad work the contractor is paid per yard of excavation, the excavated material to be placed in the fills by the contractor free of cost, provided there is no overhaul, therefore if the cuts balance the fills, and there is no overhaul, the cost to the railroad of building the subgrade depends upon the number of cubic yards of cut.

The work of the contractor in making the excavations, and the items which he must consider in making his bids, are seven, viz., loosening, loading, hauling, spreading, repairs, and interest on cost of plant, superintendence and incidentals, and profit; and in many cases there is another item, viz., keeping the roadways in repair.

301. **Loosening.**—Loosening the material in a cut depends upon the nature of the material and the method of working. In a long shallow cut of earth, sand, or gravel, the best method of loosening is by means of plows, two- or four-horse plows being used, and if the haul is not too great, drag- or wheel-scrapers can be used economically. As a wheel-scraper holds about $\frac{1}{2}$ cubic yard and requires two horses, it is not economical to have the team travel too far empty.

When the soil is of a clay nature, it is sometimes difficult to plow, and picks must be used. It is considerably more expensive to loosen material with picks than with plows. When picks are used, as far as possible, the material is removed in layers several feet thick, which enables the men with the pick to undermine a more or less vertical face and then to bring down a considerable quantity at one time.

Powder is often used to advantage to loosen up material in order to facilitate the work with picks, particularly in some kinds of clay, shales, and frozen earth. There is so much variation in materials that go by the same name that no certain method can be stated for loosening a material. The experience and ability of a contractor and his foremen to use the most economical method govern the cost of all excavation work. Some idea of this may be obtained from the statement that it is sometimes economical to blast and pick some forms of earth and to plow some forms of shale.

The above statements apply to everything but solid rock, which must always be blasted in order to loosen it. This will be considered separately.

It costs from ½ to 2 cents per cubic yard to loosen earth by plowing, and from 1½ to 7 cents per cubic yard to loosen earth with picks.

302. Blasting.—It is necessary to loosen all solid rock by blasting. In blasting the loosening is produced by the sudden expansion of a gas which is developed by the explosion of the blasting compound. Blasting compounds may be divided into two general classes, viz., slow-burning and detonating, the most common forms in general use for blasting purposes being gunpowder and dynamite respectively. Gunpowder is a slow-burning explosive which is ignited by heat, generally a fuse or a wire connected with an electric battery; each grain ignites the adjacent grains, and the heat and pressure are comparatively low. Dynamite is composed of nitroglycerin and infusorial earth; if mixed in the proper proportions, it is nearly or quite as powerful, cheaper, and safer to handle than pure nitroglycerin. Dynamite is exploded by a shock which explodes the whole mass instantly, usually by means of a fulminating cap which is fired by means of a wire and an electric battery. Many other explosives are used, but these illustrate the general idea.

There is great economy in using the proper explosive with a certain kind of rock. The tendency of the slow-burning compounds is to loosen without shattering, while dynamite tends to shatter, and in many cases the loosening effect is not far-reaching. In general a hard brittle rock is most effectively blasted by dynamite, provided the only object is to loosen the rock; if the rock is to be used for building purposes, dynamite will probably shatter it too much. A softer, tougher rock will give better results when powder is used. It takes considerable experience and judgment to determine the amount and kind of explosive to be used, powder being mostly used in open cuts and dynamite in tunnels.

303. Drilling.—In order to be effective powder and dynamite must be rammed in holes drilled in the rock. Drilling is one of the most expensive operations in connection with rock excavation. When there is sufficient drilling to be done in a comparatively small area, such as a tunnel, where is it economical to install an air compressor, machine rock-drills are used; but in small cuts strung out along a considerable length of line drilling must be done by hand.

Drills for hand-drilling consist of bars of steel of various lengths sharpened as shown in Fig. 160. They are usually about $1\frac{1}{4}$ inches in diameter and are sharpened and tempered according to the nature of the rock being drilled; the harder the rock, the blunter the point of the drill. The cutting-edge is wider than the main body of the drill by from 15 to 30 per cent., and is sharpened by grinding after a short distance—6 to 18 inches of hole—has been drilled; and after the whole point of the drill has become too blunt, it is repointed by the blacksmith, this being necessary every two or three days. Hand-drills are from 1 to 4 feet long or even longer. A *churn-drill* is a bar of wrought-iron shod with steel or a bar of steel; it is pointed like a hand-drill and ranges from 6 to 20 feet in length, and in some cases even longer.

The method of drilling a hole depends upon the depth of the hole. If the hole is to be only a foot or two deep, it will probably be drilled by one man. If it is to be 6 or 8 feet deep, it will probably be started for a few inches by one man, and then one man will hold the drill while one, two, or three men strike it with hammers, drills of suitable lengths being used as the hole becomes deeper. If the hole is to be very deep, a churn-drill will be used as soon as the hole is deep enough to guide the drill and keep it going true. In churn-drilling two or more men raise the drill a few inches and allow it to drop, giving it a partial turn each time, the work being done by the weight of the drill. Holes may be drilled 20 or more feet by means of churn-drills.

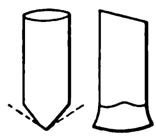


FIG. 160.

304. Loading and Firing.—On account of the great expense of drilling a hole, great care is taken in charging, tamping, and firing. When the blasting is to be done by dynamite, the required amount is placed in the drill hole. It is not absolutely necessary to tamp dynamite, but it will be more effective if it is tamped. A fulminating cap attached to a wire is placed in contact with the dynamite, and then clay or sand is carefully rammed around the wire and against the dynamite with a wooden rammer; after this is done and proper warning given, the charge is fired by means of an electric battery.

The effect of the explosion of powder depends to a great extent upon the amount of ramming; the more thorough the ramming, the greater the effect. In many cases, in order to increase the amount of powder that can be used and also the effect of the explosion, the hole is first *sprung*. *Springing* the hole consists in exploding a small quantity of dynamite in the bottom of the hole, which has the effect of forming a small chamber at the bottom of the hole, as shown in Fig. 161, and also shatters the surrounding rock to a certain extent. The extra space at the bottom of the hole allows more powder to be used, and the shattering of the rock causes the work of the powder to be more effective. After the powder is placed in the hole a fuse is run from the powder to the surface of the ground. The hole is then tamped with clay or sand, care being taken not to injure the fuse, which consists of a cord through which runs a thin vein of gunpowder, the cord being protected by coverings to protect it from dampness and injury.

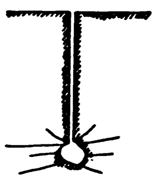


FIG. 161.

Gunpowder should never be tamped with an iron bar, a wooden bar being generally used, although copper bars are used.

Blasting for excavation may cost from 30 to 60 cents per cubic yard, depending upon the nature of the rock and the depth of the cutting, a shallow cut being quite expensive.

305. **Loading, Hauling, and Spreading.**—In ¶ 300 the second, third, and fourth items of the expense of excavation were loading, hauling, and spreading, the three items being so closely related that they might well be considered one—moving the loosened material. Leaving scrapers and steam-shovels out of the question, the excavated material must be loaded into the wheelbarrow, cart, wagon, or car; must be hauled to the fill, emptied, and, sometimes, roughly leveled up. The cost of loading is the same per cubic yard for the same material, it making no difference whether it is shoveled into a cart or wagon, and very little difference between a wheelbarrow and a cart. There is considerable difference between the time it takes to unload a wagon, a cart, or a wheelbarrow, unless patent dumping wagons are used; but the main items that vary are the distance of haul and the amount hauled. A wheelbarrow will hold about $\frac{1}{8}$ of a cubic yard, a cart about $\frac{1}{2}$, and an ordinary wagon about 1 cubic yard. The exact limits of distance that will be economical for each will depend upon other conditions than the above, and are difficult to state, but the economical limit for wheelbarrows may be placed at 100 feet, carts from 100 feet to 500 feet, and wagons for distances over 500 feet, this being governed to a great extent by the distance a driver and team must travel in returning. A man, horse, and cart carry $\frac{1}{2}$ cubic yard; and a man, two horses, and a wagon carry at least 1 cubic yard, but take longer in dumping the load.

306. Method of Working.—When cuts are earth and shallow and the fills not too long, excavation and fill are most economically made by means of plows and wheel-scrapers; but if the material can be handled by steam-shovels and the cuts are large enough, steam-shovels and wagons or cars would be used.

If the cut is rock with a thin covering of earth, the method of working will be about as follows: A few men will excavate the part B*a*, Fig. 162, with picks and throw it into the fill B*b* with shovels, until the distance is too great for shoveling—probably 12 to 15 feet. Then the material will be moved by wheelbarrows until the distance is great enough to make horse-carts economical; and if the haul becomes very long, two-horse wagons are economical, or even a small track and dump-cars. As soon as the loose or earthy material has been removed, the drilling and blasting begin.

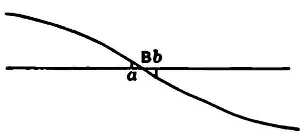


FIG. 162.

307. Profits of Contractor.—Contracting is a gamble. Despite experience and careful estimates, a contractor cannot count on his profits until the work is finally accepted and he is paid the full amount. It has frequently happened that with two contractors working on the same class of work under about the same conditions one will make money and the other will lose; this is particularly the case in rock excavation. The contractor or his representative goes carefully over the work, estimates the probable cost of doing the work, adds as large a percentage for contingencies and profits as he possibly can and still underbid the other contractors. If the contractor has been on similar work and owns the necessary outfit, he can underbid the contractor who must buy a large portion of his outfit. He must pay his men and interest on his plant and make repairs, and should have a fair profit clear of all expenses—possibly 10 per cent. New machinery that is bought for the work cannot all be charged against the one piece of work, but part of the cost must come out of the profits.

There is great economy in properly handling the men. If the contractor furnishes quarters and board to the men, it is not only a source of profit, but he has the men under better control. Instances have occurred where a profitable commissary counterbalanced a loss on the work.

308. Force Account.—Where the railroad wishes to have absolute control of the work, or where there are so many uncertainties in connection with work that contractors are afraid to bid, the work is often let by *force-account* work. In this method the contractor furnishes all men, machinery, materials and repairs, and is paid a percentage on the total cost, usually 10 per cent. If there are a great many uncertainties about a piece of work, a contractor cannot afford to bid a fixed price without adding a percentage for contingencies that will make him safe against all probable delays and losses; this makes the cost too high for the railroad, and under these circumstances the force-account method is the fairest; the contractor makes a fair profit and the railroad pays the exact cost.

309. Measuring Cuts and Fills.—The width of roadbed in cut and in fill and the corresponding slopes are specified in the contract. The volume is computed by taking the area of the cross-section between the original ground surface and the specified shape of roadbed. If the cuts are made wider than the contract calls for, or when a fill made from borrow is made too wide, the contractor is paid for the volume determined by the specified sections, and cannot claim pay for the extra work unless he had previous written instructions from the resident engineer.

Cuts should be taken out to true lines and surfaces in the same manner as for fills, ¶ 272. It is very difficult to do this except when the cut is entirely in earth, but an effort must be made to do the work so as to leave as neat an appearance as possible. A contractor will usually do neat work without compulsion; he must take out all the material, and does not get paid for excess material, and it is greatly to the advantage of a contractor to be known as one who does good work.

The final cross-section taken by the engineer is therefore to determine whether or not the cuts and fills are as large as specifications demand as well as to determine the amounts.

310. Excess Cutting.—There is one case in which the contractor is always paid for excess material. If, owing to natural conditions, after the cut has been made it is found that a part of a slope is unstable and liable to slip into the cut, this material must be removed and the contractor is paid for it. Suppose, for example, in the rock cut shown in Fig. 163, the strata stood on end and the part B were loose and tended to slide along the line *a b*, then the contractor would be paid for removing the part B. If, however, the slopes were shattered by the explosion of excessive charges of powder, then the contractor would have to remove all dangerous material at his own expense.

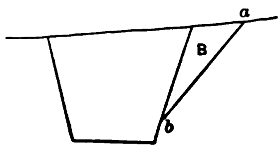


FIG. 163.

In all cases where an extra is paid, the contractor must have a written order from the engineer authorizing the extra work, before the work is done, otherwise the contractor cannot enforce a claim.

311. Letting Contracts.—After the Location Corps has finished running the line, made the preliminary estimates, and put everything into shape for construction, contractors are asked to submit bids for the construction: They are supplied with blank forms similar to Table XXIV, and after they have studied the kind and amount of work to be done, they fill in the unit prices at which they will do the work in each Section, in Table XXIV. The bids must be submitted on or before a specified date. After the time of bidding has been closed, computations are made in order to determine the lowest bidder on each Section. It is seldom that one contractor will be the lowest bidder on every item, and it is necessary to determine the lowest total sum bid on each Section. This is done by multiplying the probable amount of each kind of work by the unit prices bid, this gives the probable total cost of each item, and then these totals are added in order to determine the probable total cost of the Section. The amounts (cubic yards, etc.) are obtained

TABLE XXIV.

PROPOSAL.

For the Gradation and Masonry on the..........................*Rail*..............

The undersigned hereby certif that he ha sufficiently examined the locality and section of the Rail on which the work proposed for below is situated; and that he ha also carefully examined the specifications, terms, and conditions applicable to said work, set forth in the printed form on the same sheet with these proposals; and having made such examinations and understanding thoroughly the nature and conditions of the work to be let, the undersigned hereby propose to the Rail Company, to do all the work on either or all of the to which prices are affixed in the following schedule, according to the specifications, terms and conditions aforesaid; and on the acceptance of these proposals for all or either of the named therein, do hereby bind to enter into and execute a contract according to the requirements aforesaid, for all the work thereon, at the following

PRICES, VIZ.

NAME, NO., OR LOCALITY OF	SECTION.		SECTION		SECTION.		SECTION.	
....	$	Cts	$	Cts	$	Cts	$	Cts
Grading:								
1. Clearing.......................per Acre								
2. Grubbing.......................... " "								
3. Solid Rock Excavation, per Cubic Yard..								
4. Loose Rock " " " "								
5. Hard Pan " " " "								
6. Earth " " " "								
7. Borrowed Embankment " " "								
Foundation Excavation in Water:								
8. Solid Rock Excavation, per Cubic Yard..								
9. Loose Rock " " " "								
10. Hard Pan " " " "								
11. Earth " " " "								
Masonry:								
12. First Class Masonry, per Cubic Yard								
13. Second Class Masonry " " "								
14. Third Class Masonry " " "								
15. Fourth Class Masonry " " "								
Arch Culvert Masonry:								
16. First Class Masonry, per Cubic Yard								
17. Second Class Masonry " " "								
18. Third Class Masonry " " "								
19. Rectangular Culvert Masonry " "								
20. Slope Wall Masonry " " "								
21. Brick Work Masonry " " "								
22. Concrete Masonry " " "								
Stone Paving:								
23. Laid dry " " "								
24. Laid in Cement " " "								
25. Rip Rap " " "								
Timber in Trestles and Foundations:								
26. Oak per M. Squared..								
27. White or Yellow Pine " " Squared..								
Flatted...								
28. Pitch Pine " " Squared..								
Flatted...								
29. Spruce " " Squared..								
Flatted...								
30. Hemlock " " Squared..								
Flatted...								
Piles:								
31. Oak per Lineal Foot............								
32. Yellow Pine " " "								
33. Spruce " " "								
34. Hemlock " " "								
35. Wrought iron, per pound................								
36. Cast iron, per pound...................								

The undersigned further propose to commence work on such or as may be alloted to within days from the date hereof, and to complete on or before the day of , 191

....

....

Signed this day of , 191 ....

Proposer's Residence.................. ....

Nearest Post Office.................. ....

from the preliminary estimates. It frequently happens that the highest bidder on an item of which the quantity is small, will be the lowest bidder on the total because he has bid low on an item of which the quantity is large.

The contract is usually let to the lowest bidder, particularly if the contractor has the reputation of doing good work and finishing on time.

CHAPTER IX.

TRESTLES.

ARTICLE XXIX.

FRAMED TRESTLES.

312. Permanent Trestles.—In the best type of construction the fills are completed when the road is built, and no openings are allowed excepting where absolutely necessary for waterways or undergrade crossings, in which cases masonry or concrete arches are used whenever possible. When the roadbed is built in this way there is no necessity to rebuild bridges for heavier locomotives and no danger from rust in some hidden part of the structure. In some cases, such as a wide stream or the depth of the fill being too shallow for an arch, it is necessary to bridge the opening, and in other cases it is economy to use trestles.

Trestles may be divided into two general classes, viz., permanent and temporary. Permanent trestles are usually built of steel and are called viaducts. A steel viaduct is built over a long stretch of low country of such nature that good foundations for the posts are obtainable, and where the difference between the elevation of the ground and the track is too great to make a fill economical, and where the stream is not large enough to interfere with the foundations. They are also built over deep narrow gorges, such as the Kinzua Viaduct, on the Oroya R. R., in Peru. Many items must be considered in order to determine the most economical method of bridging an opening, and a general rule is an impossibility.

313. Temporary Trestles.—Temporary trestles may be built in the following cases: (1) to replace a structure temporarily so that traffic will not be delayed; (2) to run around a structure while it is being rebuilt; (3) to save fill temporarily on account of the excessive cost of borrow; and (4) to give time to study the area of waterway required. The first two cases are self-explanatory. It frequently happens that it is difficult or very expensive to get the borrow with which to complete the fill, and it is found much more economical, both in cost and in time saved in opening the road to traffic, to put in a temporary trestle. They are built of wood and will last ten years on an average. After the road is in operation and long before the trestle will need repair, it will be possible to haul the necessary material in trains and replace the trestle with embankment. This will be more expensive than earth borrow with a short overhaul, but much cheaper than rock borrow.

It is frequently found difficult to approximate closely the area of waterway required by a stream. It is as poor engineering to build an opening too large as it is to build it too small; consequently if, as is often the case, it is about as economical to put in a temporary trestle, it is better to put in the trestle and then find the necessary data and construct the permanent opening before it is necessary to repair the trestle.

314. Framed Trestle Bents.—Trestle bents are of two general types, viz., frame and pile. Framed trestle bents are built of squared timbers, usually all being the same size, 12 by 12 inches.

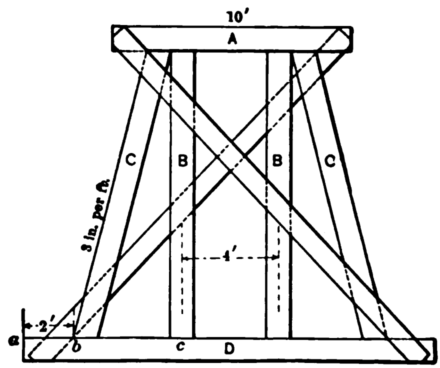


Fig. 164.

In Fig. 164 is shown the elevation of the simplest form of framed bent—the timber A is the *cap*, B the *posts*, C the *batter posts*, and D the *sill*. These members are framed together in five different ways, viz., mortise and tenon, dowels, drift-bolts, plaster-joints, and iron-plate joints.

315. Mortise and Tenon Joint.—The mortise and tenon is, everything considered, the best form of joint, the principal objections to it being that it lessens the vertical bearing strength of the cap and sill and is expensive to make. The hole is bored through the mortise and tenon separately in such a way that when the wooden pin is driven through the finished joint, the tenon is drawn firmly into the mortise. In Fig. 165 in *a* and *b* are shown two views of the mortise, and in *c* and *d* are shown two views of the tenon.

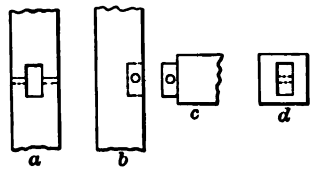


FIG. 165.

316. Dowel and Drift-bolt Joints.—A dowel is an iron pin driven an equal distance into each of the members composing the joint. In a trestle joint the dowels are usually a piece of square or round ¾-inch iron about 8 inches long, driven into holes bored to receive them. Two dowels should be used, as shown in Fig. 166. If only one dowel is used, the upright timber is free to turn, but two dowels prevent it from turning and also give greater security against slipping out of position laterally. Dowels would be of little value to hold members if they were not in a vertical or nearly vertical position, as they are in trestle bents, batter posts never being far from a vertical position.

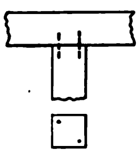


FIG. 166.

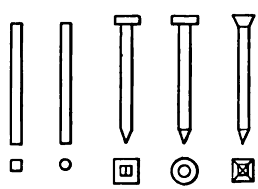


FIG. 167.

Drift-bolts vary from a piece of round or square iron cut in the right lengths without either head or point to a piece of the same iron with a head on one end and a point on the other, Fig. 167. The heads are round, square, or countersunk. The points are usually blunt, being from one-half to one and one-half inches in length, and may be either wedge, pyramid, or conical-shaped; they should be symmetrical in all cases. Drift-bolts vary in length according to the size of the timbers: In the case of 12- by 12-inch timber, the drift-bolts would be about 20 inches long. They are usually either $\frac{3}{4}$-inch square or $\frac{3}{4}$-inch round iron, and are driven into a hole bored $\frac{5}{8}$ inch in diameter.

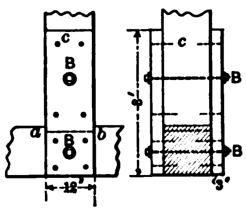


FIG. 168.

317. Plaster Joint.—The plaster joint is made by spiking and bolting two pieces of plank as wide as the main members of the joint, as shown in Fig. 168.

The post is notched into the cap and sill about 1 inch, as shown at *a b* in the figure, in order to prevent motion parallel to the surface of the splices. The plaster joint is quite convenient to use in making repairs, as it can be made with the timbers erected. The joint in Fig. 168 is formed of two pieces of plank 3 by 12 inches and 3 feet long; these are fastened on each side of the main members by the bolts B and large spikes *c*, the spikes being of the same general pattern as ordinary nails, and 6 inches long.

318. Iron Plate Joint.—The front and side views of an iron-plate joint are shown in *a* and *b*, Fig. 169, and an isometric drawing of the joint is shown in the same figure at *c*. The joint may be made from a wrought-iron or steel plate about ⅜ inch thick. The members are bolted together through the holes shown, two bolts passing through each member. This joint is easy to put together; members may be replaced easily, but it is expensive.

A joint should hold the parts firmly in place, give firm uniform bearing, allow members to be replaced without too much trouble, and should be cheap. As stated above, the mortise and tenon joint is probably the best, everything considered, for the trestle bent,

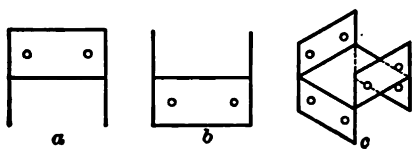


FIG. 169.

and the plaster joint is very convenient in repairing. The iron plate joint gives the best bearing for abutting members, holds the members together firmly when well bolted, allows parts to be replaced readily, and probably makes as good a joint as the mortise and tenon, the main advantage of the mortise and tenon joint being that it can be made in the field from the timber, while any parts that are ordered from a factory are liable to cause delay.

319. Dimensions of Trestle Bents.—The main points of trestle bents that are standardized by railroads are the dimensions of the members, the kind of joints, the length of the cap, the distance between centers of vertical posts, the projection *a b*, Fig. 164, of the sill, and the slope of the batter posts. An examination of the standard plans of fifteen railroads* shows a surprising variation in some dimensions that are susceptible of almost exact theoretical design. The standard plans mentioned above show the distance between the centers of the vertical posts to range from 3 feet to 6 feet 6 inches for single-track bents, the usual distance being 5 feet. The distance between the centers of heads or bases of rails may be taken as 5 feet. If it is assumed that the vertical posts are to carry the entire load, then they should be placed 5 feet apart between centers; this assumption throws only lateral thrust into the batter posts. If the vertical posts are placed 4 feet between centers, and the batter posts are arranged as shown in Fig. 164, the load will be distributed equally on the vertical and batter posts, the principal advantage of this arrangement being that a greater bearing surface under the load is presented to the cap.

320. The Cap and Sill.—The length of the cap in the fifteen cases ranged from 10 feet to 16 feet; 10 feet is ample for the arrangement shown in Fig. 164. Timber will crush more easily when the load is applied at right angles to the grain, than it will when the load is applied in the direction of the grain, therefore the cap and sill have a tendency to crush where the ends of the posts press against them. For this reason it has been the custom to make the cap and sill 12 by 12 inches, and sometimes of hard wood, the difference between the compressive strength of wood parallel to the grain and at right angles

* Wooden Trestle Bridges, Foster.

to the grain being so great that a soft-wood post is as strong as a hard-wood cap and sill. The length of the sill depends upon the height of the trestle bent, being equal to the distance between vertical posts plus 2 feet on each end projecting beyond the outer edge of the batter post plus twice the distance *b c*, Fig. 164, governed by the height of the bent.

321. Posts.—The posts are also made 12 by 12 inches. The vertical posts are placed as described in ¶ 314 and Fig. 164. The function of the batter posts is to carry part of the load, to stiffen the bent, and to prevent deformation by lateral thrust, which may be caused by the lateral vibration of locomotive and train and by wind blowing on both train and trestle. In many of the designs there is a space between the outer edge of the vertical post and the inner edge of the batter post under the cap, in one case the distance between the centers of the tops of the batter posts being 11 feet. A triangle is the only stable figure in framework; consequently when there are no diagonal braces in the trestle bent, the tops of the batter posts should touch the vertical posts, as shown in Fig. 164, making the distance between centers 6 feet. The batter varied from 2 to 4 inches per foot, 3 inches per foot being the average and also the amount used in most cases.

While it is undoubtedly a waste of lumber in many cases, all main timbers in a trestle bent are usually made 12 by 12 inches in cross-section. The necessary size of timbers varies with the load, the height of the bent, and the kind of timber. A correct theoretical design would require a great variety of sizes of cross-sections, and the trouble and cost of furnishing the odd sizes would in many cases more than counterbalance the material saved; consequently it is the almost universal custom to specify the same size for all the main members of a bent.

322. Height of Trestle Bents.—The height of a trestle is the distance from the base of rail to the bottom of the sill. The height of the bent is the height of the trestle less the distance from the base of rail to the top of the cap; the latter distance being the

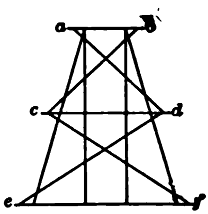


FIG. 170.

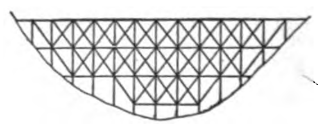


FIG. 171.

thickness of the tie, the depth of the stringer, and the net thickness of the corbel. The height of the trestle is determined from the profile, and then the height of the bent is computed. The trestle bent shown in Fig. 164 can be used for all heights of trestle not greater than 24 feet. Some railroads require the diagonal sway bracing shown in Fig. 164 for this height, but others do not. When the trestle is more than about 24 feet high, it is necessary to build the trestle in stories; this is done in several ways, one of which is shown in Fig. 170, which represents a two-storied bent in which all the members are 12 by 12 inches except the sway braces *a d*, *b c*, *c f*, and *d e*, which are 2½ by 10 inches in section. The diagonal braces are called *sway braces;* those shown in Fig. 170 are called *lateral* sway braces, and those in Fig. 171 are called *longitudinal* sway braces.

The height of the stories is governed by the length of timbers that can be conveniently obtained, it being necessary in some cases to splice the sway bracing even when the longest planks are used. Ordinary lumber and timber is kept in stock in lengths of 12, 14, 16 and 18 feet. Any length over 18 feet usually must be sawed by special order, may cost more per thousand B. M., and is liable to cause delay. The stories of the bents of high trestles may be of different heights in the same trestle, and are arranged and braced as shown in Fig. 171, but all the stories at the same elevation are the same height, the odd dimensions being near the ground.

Timber trestles similar to that in Fig. 171 are more likely to be built in a section of the country where timber is plentiful.

323. **Foundations for Framed Trestles.**—The sill of a framed bent may rest on masonry, mud-blocks, or piles. For high trestles the foundations are usually masonry or piles; for trestles of ordinary heights the foundations may be any one of the three forms mentioned above, but usually consist of mud-blocks, or mud-sills and mud-blocks. The most economical foundation for a trestle depends upon (1) the nature of the ground, and (2) the price of materials.

324. **Masonry Foundations.**—The plan and elevation of a masonry foundation for a trestle bent is shown in

Fig. 172. C D is the sill, and A B the ground surface. The length *d e* of the masonry depends upon the length of the sill and the projections *a b*; the width *c d* and the depth depend upon the nature of the soil. In a very firm soil giving good support, a horizontal projection of 6 inches on the sides and ends of the sill and a depth just below the frost line are sufficient; this would require the foundation to be 12 inches longer and wider than the sill, and about 2½ feet deep. If the bearing

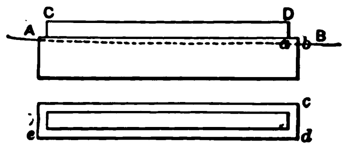


FIG. 172.

strength of the soil is poorer, the area of the base and the depth of the masonry must be greater.

325. Pile Foundations.—When the soil is too soft and too deep for masonry foundations, unsuitable for mud-block and mud-sill foundations, and it is not desired to build a pile trestle, which would usually be built under the above conditions, piles are driven to support the sill. The number of piles to each bent depends upon the bearing resistance of the piles, depending upon the material through which they pass and upon the material upon which their points rest. The piles are sawed off square and at the same level, and the sill rests directly upon them. The spacing of the piles depends upon circumstances, and the distances between them may vary on the same principle shown by the mud-blocks in Fig. 173.

326. Mud-blocks.—In soil such as is likely to be found in valleys the foundation for framed trestle bents is usually formed of mud-blocks and mud-sills. In the firmer soils, where the bearing strength is sufficient, the mud-sills are often omitted. In Fig. 173 is shown one of the best arrangements of blocks and sills, all being

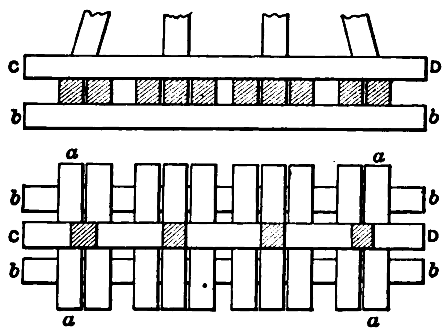


FIG. 173.

12 by 12-inch timbers. The mud-sills *b b* are first laid in true surface at the proper elevation and 3 feet apart, center to center; across the mud-sills the mud-blocks *a a* are laid and spaced as shown, the mud-blocks being 6 feet long, and then the bent is placed centrally upon the blocks, the sill C D being placed as shown in the figure.

ARTICLE XXX.

PILE TRESTLE BENTS.

327. Economy of Pile Trestles.—Pile trestles are limited by the length of the piles and are seldom over 30 feet from the base of rail to the ground or water surface, and are usually considerably less than 30 feet high. Under proper conditions, such as through a swamp or marshy ground, or over a broad shallow stretch of water, pile trestles are the cheapest and best form of temporary work. There are over 2500 miles of single-track railroad trestle in the United States alone, the longest stretch being across Lake Pontchartrain, near New Orleans which was originally 22 miles long.

The greater the number of piles the cheaper the rate per foot of pile at which they can be driven; it is, therefore, expensive to build short stretches of pile trestles at considerable distances apart. The great objection to pile trestles is the rapid decaying of the wood in dry earth and at the surface of the water, and the great difficulty of renewal.

328. Bents with Piles Vertical.—Single-track pile trestles have four piles in a bent. The center piles are always vertical, but the end piles may be vertical or with a batter, as shown in Fig. 174. The arrangement with vertical posts is used for low trestles; the cap is usually about 12 feet long, and there is considerable variation in the spacing of the piles, one extreme being to space the piles at equal distances of 3 feet 8 inches between centers, and in the other extreme the middle space is 5 feet and the two outer spaces each 3 feet between centers.

329. Bents with Outer Piles Inclined.—In Fig. 174 is shown a design for a trestle having a height varying from 10 to 24 feet. For heights of 5 to 10 feet no sway bracing is necessary. When the height is over 24 feet, the bent is built in two stories, the top story being about 15 feet. Piles should be straight and not less than 10 inches in diameter at the small (lower) end. The braces

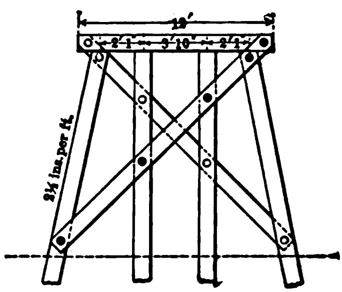


FIG. 174.

are 4 by 9 inches, and are bolted and spiked as shown in the figure. The cap is 12 by 14 inches and 12 feet long; the piles under the cap are spaced 2 feet 1 inch and 3 feet 10 inches, as shown; and the end piles have a batter of 2½ inches per foot. The longest pile that it is practicable to handle is 65 feet; this length requires the full length of two ordinary flat cars to transport them.

330. Split Caps.—The cap of a pile trestle bent may consist of a solid piece of 12 by 12-inch timber fastened to the tops of the piles by mortise and tenon joints or by drift-bolts in the same manner as in a framed bent, but the split cap is used in most cases with piles. The details of a split cap are shown in Fig. 175. It consists of a tenon 4 inches thick, as wide as the pile, and as long as the depth of the cap, as shown in Figs. 175, *a* and *b*. The cap consists of two 6 by 12 or 6 by 14-inch timbers, bolted through the tenon as shown in Fig. 175, *c*. The bolts are $\frac{3}{4}$ inch in diameter, and usually have a head on one end, as in the ordinary bolt, but in some cases a bolt with a thread and nut on each end is used, which allows one part of the cap to be replaced at a time, and also allows both parts of the cap to be screwed tight independently. Split caps may also be used on frame trestle bents.

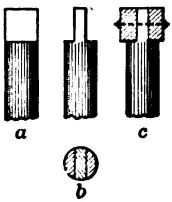


FIG. 175.

ARTICLE XXXI.

TRESTLE SUPERSTRUCTURE.

331. Corbels.—In both frame and pile trestles the superstructure consists of everything above the cap, viz., corbels, stringers, cross-ties, and guard timbers. The first sketch in Fig. 176 represents a side view of the superstructure at the bent, and the second sketch shows a longitudinal view of part of the superstructure, *a a* being the cap.

The corbels, or bolsters, *b b*, for two 8 by 16-inch stringers, consist of a block 8 inches thick, 16¼ inches wide, and 4 feet long, resting symmetrically upon the cap *a a* and supporting the stringers *c c*. The corbels are notched 1 inch over the cap, and should be drift-bolted to the cap; they form part of the stringer splice, give a good bearing for the ends of the stringers, distribute the weight uniformly over the part of the cap with which they come in contact, and fasten the superstructure to the bent; the drift-bolts have countersunk heads.

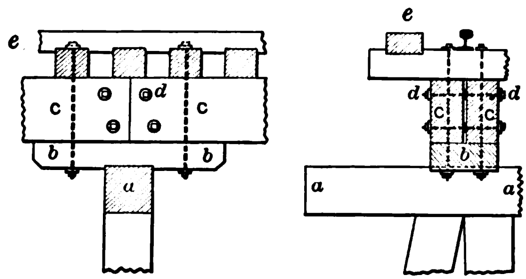


FIG. 176.

332. Stringers.—Stringers are the longitudinal timbers which support the track between bents. Two stringers are generally used under each rail, three being used in exceptional cases. In Figs. 176 and 177 is shown the arrangement of the stringer, *c c*, when composed of two timbers. The timbers are long enough to span the distance between three trestle bents, or twice the distance between bents, and are arranged with broken joints, the ends of two timbers and the center of the companion timber being over the center of each cap; the dotted lines *d d* and *b b* in Fig. 177 show the position of the corbel, *a* being the cap.

Two 8 by 16-inch timbers are used for fairly heavy traffic. The timbers are spliced together over each bent by four $\frac{3}{4}$-inch bolts *d d*, Fig. 176, and are held apart by cast-iron separators $2\frac{1}{2}$ inches in diameter, $\frac{3}{4}$ inch thick, with $\frac{7}{8}$-inch holes through them. The separators are shown in the second sketch in Fig. 176. The stringers are fastened to the corbels by means of

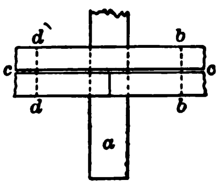


FIG. 177.

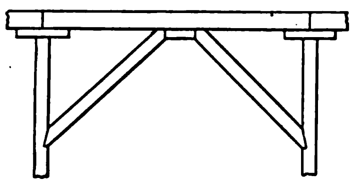


FIG. 178.

$\frac{3}{4}$-inch bolts which pass through the tie, stringer, and corbel, there being four bolts to each corbel, as shown in Fig. 176.

333. Length of Stringers.—When the stringers act as a simple beam between bents, the distance between the centers of bents is usually 12, 13, or 14 feet, some railroads specifying 12 feet for main line and 14 feet for branch lines, on trestles of ordinary height. In a high trestle, within limits, the longer the span between bents, the cheaper the trestle. In the endeavor to follow the above principle, the stringers in some cases have been made longer and stiffened by the system of braces shown in Fig. 178; this is seldom done, however, simple stringers being used in almost all cases. It is very difficult and expensive to get 8 by 16-inch stringers in lengths greater than 24 or 26 feet; therefore when the span between bents is made more than 13 or at most 14 feet, both timbers forming the stringer must join over the center of each bent.

334. Cross-ties.—Cross-ties for bridges and trestles are usually sawed and are 6 by 8 inches and 9 feet long, and are spaced about 14 inches center to center on main line and 16 inches on branches. They are fastened to the stringers with 5 by $\frac{3}{4}$-inch dowels.

335. Guard Rails and Guard Timbers.—Standard railroad rails are used for guard rails and are placed

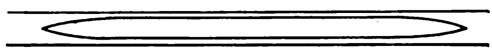


FIG. 179.

inside the main rails as shown in Fig. 179; they are parallel to the main rails and five inches from them throughout the length of the trestle or bridge, and are brought together at the center of the track beyond the limits of the opening. If the train jumps the track, with this arrangement of guard rails the inner wheel strikes the guard rail and the tendency is to throw the wheel back to the rail it left.

Long trestles, particularly high ones, should be operated with the train under complete control.

Guard timbers, often miscalled guard rails, are the longitudinal timbers *e e*, Fig. 176. Their purpose is to tie the superstructure together and to prevent the ties from creeping. As a guard rail they are more of a menace than a safety device. If the wheels leave the rails and the outer forward wheel strikes the guard timber, it is probable that it will cause the truck to slew around into a position that will almost certainly throw it off the trestle. Guard timbers are 5 or 6 inches deep and 8 or 9 inches wide, usually being 6 by 8 inches; they are notched 1 inch over the ties, and are fastened to the ties by 7 by ¾-inch lag-screws. The inner edge of the timber is 1 foot from the gauge of the rail, as shown in Fig. 176; this distance gives the guard rail a full chance to act in case of a derailment, without interference by the guard timber.

336. Ballast Roadbed for Trestles.*—In Fig. 180 is shown the cross-section of a ballast floor system for a pile trestle. The cap A A is 14 by 16 ins. and 16 ft. long, and is drift-bolted to six piles forming the trestle bent, the bents being 14 feet apart.

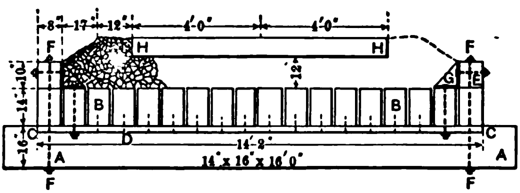


FIG. 180.

Nineteen 8 by 14-inch stringers B B, four of which are 28 feet, and fifteen of which are 14 feet long, rest directly upon the caps and form the floor of the roadbed. The four 28-foot stringers are placed one on each outer edge and one under each rail. The stringers are held in position by 2 by 6-inch planks C C, which are spiked to the bottoms of the stringers by 6 by ⅜-inch boat spikes, D D. Two strips C C are used at each bent, one being spiked on each side

* Illinois Central Railroad.

of the cap. The ballast is retained by 8 by 10-inch timbers E E, 28 feet long, which are fastened over the outside stringers as shown in the figure, $\frac{3}{4}$-inch bolts F F, 41 inches long, running through this timber, the stringer, and the cap. The timbers E E are also held in place and kept from overturning by cast-iron angles G G, which are bolted to the timber and the stringers. Cross-ties H H, 6 by 8 inches and 8 feet long, are laid with one foot of ballast under them. The ballast extends horizontally one foot from each end of the tie and then has a slope of 1 on $1\frac{1}{2}$.

All the timbers in the above structure are first framed and then creosoted and erected. There is a space of one inch between the stringers, which allows the water to drain out, thus reducing the tendency of the timbers to decay.

This form of trestle superstructure has two important advantages over the ordinary superstructure, viz., it is far less liable to be damaged by fire, and if any part of the trestle settles, the track can be put in true line and surface in the same way as on ordinary roadbed. It has the disadvantage of being more expensive, and is used only for permanent structures.

337. **Trestles on Curves.**—In order to run at full speed around a curve it is necessary to elevate the outer rail so as to counterbalance the centrifugal force of the train. One rule is to elevate the outer rail 1 inch for each degree of curvature up to 6 inches for a 6-degree curve, and for curves sharper than 6 degrees to reduce the speed a proportionate amount. The outer rail of a trestle on a curve is raised by one of the following meth-

ods: (1) sloping the foundation; (2) an unsymmetrical bent; (3) changing the shape of the cap; (4) changing the shape of the corbels; and (5) by means of the cross-ties. If the trestle is on a uniform curve, the same amount of elevation must be made at each point, but if it is on a transition curve, the amount of superelevation must be changed at each point. In all of the above methods the trestle bent is made symmetrical except in the second case. In framed trestle bents it is much better practice to use some method that keeps the bent symmetrical. It is comparatively easy to adjust pile trestles, as it is only necessary to saw the piles off at the proper elevation.

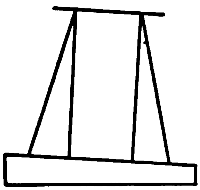


FIG. 181.

338. Sloping Foundation.—One of the best methods of providing for superelevation of the outer rail is to slope the foundation, either masonry or mud-block, at the proper rate, and use a symmetrical bent. If the rail were to be raised 4 inches for a 4-degree curve, assuming the width of track between centers of rails to be 5 feet, the foundation would be sloped at the rate of 4 inches in 5 feet, or $\frac{4}{5}$ inch per foot. This method is shown in Fig. 181.

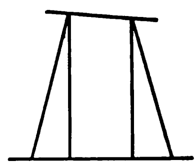


FIG. 182.

339. Unsymmetrical Bent.—This method is shown in Fig. 182, and consists in making the outer vertical and batter post longer by an amount sufficient to give the required slope to the cap, the sill and foundation remaining level. The work of framing an unsymmetrical bent is considerably greater than for a symmetrical bent.

340. Changing the Shape of the Cap.—The superelevation may be provided for by changing the shape of the cap in two ways, viz., by means of a notched cap and by a cushion cap.

A notched cap is shown in Fig. 183, and consists in cutting away a part of the top of the cap by an amount

FIG. 183.

equal to the required superelevation. In doing this, care must be taken not to make the smaller end too thin, and if the notch is to be deep, it will be necessary to increase the depth of the original cap.

A cushion cap is shown in Fig. 184. The small end of the cushion timber should not be too thin; in order to prevent this, it may be better in some cases to make the

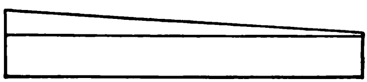


FIG. 184.

depth of the cap an inch or two less, adding the difference to the thickness of the cushion. The cushion must be firmly fastened to the cap, preferably with bolts.

341. Corbels of Different Thickness.—In using corbels of different thickness, the amount of the superelevation must be added to the thickness of the outer corbel, as it would not be good practice to weaken the inner corbel by making it thinner in order to allow for part of the superelevation.

The methods of providing for the superelevation of the outer rail described above are more economical than those that follow, as the changes are made to the bents and below the stringers and the superstructure is not changed.

342. Special Cross-ties.—Superelevation of the outer rail may be provided for above the stringers in three ways, viz., by two forms of cross-ties and by blocks.

In Fig. 185, *a*, is shown a cross-tie sawed to the required shape; in Fig. 185, *b*, is shown a regulation cross-tie with blocks under the rails, and in Fig. 185, *c*, is shown a cushion tie. The first and last methods are preferable to the second, and the first is probably the best of the three methods. The method in Fig. 185, *a*, requires a tie considerably thicker than the regulation thickness, at the outer end, and it may be made not less than 4 inches thick at the inner end, which for a 6-degree curve would require a maximum thickness of 10 inches at the outer end, and require that the ties be cut from 8 by 10-inch timber. A properly proportioned cushion-tie, in addition to the regulation tie under it, would require considerably more timber than the tie shown in Fig. 185, *a*.

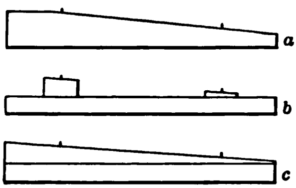


Fig. 185.

Considering all the methods for providing for the superelevation of the outer rail on curves, tipping the entire bent, or sloping the foundation is the best method, not only on account of all the parts of the structure being symmetrical, but also on account of the thrust of the train being normal to the foundation; of the other methods, the most economical is probably the method described in ¶ 341, viz., corbels of different thickness.

343. Locating and Erecting Trestles.—The resident engineer makes a situation plan showing the location of each bent, and places a stake on the center line at the exact location of the center of the bent. The elevation of the bottom of the sill is marked on the stake, and the contractor builds the foundation to the exact level. The elevation of bottom of rail and bottom of sill is given to the contractor; then, knowing the constant distance from the base of rail to the top of the cap, the bent is framed and put together, and raised to its proper position on the foundation. The bent is held in place by guys or temporary bracing until the stringers are placed between it and the preceding bent; then the guys or temporary bracing can be removed, and the balance of the floor system put in place.

344. Pony Bents.—Where an entire opening is occupied by a trestle, there must be a support for the stringers at each end of the trestle where they reach the cut; a pony bent is used for this purpose. In Fig. 186, let A B be the grade of the base of rail and C D the slope of the ground at the end of the opening, C being the grade point. At the point E where the ends of the stringers reach, a pony bent E F is placed, E F being a side view of the bent. An excavation is made to a depth that will give good support for the mud-blocks *a a*, and a regulation bent is framed, the only difference being that the posts *b b* are only two or three feet high. The entire back of the bent is boarded up with 2-inch planks, *c c*, and the back of the bent is filled up with earth to sub-grade, as shown in Fig. 186.

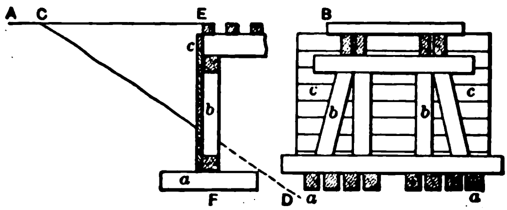


FIG. 186.

345. Trestles Instead of Borrow.—When a trestle is used instead of borrow, the end of the trestle is usually made as in Fig. 187. The trestle is built as far as the embankment reaches, the foundations for every bent being placed on the original ground surface, the end bent

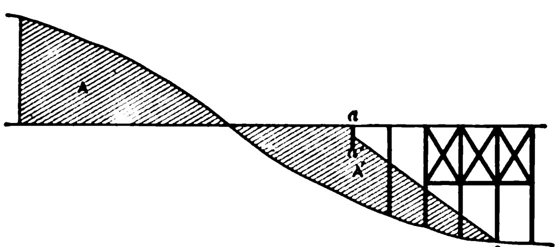


FIG. 187.

being completely buried by the embankment, or a pony bent may be used as shown at *a a'*, Fig. 187.

The end of the fill *a e* has a slope of 1 on 1½ and covers the lower part of one or more bents. If the fills are made early in the construction of the road, are of heavy material, and have had ample time to settle, and the trestle is built last, sometimes the mud-blocks are placed in the slope *a e* of the fill, in the same manner as the pony bent is placed, and no part of the trestle is buried by the fill. There is always danger of additional settling, and it is far safer to run the bents from the original ground surface. The part of the timber that is buried will decay rapidly; therefore in a permanent structure masonry foundations are built to a height from the ground that will prevent any part of the structure being buried.

346. Protection against Fire.—Constant care is necessary to guard against the destruction of trestles by fire, not only by incendiaries, but also by live coals dropping from the firebox of the locomotive. In order to guard against the danger of the locomotive setting fire to the trestle, some railroads cover the caps of the bents with a strip of galvanized iron; others use the ballast floor system partly for this reason. In all cases barrels of water are placed on the trestle at intervals of 200 or 300 feet, if water is not otherwise accessible, special platforms being built at the level of the track to hold the barrels.

347. Cost of Framed Trestles.—The cost of framed trestles depends principally on the cost of timber delivered on the site of the trestle. Trestles cost less in a timber country. If timber must be brought from a distance, three items of cost must be considered, viz., (1) the cost of the timber at the mill; (2) the freight to the nearest point, and (3) hauling to the site of the trestle. The cost of timber trestles depends upon the cost of the timber, the amount of iron used, and the cost of erection. Contractors usually bid a price per thousand feet B. M. for the timber in the finished trestle, including all timber, iron, and work. In the timber country trestles may be built for $30 per thousand feet B. M. In sections remote from the timber country a trestle of long-leaf yellow pine may cost $60 or more per thousand feet B. M. The amount of iron used in a trestle depends upon the detailed design, but will be about $2.00 per thousand feet B. M. of timber.

ARTICLE XXXII.

AMOUNT OF TIMBER IN A FRAMED TRESTLE.

348. Amount of Timber in the Superstructure.—The amount of timber in the superstructure of a trestle is independent of the height of the trestle and may be computed per running foot of trestle. Assuming the bents to be 12 feet apart center to center, ¶ 333, the guard timbers 6 by 8 inches, ¶ 335, the ties 9 feet long and 6 by 8 inches, ¶ 334, two stringers each consisting of two timbers 8 by 16 inches, ¶ 333, and two corbels 4 feet long and 8 by $16\frac{3}{4}$ inches, ¶ 331, the number of feet B. M. will be as follows:

2 guard timbers	96
10 ties	378
4 stringers	512
2 corbels	90
Total	1076

This is equivalent to 90 feet B. M. per running foot of trestle.

349. **Amount of Timber in a Bent.**—The height of the trestle is the distance from the base of rail to the bottom of the sill, ¶ 322, and the height of the bent is the distance from the top of the cap to the bottom of the sill. The above superstructure is 2 feet 5 inches in height, therefore the height of a bent will be 2 feet 5 inches less than the height of the trestle. Assume the lengths of the caps to be 10 feet, ¶ 320, and the posts and braces to be arranged as in Fig. 188. The cap and all the timbers in the superstructure can be bought cut to the exact dimensions on account of the duplication, but since the heights of the bents will vary, it may be necessary to buy stock lengths for the posts, sills and braces and saw them to the proper length, thus in many cases causing considerable waste. In mortise and tenon joints it is necessary to allow for the tenons, which should not be less than 4 inches, Fig. 165. The lengths of the posts, sills and braces can best be determined from a scale drawing. Since stock lengths vary by two feet, being 12, 14, 16, 18, 20, and 22 feet long, and the tenons may be from 4 to 6 inches in length, it is not necessary to compute the lengths of the posts, sills and braces closer than about 1 inch. The lengths can be quickly and accurately determined by means of a drawing similar to Fig. 188. On a piece of ordinary cross-section paper, 10 divisions to the inch, draw an elevation of the highest bent required in the trestle, using a scale of two spaces to the foot, or 1 inch = 5 feet; and take a narrow strip

of the same paper and make a scale as shown in Fig. 188, and use it to measure each member to the nearest foot, being careful to take the foot next larger than the true length, unless the difference should be not over

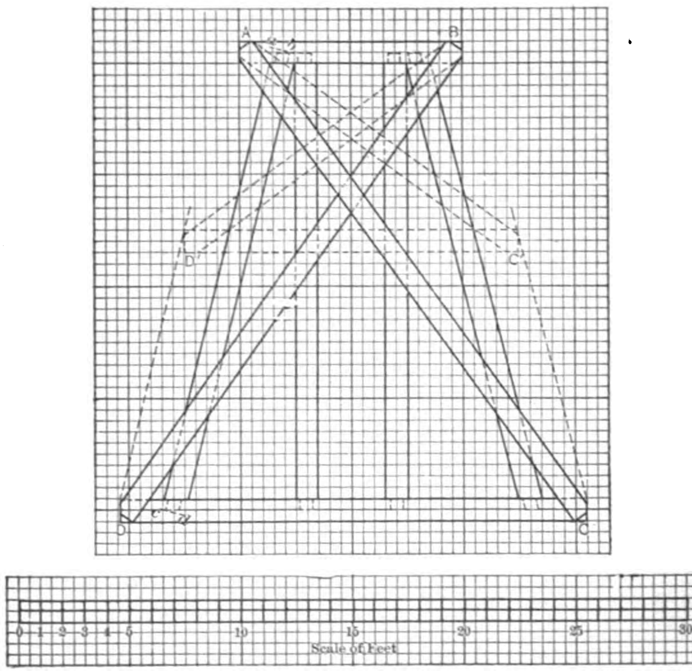


FIG. 188.

2 inches on the braces, and also on the posts when the tenons are drawn 6 inches long as in Fig. 188.

Assuming the maximum height of the trestle to be 24 feet, then the highest bent required will be 21 feet 7 inches: These dimensions are shown by A B C D, Fig. 188. It is usually possible to make a number of the bents of exactly the same height by varying the heights of the foundations a few inches. From Fig. 188 the following lengths are found: The length of the batter post is 22 feet between the lines *a b* and *c d*; the vertical post is 21 feet; the sill is 21 feet; and the braces are 26 feet long. It will probably be necessary to cut the vertical posts and sill from the stock length of 22 feet.

350. Bill of Timber for a Bent.—For the above bent the bill of timber will be as follows:

TABLE XXV.

BILL OF TIMBER OF BENT FOR 24-FOOT TRESTLE.

No.	Member.	12″×12″ Length, Feet.	2″×10″ Length, Feet.	Feet B. M.
1	Cap................	10	..	120
2	Vertical Posts.......	22	..	528
2	Batter Posts........	22	..	528
1	Sill................	22	..	264
2	Braces.............	..	26	109
			Total	1549

The drawing for a bent 9 feet 7 inches high, or a trestle 12 feet high, is shown by A B C′ D′, Fig. 188, and in the same manner as above, the bill of timber will be as follows:

TABLE XXVI.

BILL OF TIMBER OF BENT FOR 12-FOOT TRESTLE.

No.	Member.	12″×12″ Length, Feet.	2″×10″ Length, Feet.	Feet B. M.
1	Cap................	10	..	120
2	Vertical Posts.......	9	..	216
2	Batter Posts........	9	..	216
1	Sill................	16	..	192
2	Braces.............	..	16	67
			Total	811

In the same manner bills of timber can be made by the aid of Fig. 188, for any height of trestle less than 25 feet, by drawing the sill at the proper elevation.

351. Bill of Timber for the Trestle.—After the length of the trestle is determined from the profile, and the amount of timber in the superstructure and bents computed as above, a bill of timber is made for the trestle and the timber is ordered from the mill. The bents are framed on the site of the trestle. The contractor is paid for the net amount of timber after the trestle is erected. When a large amount of timber is ordered, it may be possible to get odd lengths such as 17, 19 and 21 feet and the waste be considerably reduced. If the wrong lengths of timber are ordered, the contractor is not paid for the waste.

PROBLEM 31.—How many feet B.M. will there be in a trestle bent proportioned as in Fig. 188, the distance from the base of rail to the bottom of the sill being 23 feet?

PROBLEM 32.—How many feet B.M. will there be in the stringers, corbels, ties, and guard timbers, if the span is 12 feet and the dimensions as in paragraphs 331, 332, 334, and 335?

PROBLEM 33.—How many feet B.M. will there be in the foundation of the above bent, if proportioned as in Fig. 173?

PROBLEM 34.—If all the bents in the trestle are the same height, what will be the cost of the above trestle per running foot at $60 per thousand B.M.?

CHAPTER X.

CULVERTS.

Article XXXIII.

DRAINAGE.

352. Items Governing Drainage.—One of the most important problems in connection with railroad construction is the determination of the size of the openings required by the streams over which the line passes, usually referred to as drainage. It is practically impossible to determine the required area of waterway by theoretical methods. Many elements enter into the discussion, and an approximation to the true area is made. The principal points to be determined as closely as possible are as follows:

1. Rate of rainfall.
2. Area of the watershed.
3. Shape of the watershed.
4. Character of soil and vegetation.
5. Slope of watershed.

353. Rate of Rainfall.—The rate of rainfall varies with the locality, different sections of country having not only different average yearly rainfalls, but heavy storms of short duration are more common in some localities than in others. Very heavy rates of rainfall are usually of short duration, but they occur more frequently in some sections, and an immense amount of water falls in a short time. The very heavy rate of rainfall seldoms covers more than a small part of the territory over which the storm occurs. In the United States records covering a number of years have been kept, and it is possible to obtain data of the maximum, minimum, and average annual rainfall, and the rate of rainfall, duration of the storm, and territory covered by sudden heavy storms, of all parts of the country.

354. **Area of Watershed.**—In parts of the United States that have been thoroughly mapped by the U. S. Geological Survey it is possible to determine the area of the watershed of small sections of country from the maps sold by the U. S. Geological Survey, particularly if the watershed is of considerable size. If the watershed is small, it will be necessary to determine the area in a more accurate manner, and it may be necessary to run a stadia survey around the watershed, the survey corresponding to a rough farm survey. The notes of the survey should be plotted, the error of closure showing the accuracy of the work, and the area computed. The area may be computed by latitude and longitude differences, but it will be accurate enough to measure the plat with a planimeter, or by counting the squares if plotted on cross-section paper; it will be seen later that the area need not be determined with great accuracy. The size of the drainage area governs the total amount of water that runs off.

355. Shape of Watershed.—The shape of the watershed can be determined at the same time that the area is obtained. The shape of the watershed is as important as its size. If it is long and narrow, or has long branches, a large proportion of the total rainfall will pass through the opening before the water from the farthest portions reaches the opening, particularly if the area is large and the slopes flat. The other extreme is an almost circular basin with steep slopes, in which case a proportionately larger opening must be provided.

356. Character of Soil and Vegetation.—A large proportion of the rainfall will percolate through a sandy or cultivated soil and will not be a part of the flood-flow. A clay or uncultivated soil will absorb very little of the rainfall and the full amount runs off immediately. Vegetation of any kind tends to retard the run-off by absorbing part of it and also by interfering with the flow over the surface. Rocks and trees also interfere with a free flow and retard the rate of run-off.

357. Slope of Watershed.—The slopes of the watershed are one of the most important items in governing the rate of run-off. If the side slopes are steep, and the slope of the main stream is also steep, as in a mountain gorge, the stream becomes a torrent almost as soon as the storm begins, and the largest openings in proportion to the area of the watershed must be provided. If, on the other hand, all the slopes are flat, in which case there is usually vegetation, the slowest rate of run-off will be found.

358. Methods of Estimating the Area of Waterway.—It will be seen from the discussion of the five governing items that a theoretical formula for determining the area of waterway, or opening, required is an impossibility. There are two ways of estimating the area of opening required:

1. Empirical formulas.
2. By observation.

Both methods must be governed by good judgment and experience. There are a number of empirical rules for computing the required area of waterway, two of which are in common use, viz., Myer's Formula and Talbot's Formula.

359. Myer's Formula.—Myer's formula is

$$A = C\sqrt{\text{area of watershed in acres}}$$

in which A is the area of waterway in square feet, C is a coefficient varying from 1 for a flat country under cultivation to 4 for a mountainous country and rocky ground. This formula is deficient in that it does not take into account the rate of rainfall and the shape of the watershed, and gives the same area of waterway for all parts of the world, which is manifestly untrue. In determining the value of the constant C to use, the engineer must keep in mind the five items of ¶ 352, together with experience in the same general region in which the opening is located.

360. Talbot's Formula.—Talbot's formula is

$$A = C\sqrt[4]{(\text{acres})^3}$$

in which A is the area of waterway in square feet, C is a coefficient ranging from 1 for steep rocky ground to $\frac{1}{6}$ for a long flat valley, and the acres under the radical sign is the area of the watershed. In this formula the coefficient C has the following values:

$C = 1$, for short valleys with steep rocky slopes.
$C = \frac{1}{3}$, for a rolling agricultural valley three or four times as long as wide and subject to floods due to melting snow.
$C = \frac{1}{5}$ or $\frac{1}{6}$, for long valleys where there is not much snow.

This formula takes into account, depending upon the judgment of the engineer, four of the five items in ¶ 352, but does not take into account the rate of rainfall. Both of the above methods are in reality only a careful approximate estimate as to the area of waterway required, based upon the number of acres in the drainage basin.

361. Example.—Assume the area of the drainage basin, or watershed, to be 1000 acres. From Myer's formula area of waterway required will be between 32 and 128 square feet; and from Talbot's formula, 30 and 178 square feet. These results show a very close agreement for the minimum area of waterway, but a considerable variation for the maximum. It devolves upon the engineer to approximate between these extremes and obtain as near as possible to the true area. An experienced engineer will be able to approximate the true area of waterway required close enough for all practical purposes.

It is not necessary to determine the area of waterway with extreme accuracy. The area of opening can be increased considerably by a small increase of masonry. Other conditions being equal, a circular culvert 8 feet in diameter will discharge nearly twice as much as a culvert 6 feet in diameter; but an 8-foot culvert will cost far less than twice as much as a 6-foot culvert.

362. Practical Methods of Determining Waterway.—There are two practical methods of determining the required area of waterway, viz., by comparison and by observation and measurement. The safest and easiest method is, where possible, to observe the action of a culvert over the same stream. This method can seldom be used for small openings, as a short stream is not likely to be crossed by another road, but on larger streams it is frequently possible to find another bridge which may be used for comparison.

When the conditions are such that it is impossible to determine the area of opening within reasonable limits, it will in some cases be economical to put in a temporary trestle and observe the conditions during heavy rainfalls. A trestle will last eight or ten years, which will give ample time to study the problem and obtain data from which an economical structure can be built. The depth, area of cross-section, and velocity of the water should be measured during the heaviest storm, and the volume of water in cubic feet per second be computed. The culvert can then be designed economically.

363. Storm Flow and Economic Design.—It is not economical to attempt to design a culvert with a waterway large enough for any storm that might occur. Every few years there is an unusually heavy storm. At longer periods—twenty, thirty, or forty years—there may be a storm that breaks all previous records, or at least "as bad as the storm of forty years ago" which exists in the mind of all "old inhabitants." To build a culvert to carry a storm of the last-mentioned variety would require an opening considerably larger than for ordinary storms, and the cost would be excessive. This is not economy, for two reasons: First, if well built, a culvert will not necessarily fail when its opening is insufficient, as the water can back up and discharge under a head; and, second, the interest on the difference in the first cost required to build the "safe" culvert and the culvert to withstand ordinary conditions will, if compounded, more than pay for the few culverts that may be destroyed. Culverts are therefore built to carry the ordinary heavy storms.

PROBLEM 35.—A culvert costs $3000, is washed out at the end of twenty years, and then rebuilt at a cost of $3000. How does the final cost compare with the supposition that if it had been built larger, at a cost of $4500, it would not have washed out, interest at 5 per cent.?

ARTICLE XXXIV.

CULVERTS.

364. Pipe Culverts.—Culverts are necessary at the lowest point of all railroad fills in order that the water may run off without obstruction; they usually consist of pipes, single-box, double-box, or arch culverts, the first mentioned being for the smaller openings.

For small drainage areas the most convenient form of culvert is the pipe culvert. The pipe may be either second-grade cast-iron or double-strength vitrified tile pipe. Both kinds range in size from 12 to 30 inches in diameter; a smaller size than 12 inches is not used on account of the danger of obstruction. Pipes 36, 42, and 48 inches in diameter are advertised, but only a small supply of these sizes is kept in stock, as they are not used as much as smaller sizes. These sizes must be ordered some time in advance if a large quantity is desired. Thirty-inch pipe is the usual maximum, and will be ample for an area of 2 acres under the quickest, and 25 acres under the slowest, run-off.

365. Tile Pipe.—When the embankment is not more than 10 or 12 feet high, tile pipe is better than iron pipe, being easier to handle, more durable, and cheaper. Tile pipe is more easily broken in handling, but if care is taken to cover it sufficiently with earth before dumping stone on it, after it is laid it is just as strong for all practical purposes as cast-iron pipe. Tile pipe is made in lengths of 2½ and 2 feet for small and large size respectively.

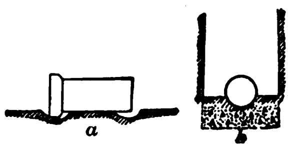


FIG. 189.

In laying tile pipe the trench is excavated with vertical sides to the depth of the horizontal diameter of the pipe; the bottom of the trench is then shaped as shown in Fig. 189, so that the bottom will be to true grade and afford a uniform bed for the body of the pipe, the earth being removed under each bell end so that the pipe will not rest on the bell. After the trench has been properly shaped and the pipe laid in, fine earth is thrown around the pipe and rammed so that the pipe will be supported uniformly throughout its length. When the soil is soft, it sometimes becomes necessary to lay the pipe in a concrete foundation, as shown in Fig. 189, *b*. In some cases a plain timber platform is used instead of concrete.

Some engineers advocate filling the joints with cement, but it seems better practice to leave the joints uncalked, in which case water in the fill may find its way into the pipe, and in case of the pipe settling it is less liable to be broken.

For culverts double-strength, salt-glazed, vitrified pipe should be used. ✓

366. Iron Pipe.—Second-grade iron pipe is used for culverts if it can be obtained, being equally as good for the purpose and considerably cheaper than first-quality pipe. It consists of pipe that has been condemned as first quality on account of minor defects, such as small blowholes or imperfect bell end. First-quality cast-iron pipe is designed to withstand internal pressure, as in a water-main; defects that would be fatal in a water-main would not hurt the pipe at all for a culvert. Cast-iron pipes are made in 12-foot lengths, and the larger sizes are heavy and awkward to handle. They are laid in the same manner as vitrified pipes, and the same discussion applies to the joints, except that cast-iron pipe with cemented joints is more liable to break in case of the foundation settling, on account of its greater length.

367. End Walls for Pipe Culverts.—In pipe culverts, either vitrified or cast-iron, the ends must be protected by masonry so that the pipe is held firmly in place and water cannot enter and seep through the fill along the outside of the pipe. The masonry may be stone, brick, or concrete, may have a plain vertical face, or may have wing walls when the pipe is large. The simplest form of end wall is shown in Fig. 190, being a rectangular wall of concrete. The foundation must be at least two feet deep in order to be below the frost line. The other dimensions will depend upon the size of the pipe and the height of the embankment to be retained. A culvert 24 inches or less in diameter will not need a more elaborate

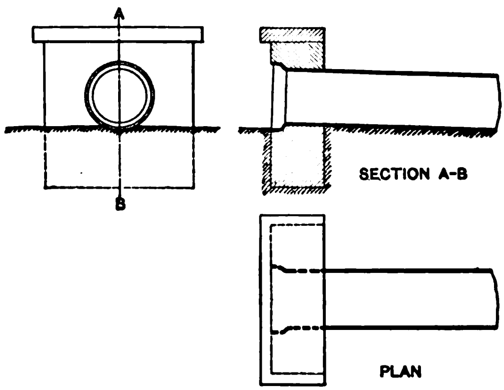


Fig. 190.

arrangement than that shown in Fig. 190, but a culvert 30 inches or more in diameter may need wing walls, an apron wall, and a paved entrance, in some cases. As end walls for pipe culverts are usually neither high, wide, nor deep, it is more convenient to build them of concrete or brick, unless suitable stone is found close at hand and cheaper. In some cases, owing to scarcity of material and there being little danger of the culvert being injured in the meantime, the end walls are not built immediately, in which cases the materials may be delivered after the track is laid, thus reducing the cost.

368. Timber Box Culverts.—In country where timber is plentiful and stone or pipe hard to obtain, culverts are sometimes built of timber. They are built large enough to allow the permanent structure to be built or placed inside of them, so that it will not be necessary to cut a trench through the embankment. In Fig. 191 is shown the general arrangement of a 3 by 4-foot timber box culvert. At intervals of about 4 feet 2 by 12-inch cross-pieces, *a a*, 5 feet long are placed.

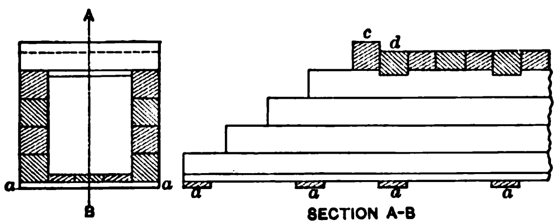


Fig. 191.

The timbers forming the walls of the culvert and the 2 by 12-inch planks forming the floor are laid on the cross-pieces. The 12 by 12-inch timbers forming the side walls are laid as shown in the figure and drift-bolted together. The top is formed of 12 by 12 and 8 by 12-inch timbers placed as shown, the end timber *c* being 12 by 12 inches, 5 feet long, and laid on the side wall timbers. The second cover timber *d* is 12 by 12 inches and notched four inches, so that it acts as a strut to hold the side walls from being pushed inward by the thrust of the embankment. Every fourth cover timber is notched in this way, and the balance of the cover timbers are 8 by 12-inch timbers laid with the 8-inch dimension vertical, all the cover timbers being 5 feet long.

The end of the culvert may be stepped as shown in the figure, thus forming straight wing walls, or may be cut off square, forming a vertical face. All timbers should be drift-bolted together.

At the present price of timber it is only in extreme cases that timber culverts are economical, and very few of them are built at the present time, particularly as they are at best only temporary, not lasting more than eight or ten years.

369. Stone Box Culverts.—Waterways under embankments are built of masonry whenever it is economically possible. A piece of well-laid masonry is practically indestructible, and in the long run is cheaper than temporary structures that cost less in the first place but must be repaired and renewed. Culvert masonry is laid in two ways, viz., with mortar and without mortar. Rubble masonry without mortar is called *dry rubble masonry*. In most cases mortar is used in the construction of culverts.

Box culverts are single- and double-box culverts.

370. Cover Stones.—The limiting feature of box culverts is the cover stone. The usual specification is that the cover stone shall have a footing of not less than one foot on each side wall and be twelve inches thick; thus for a 4-foot culvert the cover stone must be at least 6 feet long and 12 inches thick. If the stone be only 2 feet wide, it will contain 12 cubic feet and weigh about 1900 pounds. This is a size that is difficult to obtain and hard to handle; consequently a clear width of four feet is the largest box culvert built. If a greater opening is necessary, a double-box culvert is built.

The required thickness of the cover stone cannot be computed theoretically, on account of the uncertainty about the amount of load that comes on it. The greatest possible load that could come on it would be the weight of the prism of earth directly over it plus a pressure from the train; but the pressure is never as great as the above, unless there is very little fill above the cover stone, in which case the pressure could not be very great. If there is a considerable depth of fill over the cover stone, after it has thoroughly settled the earth will act as an arch, and there may be hardly any pressure at all on the cover stone.

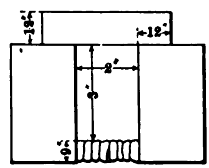


FIG. 192.

There should be at least two feet of fill above all culverts, particularly pipe and box culverts, to act as a cushion to prevent them from being broken by shocks from the engine.

371. Single-box Culverts.—The smallest culvert that is built of masonry has a clear width of opening of 2 feet and a height of 3 feet, as shown in Fig. 192. The size of opening of single-box culverts ranges from 2 by 3 to 4 by 6 feet, the dimensions varying by even feet and the first dimension being the clear width.

The narrowest wall that can be built substantially of rubble masonry is about 18 inches; the side walls of a 2 by 3 culvert are made 2 feet thick and should extend at least 9 inches below the level of the paving in firm ground and deeper in softer earth. In all cases it is necessary to have a firm masonry foundation.

In 3 by 3 and 3 by 4-foot culverts the side walls are $2\frac{1}{2}$ feet thick, in 4 by 4 and 4 by 5 culverts the side walls are 3 feet thick, and in 4 by 6 culverts they are $3\frac{1}{2}$ feet thick.

372. Double-box Culverts.—When a larger opening than 4 by 6 feet is required, a double-box culvert is built as in Fig. 193, all three walls being the same thickness. The thickness of the walls being 3 feet for 4 by 4

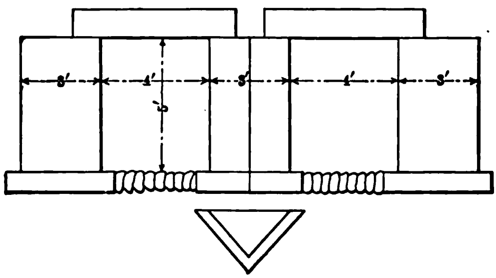


Fig. 193.

and 4 by 5 culverts, and $3\frac{1}{2}$ feet for 4 by 6 culverts. When a larger opening than 48 square feet, equivalent to a double 4 by 6 box culvert, is required, an arch culvert or a bridge must be built. If good cover stones are hard to obtain, small arch culverts will be built instead of large box culverts.

The side walls are built rectangular in form, and when the ground is soft, they are built with a footing projecting from 6 to 9 inches when, in the judgment of the engineer, it is necessary.

In double-box culverts the middle wall is built with a pointed nose, as shown in the lower part of Fig. 193; this serves the double purpose of allowing the water to enter the culvert with less contraction and also makes it more difficult for débris to lodge against it.

373. Arch Culverts.—Arch culverts are seldom built less than 5 or 6 feet in clear span, the arch being semicircular, or as shown in Fig. 194.

Arches of large span are usually built with a plain circular arc, three-centered, or elliptical. They are built in five ways, viz., stone masonry with a stone ring, stone masonry with a brick ring, all brick masonry, concrete, and reinforced concrete, the latter being used for large spans. The economical design of arch culverts is an extensive subject and will not be given here.

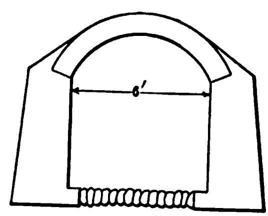


FIG. 194.

374. Special Culvert Construction.—There are a number of special features in culvert construction which are economical under the proper conditions. In many localities good masonry stone can be obtained readily, but suitable cover stones cannot be obtained. Two forms of special covers may be used, viz., reinforced concrete and old railroad rails. Reinforced concrete cover slabs are made by embedding one of the many forms of reinforcing bars in the concrete. The bars are placed about two inches from the bottom of the slab and at right angles to the length of the culvert, and at a distance apart which is governed by the clear span, the size of the bars, and the thickness of the slab. The bars extend the full width of the slab, which has a bearing of one foot on each side wall. The reinforced concrete cover slabs may be made in two ways, viz., they may be made in forms, allowed to set, and then placed in position, or the forms may be arranged so that the slabs are made in place.

Covers for culverts are made from old railroad rails by cutting them in lengths two feet greater than the clear span of the culvert and placing them on their bases, side by side across the culvert.

The culverts that have been described indicate the methods of providing for the small or minor openings, such as are most frequently met with along a railroad. Larger openings are spanned by arches or steel trusses. Wherever possible, masonry should be used, as it ranks next to a solid fill for permanency.

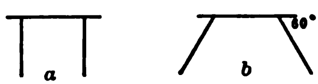


FIG. 195.

375. Wing Walls.—End walls of culverts may be plain as described in ¶ 367, or may have wing walls. Wing walls are built in two general forms, viz., at right angles to the face of the culvert, Fig. 195, *a*, or flared, Fig. 195, *b*.

The face of the culvert end wall when built without wings must be placed at the point *m*, Fig. 196, *a*, where the slope of the embankment strikes the original ground surface, in order to prevent the material forming the fill from running around the ends of the wall and into the culvert. This necessitates the length of the barrel of the culvert to be such that the part *l g* of the masonry is exposed. In addition to the extra length, the plain end wall has the further disadvantage of causing the most contraction of the entering stream of water and is the easiest form for débris to obstruct.

The straight wing walls shown in Fig. 195, *a*, may be built in two ways, viz., stepped, as shown by the full lines, and square, as shown by the dotted lines in Fig. 196, *b*. This is a very efficient form for small box culverts, the principal advantage being that it is difficult for débris to obstruct it. If rubbish strikes the outer ends of the

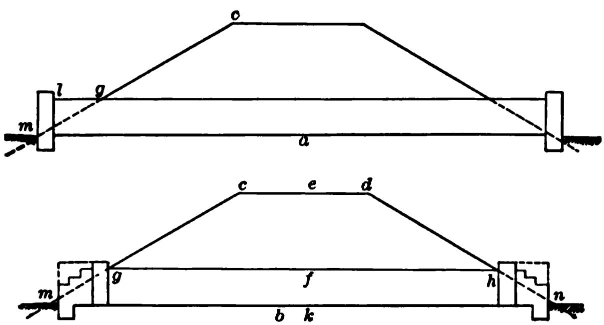


Fig. 196.

wings and lodges and forms a dam as high as the wall, the water can flow over the obstruction and drop into the culvert through the opening that will be left at the top. The principal disadvantage is that the straight wing walls are not as efficient as the flared wing walls in preventing water from entering the fill along the outside of the barrel of the culvert and undermining it.

The flared wing walls shown in Fig. 195, *b*, are the best form and have the most advantages, the only disadvantage being the cost. They are usually built at an angle of 60 degrees with the center line of track, and are stepped as shown in Fig. 196, *b*. They retain the embankment better, obstruct the entrance of the water less, débris has less chance to lodge, and the water has less chance to undermine the barrel of the culvert, than in any other form of wing wall.

376. Apron Walls.—In order to prevent water from undermining the pavement and then the whole culvert, apron walls are built. They are built at the outer

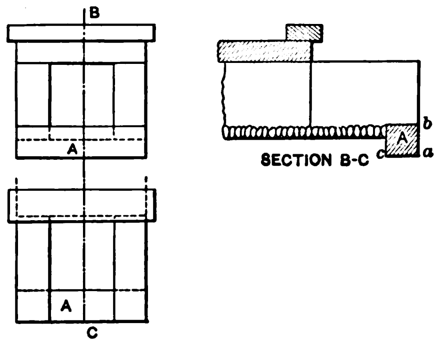


FIG. 197.

end of the wing walls, under the wing walls, and across the entire width of the opening. An apron wall is shown at A in Fig. 197. The depth *a b* should not be less than 2 feet below the top of the paving, and the width *a c* should not be less than 2 feet, and these dimensions should be made whatever amount may seem proper in the judgment of the engineer. If the end, wing, and apron walls are properly designed and built, it will be impossible for the water to undermine the culvert.

377. Paving.—The paving begins behind and against the apron wall, is about 9 inches thick, and may be laid dry or in mortar as occasion requires. The top of the paving should present a fairly uniform and smooth surface, so that the flow of water will not be impeded and that there will be no possibility of obstructions forming. The stones should be roughly of uniform size and of a thickness equal to the required depth of the pavement. On account of the smaller coefficient of friction and the consequent greater discharging capacity, it will in most cases be better to smooth the surface of the pavement with mortar. When the paving is laid in mortar, there is no chance of trouble due to water passing between the stones and softening the foundation.

The paving should slope in the direction of the current; the steeper the slope, the greater the discharging capacity of the culvert; but as masonry should be built with its foundation horizontal, the pavement cannot be sloped much without expensive special construction. A pipe culvert may, however, be laid on quite a steep slope—possibly one foot in ten.

378. Location and Length of Culverts.—Culverts are placed at the lowest part of a fill, or in such location that all water from the drainage area can find ready access to it. The top of the paving is placed at the elevation of the lowest point in the profile. In Fig. 196, *b*, the point *k* in the surface of the paving *m n* is the lowest point in the profile, *e* is the corresponding point in the grade line, *f* is the top of the barrel of the culvert, *c d* is the width of roadbed, and the distance *e f* is governed by the size of the culvert and is determined by the above conditions. If the side slopes $c\,g$ and $d\,h$ are 1 on $1\frac{1}{2}$, then the length of the barrel of the culvert is

$$g\,h = c\,d + 3\,e\,f.$$

Suppose a 4 by 4 box culvert is to be placed in a fill 20 feet high, then $e\,k = 20$ feet, $e\,f = 15$ feet, and if $c\,d = 16$ feet, $g\,h = 61$ feet.

379. Culvert Masonry.—Culvert masonry is divided into two or three classes. When divided into three classes, they are (1) culvert masonry, (2) paving, and (3) coping. In some cases the coping is included in the general term culvert masonry, which leaves only two classes, viz., culvert masonry and paving, and contractors bid on these classes, the price per cubic yard being the same for all culverts of the same general class.

In computing the amount of masonry in a culvert it is divided into two parts, one part being independent of and the other dependent upon the length of the culvert. The amount of masonry in the end walls, wing walls, and apron walls and the corresponding part of the paving for a culvert of a certain size and design is constant and independent of the length of the culvert. The amount of masonry in the barrel of the culvert depends directly upon the length of the culvert, and can be computed in cubic yards per running foot. After standard plans giving the proportions and dimensions of the culverts have been adopted, the number of cubic yards in each part of a culvert can be put in tabular form, by means of which the cost of a culvert can be quickly computed after the length of the barrel, $g\,h$, Fig. 196, *b*, has been computed.

In the following tables the wing walls are stepped on a 1 on 1½ slope, make an angle of 30 degrees with the center line of the culvert, or 60 degrees with the center line of track, and have the same width as the side walls of the culvert, being the same as given in ¶ 371. The apron walls are two feet wide for a 2 by 3 culvert, and two and one-half feet wide for all larger sizes, and three feet deep in all cases.*

TABLE XXVII.

SINGLE-BOX CULVERTS.

	Cubic Yards of Masonry in Wings and Aprons (Both Ends).					
	2 × 3	3 × 3	3 × 4	4 × 4	4 × 5	4 × 6
Wing Walls	3.975	5.469	10.722	10.722	15.417	20.733
Apron Walls	4.889	7.292	8.703	9.259	10.092	10.925
Coping	.889	1.111	1.111	1.333	1.333	1.333
Paving	.713	.780	1.476	1.711	2.550	3.426
Totals	10.466	14.652	22.012	23.025	29.392	36.417

TABLE XXVIII.

SINGLE-BOX CULVERTS.

	Cubic Yards of Masonry per Running Foot of Culvert.					
	2 × 3	3 × 3	3 × 4	4 × 4	4 × 5	4 × 6
Side Walls	.556	.694	1.056	1.056	1.278	1.750
Covering	.148	.185	.185	.222	.222	.222
Paving	.056	.083	.083	.111	.111	.111
Totals	.760	.962	1.324	1.389	1.611	2.083

* L. & N. R. R.

TABLE XXIX.

DOUBLE-BOX CULVERTS.

	Cubic Yards of Masonry in Wings and Aprons (Both Ends).		
	4 × 4	4 × 5	4 × 6
Wing Walls	11.910	16.855	22.988
Apron Walls	13.148	13.980	15.091
Coping	2.888	2.888	3.000
Paving	3.402	4.780	6.434
Totals	31.348	38.503	47.513

TABLE XXX.

DOUBLE-BOX CULVERTS.

	Cubic Yards of Masonry per Running Foot of Culvert.		
	4 × 4	4 × 5	4 × 6
Side Walls	1.583	1.917	2.625
Covering	.444	.444	.444
Paving	.222	.222	.222
Totals	2.249	2.583	3.291

380. Slope of Culvert.—The slope of the bottom of a culvert should not be less than ¼ inch per foot. In masonry culverts the courses of masonry are laid horizontal and the slope is obtained by making the paving lower at the outer end. When the transverse slope of the ground under the fill is very heavy, it is necessary to excavate deeply for the upper end of the culvert in order to have horizontal courses of masonry: In some cases the culvert is built in steps. In the case of concrete or pipe culverts, however, it is possible to build the culvert or lay the pipe parallel to the ground surface, which not only makes the construction cheaper, but also gives a greater discharging capacity owing to the greater slope.

PROBLEM 36.—Compute the length of the barrel of a 4 by 4-foot culvert, the depth of fill being 20 feet and the width of roadbed 16 feet.

PROBLEM 37.—Compute the cubic yards of masonry in the barrel of the above culvert.

PROBLEM 38.—Compute the total number of cubic yards of masonry in the above culvert.

ARTICLE XXXV.

FENCES.

381. Necessity for Fences.—Fences are of two general classes, viz., right-of-way and snow fences. State laws or the State Railroad Commission usually require the railroad company to build and maintain the right-of-way fences. Failure to comply with this law makes the company liable to heavy fines, for the market value of stock killed, or double the market value, etc. In most of the States the maintaining of a legal fence and cattle guards in good condition releases the railroad company from payment for damage to stock, as the damage is then attributed to the negligence of the owner of the animal. The payment of damages to the owner for cattle killed is not the only expense saved by good fences. In many cases derailments are caused by striking cattle, and the price of the cattle is very small compared to the loss due to possible injury to passengers or crew, and damage to track and rolling stock.

382. Post and Rail Fence.—In the majority of cases a fence 4½ feet high is required. In regions where good chestnut timber is plentiful probably the best and most suitable fence is the post-and-rail fence. The posts are made by taking a round log about 8 inches in diameter and hewing off two faces as shown in Fig. 198, and then cutting as many holes through it as there are rails, usually four. These holes are about 5 inches high and 2 inches wide. The rails consists of round timbers 4 inches in diameter, or half of a larger timber, and 9 feet long. The ends of the rails are sharpened to a long, wedge-shaped point, and are tightly wedged into the post, as shown, before the next post is rammed into place. The distance between posts is 8 feet, and this length of fence between posts is called a panel. This style of fence is the most effective for turning stock that there is, especially if five rails are used, and the two lower rails are placed near together.

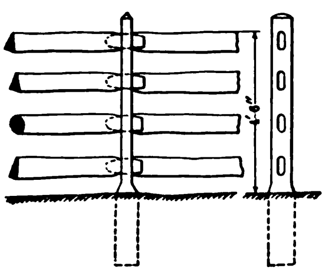


FIG. 198.

The posts are set by digging a hole not less than 2 feet deep and about 1 foot in diameter; the post is placed in it, the rails fitted in, and then the hole is filled up with dirt and thoroughly rammed around the post. From the nature of this fence there is less liability of its getting out of shape than of any other fence that is built. A fence built with chestnut rails and locust posts will last twenty and possibly thirty years. The decay of the part of the post in the ground occurs first, that being the most vulnerable part of the fence. The principal source of danger to be guarded against with this class of fence is fire.

383. **Board Fence.**—The fence that comes nearest

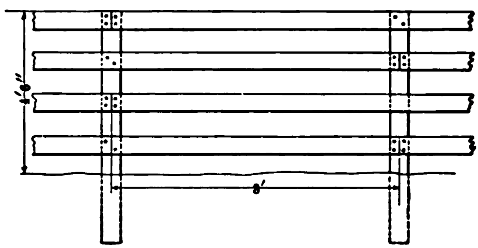


Fig. 199.

to the post and rail fence is shown in Fig. 199. This fence consists of boards one inch thick, six inches wide, and sixteen feet long, nailed to posts. The posts are square or round, with one side hewed flat for a distance of five feet, are eight feet long, and are set eight feet apart between centers. The boards are placed with ends joining on alternate posts, as shown in Fig. 199, which makes a stronger structure than if all the boards joined ends on the same post. The board fence requires considerably less timber than the post and rail fence, both the longitudinal pieces and the posts being smaller in the former;

the whole structure is lighter and the board fence is more liable to be broken. While it gives a better nailing surface to hew the front face of the post flat, very often the only requirement is that the posts shall not be less than six inches in diameter and that all bark shall be removed. The best woods for posts are locust, cedar, white oak, and chestnut.

The main advantages of post and rail and board fences are that they present an efficient barrier to stock and the stock cannot injure themselves on them. Since the requirements are that the upper part of the top rail shall be 4 feet 6 inches from the ground, four rails or boards six inches wide leave only 2 feet 6 inches for the four spaces, or 7½ inches clearance between rails, and a five-rail fence has spaces that no domestic animal can crawl through.

384. Wire Fences.—On account of the increased cost of timber and lumber, wire fences are coming into general use. The cheapest form of wire fence consists of four or more strands of either plain or barbed wire fastened to posts eight or more feet apart, by means of small staples made for the purpose, the top wire being 4 feet 6 inches from the ground. Wire fences have both advantages and disadvantages as compared to post and rail or board fences. The two principal advantages are cheapness and ease of construction, and the ease with which the ground near them can be kept clear of weeds and bushes. As the ground cannot be cultivated nearer than two or three feet from the fence, it takes continual work and watchfulness on the part of both the adjacent owner and the railroad company to prevent weeds and bushes from growing along the fence. With a wire fence this growth can be cut with greater ease, and if care is exercised around the post, the rubbish can be burned without any injury to the fence, which is impossible with a fence built entirely of wood. The burning also discourages future growth.

The disadvantages are that the smaller domestic animals, such as sheep and hogs, can force their way through it, and horses and cattle are liable to run into it and injure themselves, particularly when barbed wire is used. This latter objection has caused a board to be used for the top of the fence. This may be simply a 6 by 1-inch board nailed on like the top board in Fig. 199, A better device, which takes very little more lumber and is much stronger, is to take two strips 4 by 1 inch and nail them together T shape.

385. Patent Wire Fences.—As stated in the previous paragraph, it is almost impossible to build a fence with straight strands of wire stretched from post to post that will turn the smaller animals. This has led to the patenting of innumerable devices and kinds of wire fences. These patents vary from some method of connecting the straight strands by means of vertical strips to a wire netting. One of the simplest devices is to take small strips of wood, about 1½ by ½ inch, or plastering lath, about 1½ by ¼ inch, and weave them through the wires, as shown in Fig. 200, stapling them fast. This prevents the animal from separating the wires and squeezing through. Even when the straight strands are stretched very tight, it is possible in the space between two posts (8 feet apart) to pull one wire up and the adjacent wire down until the space between them is materially increased.

It is not worth while to describe any of the patented types of fences, as a description of one or more of them can be found in the advertisements of almost any engineering paper.

386. Gates.—On a trunk line carrying heavy traffic probably under no circumstance will an opening of any kind be allowed in the right-of-way fence, but along railroads of less importance there are still grade farm cross-

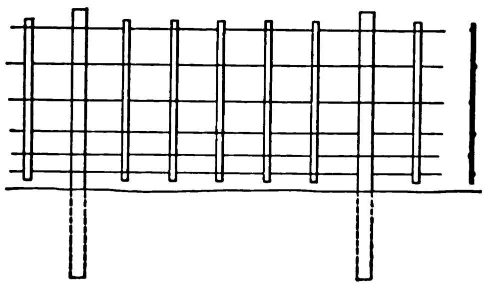


FIG. 200.

ings which necessitate a gate on each side of the railroad. While there are probably as many styles of gates as there are types of fences, gates may be divided into two general types, viz., swinging and sliding gates. A sliding gate is shown in Fig. 201. The gate is pushed to the right, sliding on the cleats *a a* until the vertical piece *b b* at the center of the gate strikes the cleats *a a*. The gate then nearly balances and is readily swung to a position at right angles to the direction of the fence. When closed, the ends of the horizontal boards of the gate project over the cleats *d d* and may be fastened by some simple contrivance.

387. Post Braces.—One of the most important points in connection with wire fence construction is

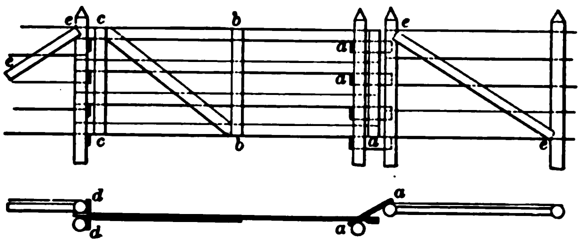


FIG. 201.

to keep the end posts in a vertical position. No post will withstand the pull of the wires unless it is securely braced. One of the simplest forms of brace is shown at *e e*, Fig. 201. This brace *e e* should not be less than

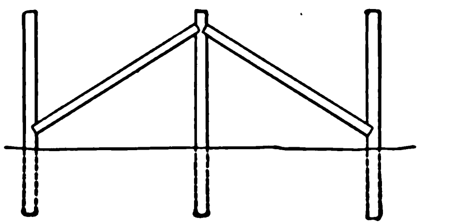


FIG. 202.

3 by 4 inches in cross-section, and should be both notched into the posts and securely nailed to the posts. When there is a long piece of continuous fence, at intervals a post should be braced both ways (Fig. 202), as it costs very little more and adds greatly to the

security of the fence, and also allows the wires to be stretched in sections.

388. Setting Fence Posts.—The depth to which posts are planted, or set in the ground, depends almost entirely upon the kind of post. The post for the post and rail fence described in ¶ 382 extends into the ground 2 feet. This amount is ample, both on account of the bottom of the post being much larger in cross-section than the top, and also, from the nature of the fence, much less strain is brought upon the post than on a wire fence post. While it is poor economy to use posts that are too light, wire fence posts are often as small as 4 inches in diameter at the top and very little larger at the bottom; this, in addition to the greater strain brought upon them, requires that wire fence posts should be planted deeper than 2 feet—probably not less than 2½ feet. The manner of planting them will depend upon the nature of the soil in which they are placed. If the ground is rocky, it will be necessary to excavate the hole the full depth, but if there is no rock, the bottom (always the larger end) may be pointed and driven the additional distance by means of heavy wooden mauls, after the hole has been dug 1½ or 2 feet deep.

389. Iron Fence Posts.—The best woods for fence posts are locust, cedar, white oak, and chestnut, in the order named. Posts fail by rotting off near the ground, due to alternate wetting and drying. All of the desirable woods for posts mentioned are becoming very scarce, and iron posts are coming into use for wire fences. On account of the small diameter of iron posts—2 or 2½ inches—it is difficult to make them stand perpendicularly and hold firmly. There are many devices for securing this. A substantial post of very simple construction is shown in Fig. 203. It consists of a piece of ordinary 2 or $2\frac{1}{2}$ inch pipe, 7 feet long, set in a concrete base. A box or nail keg is buried at the proper point, the pipe is placed in the center of it, and concrete rammed around it. Holes by means of which the wires may be attached are drilled in the post. This makes a very substantial post, and if kept painted, will last indefinitely. If the ground is firm, the concrete may be placed in a hole of the right dimensions, and no box or keg need be used. These posts can be braced by placing guy wires instead of the struts in Fig. 202.

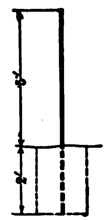


FIG. 203.

390. Snow Fences.*—" Snow is carried by the wind close to the surface of the ground and deposited in railway cuts on account of the eddies which they cause in the wind." " The function of the snow fence is to form artificial eddies on the windward side of the cut at sufficient distance to cause the snow to deposit between the snow fence and the cut."

" The location of the drift or eddy depends upon the form of the fence. A tight fence of sufficient height causes the snow to accumulate on the windward side of the fence; an open fence causes the snow to accumulate principally on the leeward side. The distance between the fence and the drift depends upon the height of the fence, the width of the openings between the

* A.R.E.A.

boards, the velocity of the wind and the character of the snow."

Where local conditions permit,* a permanent snow fence located on the right-of-way line is the most economical. The height of a permanent board fence depends upon the probable amount of snow, but it should never be over 10 feet high. In some cases temporary or portable snow fences are used.

ARTICLE XXXVI.

CATTLE GUARDS AND PASSES; ROAD CROSSINGS.

391. Location of Cattle Guards.—Where there is a permanent break in the right-of-way fence, as at a highway grade crossing, cattle guards are necessary. A stock guard, commonly called cattle guard, is a barrier in the track for the purpose of preventing the passage of stock along the track. They are placed at each side of a highway grade crossing to prevent stock from straying along the track while being driven over it; they are also placed so as to guard the approaches to

* A.R.E.A.

bridges, tunnels, and deep cuts. The important railroads are rapidly eliminating grade crossings and there are correspondingly fewer cattle guards necessary.

392. Pit Guards.—Cattle guards are of two general classes, viz., pit guards and surface guards. Pit guards are built open or covered. Practically there is only one barrier that will stop a frightened animal, and that is an open pit so wide that the animal cannot jump across it, and so deep that it cannot get out if it falls into the pit. An open pit cattle guard consists of a pit several feet deep and 8 or 10 feet wide, extending clear across the track, the ties being supported by stringers resting upon masonry walls, the whole arrangement resembling a short girder bridge. While efficient as a cattle guard, this arrangement has several serious objections. It is a serious source of danger in case of derailment, it is dangerous for track-walkers and watchmen who are compelled to walk along the track at night, and it also breaks the continuity of the roadbed, thus adding to the expense of maintaining the track. In modern railroading they are out of date and are only used in extreme cases.

393. Surface Guards.—Surface cattle guards are of two kinds, viz., those intended to present insecure footing to animals and those with projecting points intended to inflict pain. The first kind usually consists of strips of wood or metal spiked to the ties, either parallel or at right angles to the rails, both inside and outside the rails, and presenting upturned corners or edges. The ballast is usually removed as far as the bottom of the ties to aid in the intimidation of the stock. These strips or slats should be so spaced apart that there will either not be room for the hoofs of cattle or horses to slip between them, or so that their hoofs will not be caught and held fast in case they do slip between the slats.

A guard of the above description is shown in Fig. 204. The slats consist of a triangular piece of wood formed by sawing a piece of 4 by 4-inch timber as shown in Fig. 204, A. These are nailed to special ties 8 by 8 inches and 12 feet long, as shown in Fig. 204, B.

The form of surface guard designed to inflict pain is usually made of iron or steel slats, the upper edges of which are formed into saw teeth, or studded with spike-like projections, fastened to the ties in a similar manner

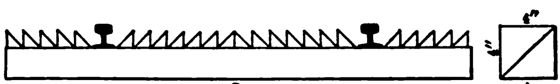


FIG. 204.

to that shown in Fig. 204. When either of these forms run at right angles to the rails, they are nailed or fastened to strips which run parallel to the rails. As a usual thing the slats run parallel to the rails. A guard formed of slats running at right angles to the rails is known as the *gridiron* pattern.

394. Relative Merits of Surface Guards.—Guards with wooden slats are most generally used. They are cheaper in first cost than metal guards, and are more cheaply and easily repaired when torn out or damaged, but this form is liable to be destroyed by fire. The objection to a device that causes pain is that it is just as severe on men who stumble on it in the dark as it is upon beasts. There is no form of cattle guard that gives entire satisfaction. In no case must the guard be of such form that man or beast can get a foot caught in it.

In all the preceding discussion only the part of the cattle guard that is placed in the track has been described. In all cases a cross fence is built extending from the right-of-way fence to a point as close to the track as the necessary clearance of the train will allow. The plan and elevation of the cross fence are shown in Fig. 205.

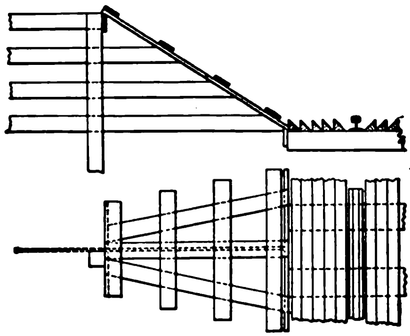


FIG. 205.

This arrangement leaves only the track apparently open, and if the track guard is efficient, stock will not be able to pass this point.

395. Cattle Passes.—Cattle passes are for the purpose of allowing stock to pass from one side of the railroad to the other without getting on the track. When a railroad crosses a farm, cutting it into two parts, and buys only the necessary width of right-of-way, the railroad is compelled to provide some way in which stock may cross. Leaving out grade farm crossings as out of date, this is usually accomplished by means of a cattle pass. They may consist of a girder bridge with the opening beneath it barely wide and deep enough for stock to pass through, or it may be large enough to drive a team through. These are subject to most of the objections mentioned in ¶ 392 about pit cattle guards. In some cases the railroad prefers to buy the entire farm, and sell the parts it does not want in such a manner that no right to a cattle pass can be claimed. If absolutely necessary to build a cattle pass and the height of embankment is sufficient, it will be better to build an arch culvert of suitable size.

396. Overhead Crossings.—On first-class railroads all highways crossing the railroad cross overhead or below the grade. No grade crossings should be put in unless absolutely necessary, and in many cases the railroad, municipality, or both jointly go to great expense to eliminate grade crossings. Grade crossings are a constant source of danger and expense. Many people are killed and injured, animals killed, and vehicles demolished every year in grade-crossing accidents. The railroad is compelled by law to maintain crossing gates and to pay the salary of a watchman to operate them, and despite these precautions, many accidents happen.

An overhead crossing consists of a bridge crossing the track, with a clearance of at least 20 feet between the top of rail and the lowest part of the clear span of the bridge. If the road crosses the railroad at a cut, the cost of the bridge is the principal expense. The general arrangement is as shown in Fig. 206. The bridge is supported on two piers and the two abutments. The distance between the gauge of the outside rail and the closest side of the adjacent pier should not be less than 5 feet, and is usually more, as the ditch should pass between the piers and the track. When the road does not cross at a cut and cannot be conveniently diverted so that it will cross at a cut, it is necessary to build artificial approaches, usually of earth. The slope of the road on the approaches should not be greater than ten feet to the hundred.

397. Under-grade Crossings.—In many cases it is found more convenient to build the road under the rail-

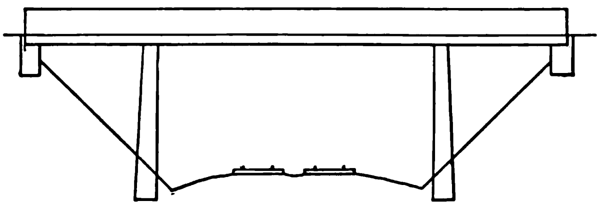


Fig. 206.

road. When there is plenty of headroom, the highway may pass through an arch, but in most cases there is not sufficient height for an arch, and a bridge is built to carry the railroad. In many cases it is necessary to lower the highway in order to get sufficient headroom under the railroad. This grading is commenced at such a distance from the railroad that the grade of the highway will not be too steep. When the highway slopes downward toward the railroad from both sides, it is often quite a problem to drain the crossing properly, as it is lower than any of the surrounding ground surface.

An overhead crossing does not interfere with the track, but it is quite expensive to lay an additional track unless the bridge was designed for the additional track in the first place. If the original bridge was not designed with a length sufficient to allow the additional track to pass under it, it will be necessary to build an entire new bridge when the new track is laid.

The ideal highway crossing is where the highway passes through a masonry arch under the railroad. In this case the track is not interfered with, and additional tracks can be laid by extending the arch. An undergrade crossing which has a bridge in the track has all the disadvantages of bridges as compared to a solid and continuous roadbed. It has the advantage, however, of allowing additional tracks to be laid by simply extending the abutments and placing additional girders or trusses.

CHAPTER XI.

GRADES.

Article XXXVII.

THE VERTICAL CURVE.

398. Change of Grade.—Gradients are shown on the profile as straight lines intersecting at an angle as at B, C, and D, Fig. 207. Assuming that the survey

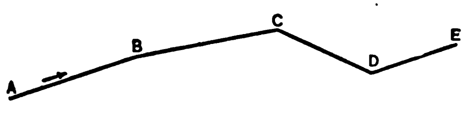


Fig. 207.

has been run from left to right as indicated by the letters A, B, C, D, and E, Fig. 207, A B is an ascending, or *plus*, gradient and B C is a plus gradient of a smaller rate per cent; C is a *summit* and C D is a descending, or *minus*, gradient; and D is a *sag*, or dip, and D E is a plus gradient. The roadbed is never built with angular, or sharp, changes as shown in Fig. 207, the change of grade being rounded off at B, C, and D by vertical curves. An abrupt change in grade, particularly as at C and D, Fig. 207, would be both dangerous and also hard on the rolling stock and track. As the engine pulling a train up the grade B C begins to descend the grade C D, the speed of the train steadily increases as the train passes over the summit C, and the engine and the part of the train on the grade C D tends to pull the rear part of the train down against the track B C, thus causing an additional strain on the car couplings as they pass C and also additional wear on the track at C. The same conditions hold for a train moving in the opposite direction on a single-track road.

The most dangerous point is at D. The train acquires a high velocity in descending the grade C D, and as the engine begins to climb the grade D E, it begins to go slower than the rear part of the train, and the rear cars crowd the forward cars. If the change of grade at D is abrupt, it may cause a car near the center of the train to jump the track and cause a wreck.

399. The Parabola.—The vertical curve to round off the change of grade could be either a part of a circle or a parabola. Since vertical curves are always flat in proportion to their length, there is no appreciable difference between the circular and the parabolic arc, and since the parabola is much simpler to construct, it is always used for vertical curves, in fact the parabola is actually used in a great many engineering problems where the theory is apparently based on the circle, assumptions having been made which in reality change the curve to a parabola.

In Fig. 208, let A B and B D represent two gradients intersecting at B, and let A P E D be the parabolic curve joining them. Draw the line A D, and the line

B e, e being the middle point of A D. Locate the middle point E of the line B e. Let P be any point on the curve, and draw P N parallel to B e. There are only two properties of the parabola that need be known in order to construct the curve, viz., the relation

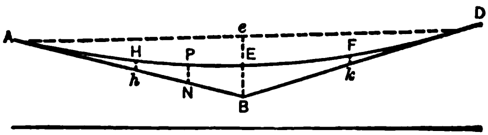


FIG. 208.

between the distances A N and N P and the distance B E. These relations are as follows:

$$BE = \tfrac{1}{2}Be \quad (a)$$

and

$$NP : BE :: \overline{AN}^2 : \overline{AB}^2,$$

or

$$NP = \frac{\overline{AN}^2}{\overline{AB}^2} \cdot BE \quad (b)$$

Since all measurements in a profile are made horizontally and vertically, and A B is always made equal to B D, we have A B = A E = E D = B D, and A N = A P, and letting A N = x, N P = y, and A B = l, and substituting in (b), we have

$$y = \frac{x^2}{l^2} \cdot BE. \quad (104)$$

If the lines h H and k F be drawn through the middle points of A B and B D parallel to B e, x in (104) becomes $\frac{1}{2}\,l$ and $y = h\,H = k\,F = \frac{1}{4}$ B E, and similarly the distance y of any point on the curve from the corresponding point on the tangent, measured on a line parallel to B E, can be determined in terms of B E.

400. The Rate of Change and the Length of the Vertical Curve.—The rate of change is the algebraic difference of the rates of grade divided by the total length of the vertical curve, or $2l$, therefore if r and r' are the rates of grade, and a is the rate of change,

$$a = \frac{r - r'}{2l} \quad (105)$$

or

$$l = \frac{r - r'}{2a} \quad (105')$$

The Am. Ry. Eng. Ass'n makes the following statements: "The length should be determined by the gradients to be connected." "On Class A roads rates of change of 0.1 per station on summits and 0.05 per station in sags should not be exceeded." "On minor roads 0.2 per station on summits and 0.1 per station in sags may be used."

A rate a is assumed within the above limits that will make l a whole number of stations.

401. Example.—Vertical Curve at a Summit.—The +0.65 grade changes to a −0.45 grade at the summit station 138, Fig. 209, the elevation of Sta. 138 being 124.00 feet above datum. Then taking a as 0.1 for a Class A road and substituting in (105′), we have

$$l = \frac{0.65 - (-0.45)}{2(0.1)} = \frac{1.1}{.2} = 5.5 \text{ stations,}$$

therefore l should be taken as 6 stations, making the total curve 12 stations long. The curve will start at

Sta. 132, elevation 120.10, and go to Sta. 144, elevation 121.30. The elevation of e will be one-half the sum of the elevations of A and C, or $\frac{1}{2}(120.10 + 121.30) = 120.70$, therefore B e = 3.30, and B E = 1.65 feet. The corrections at each station and the corrected eleva-

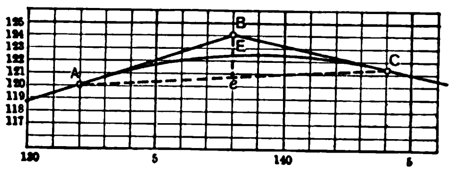


FIG. 209.

tion of each station on the curve are determined as follows:

From (104)

$$y = \frac{x^2}{l^2} \cdot BE = \frac{x^2}{36} \times 1.65 = 0.04583x^2.$$

For Stas. 132 and 144,	$x = 0,$	$y = 0$	
" 133 " 143,	$x = 1,$	$y = 0.04583 \times 1$	$= 0.046$
" 134 " 142,	$x = 2,$	$y = 0.04583 \times 4$	$= 0.183$
" 135 " 141,	$x = 3,$	$y = 0.04583 \times 9$	$= 0.412$
" 136 " 140,	$x = 4,$	$y = 0.04583 \times 16$	$= 0.733$
" 137 " 139,	$x = 5,$	$y = 0.04583 \times 25$	$= 1.146$
" 138	$x = 6,$	$y = 0.04583 \times 36$	$= 1.650$

The elevations of the stations on the vertical curve are obtained by subtracting the above corrections from the original elevations of the stations as in Table XXXI.

402. Example.—Vertical Curve in a Sag.—Suppose that D, Fig. 207, is Sta. 723, elevation 225.00, and that C D is a − 0.25 and D E a + 0.40 per cent

TABLE XXXI.

ELEVATIONS OF STATIONS ON VERTICAL CURVE.

Station.	132	133	134	135	136
Elevation	120.10	120.75	121.40	122.05	122.70
Correction	0	0.046	0.183	0.412	0.733
Corrected Elevation	120.10	120.704	121.217	121.638	121.967

Station.	137	138	139	140
Elevation	123.35	124.00	123.55	123.10
Correction	1.146	1.650	1.146	0.733
Corrected Elevation	122.204	122.350	122.404	122.367

Station.	141	142	143	144
Elevation	122.65	122.20	121.75	121.30
Correction	0.412	0.183	0.046	0
Corrected Elevation	122.238	122.017	121.704	121.30

grade on a Class A line, then the elevations of the vertical curve will be computed as follows:

$$l = \frac{-0.25 - 0.40}{2 \times 0.05} = -6.5,$$

the minus sign being neglected after the rates of grade have been properly combined as above. The curve will be 14 stations long and will run from Sta. 716 to Sta. 730, and the elevations will be as in Table XXXII.

TABLE XXXII.

ELEVATIONS OF STATIONS ON VERTICAL CURVE.

Station.	716	717	718	719	720
Elevation	226.75	226.50	226.25	226.00	225.75
Correction	0	0.024	0.097	0.218	0.388
Corrected Elevation	226.75	226.524	226.347	226.218	226.138

Station.	721	722	723	724	725
Elevation	225.50	225.25	225.00	225.40	225.80
Correction	0.606	0.873	1.188	0.873	0.606
Corrected Elevation	226.106	226.123	226.188	226.273	226.406

Station.	726	727	728	729	730
Elevation	226.20	226.60	227.00	227.40	227.80
Correction	0.388	0.218	0.097	0.024	0
Corrected Elevation	226.588	226.818	227.097	227.424	227.80

From the above it is seen that the computations for a vertical curve are made much easier by first making a drawing or accurate sketch of the lay-out, since the distance B E, formula (104) is thus easily obtained.

PROBLEM 39.—On a Class A road a +0.4 grade changes to a −0.3 per cent. grade at the summit station 286, elevation 273.00. Compute the elevations on the vertical curve.

PROBLEM 40.—On a Class B road a −0.8 grade changes to a +0.5 per cent. grade at the sag station 493, elevation 177.00. Compute the elevations on the vertical curve.

ARTICLE XXXVIII.

CLASSES OF GRADES.

403. Grades in General.—The ideal grade for a through run without stops is a straight, level track, but at points where most of the trains stop, properly designed grades may be very economical in aiding trains to stop and start. Grades are necessary on all roads in order to reduce the cost of construction: In general, the lighter the grades and the straighter the line, the greater the first cost of construction and the less the operating expenses. The road may be built more cheaply by using heavier grades and more and sharper curvature, but the cost of operating will be greatly increased. The proper grades and curvature to use can be determined only after a thorough economic study of the country through which the road is to pass, the amount of traffic, etc.

Grades are divided into two general classes, as follows:

1. Limiting, or Ruling Grade.
2. Rise and Fall.

404. Ruling Grade.—The ruling grade is the grade that limits the weight of the train that the locomotive can haul over a division of a railroad, and is usually, but not always, the heaviest grade on the division. A short grade heavier than the ruling grade, in many cases may be operated as a virtual grade, and therefore does not limit the weight of the train.

About $0.67 out of every $1.00 received by a railroad is paid out as Operating Expenses, and the greater part of Operating Expenses depends upon the size of the train load, particularly for freight, and as stated above, this depends upon the ruling grade. A road that will probably not get out of Class C, is not justified in spending much money in order to get a lighter ruling grade: On the other hand, a great trunk line is thoroughly justified in spending large sums of money in order to take out curvature and reduce the rate of the ruling grade.

405. The Length of a Division.—In locating a railroad, there are a number of governing points averaging about one hundred miles apart, through which the line must pass. These governing points are usually of considerable commercial and industrial importance, and railroad yards and shops are located there. The part of a railroad between two of these points is called a Division, and the length of the division must be such as to give an economic engine run, which is governed in many cases by the ruling grade of the division. Locomotives are changed at the end of each division, and more powerful locomotives are used on the division with heavier grades, thus allowing the same weight of train to be hauled over the entire road. In many cases it has been necessary to place the end of the division at what was originally an unimportant point, but these points soon become of importance on account of the railroad.

The lengths of some of the divisions of the Pennsylvania and the Lehigh Valley Railroads to the nearest mile is as follows:

Railroad.	Division.	Location.	Length.
P.R.R.	New York	Philadelphia to New York	92
P.R.R.	Philadelphia	Philadelphia to Harrisburg	104
P.R.R.	Middle	Harrisburg to Altoona	131
P.R.R.	Pittsburgh	Altoona to Pittsburgh	114
P.R.R.	P. B. & W.	Philadelphia to Washington.	135
L.V.R.R.	Easton & Amboy	Perth Amboy to Easton	77
L.V.R.R.	Lehigh	Easton to Mauch Chunk	44
L.V.R.R.	Wyoming	Mauch Chunk to Falling Springs	66
L.V.R.R.	P. & N.Y. (No. Br.)	Falling Springs to Sayre	83
L.V.R.R.	P. & N.Y. (Seneca)	Sayre to Manchester	90
L.V.R.R.	Buffalo	Manchester to Buffalo	87

406. Rise and Fall.—The second class of grades mentioned in ¶ 403 is Rise and Fall, which is divided into three classes as follows:

Class A. Grades so light as to require no extra effort on the part of the engine in ascending, or the use of brakes in descending.

Class B. Grades not heavy enough to be a serious tax on the engine in ascending, but require the shutting off of steam but not the use of brakes in descending.

Class C. Heavy grades, less than the ruling grade, that require the full power of the engine in ascending and both the shutting off of steam and the use of brakes in descending.

In pulling a train up a grade an engine performs work which is equal to the weight of the train multiplied by the height through which the train is raised. When the grades are properly designed, the extra work required in ascending a grade is largely compensated by the work saved in descending the next grade, particularly if brakes are not used, and the only extra work will be that necessary to lift the train through the difference between the elevations of the terminals.

The cost of rise and fall varies directly as the rise and is independent of the rate of grade. Since the ruling grade limits the train length, the cost of the ruling grade varies as the rate of grade and is independent of the rise, or length, of grade.

In the above statements, it must be kept in mind that the work due to grades is in addition to the power required to haul the train over a level track.

407. Rate of Ruling Grade.—The locating engineer cannot decide on the rate of the ruling grade until after the complete surveys of the road have been made, so that he can make a study of the grades of the whole line. Since, as stated above, the governing points divide the road into natural divisions, and the length of the division can be made an economic engine run, the problem of the locating engineer is greatly simplified, and each division may be an almost entirely distinct problem.

The ideal grade would be one over which the same class of engine could pull the train over the entire length of the road, which would be the case of a level virtual profile.

When the rate of the ruling grade is not the same on the different divisions, the weight of the train must be adjusted to the power of the locomotive, and this adjustment can be made only at the end of the division, as it would be impracticable to sidetrack a few cars whenever a heavy grade is reached and to take on extra cars after the heavy grade has been passed.

The grades on a road may be as follows:

1. All the grades may be class A and the same type of engine pull the maximum train load over the entire road.
2. The grades on a division may be class B or C and a heavier engine be used to pull the maximum train load.
3. The division may have a ruling grade and the train load must be reduced.
4. The division may have a maximum grade, heavier

than the ruling grade, upon which pusher, or assistant engines must be used.

408. Grades with and against Traffic.—A large portion of the railroad traffic of the eastern part of the United States is carried to tide-water, consequently

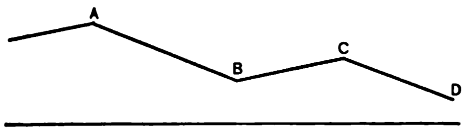


FIG. 210.

the general grade is downhill from the West towards the East. In some cases the freight traffic in one direction is nearly four times that in the opposite direction, in such cases, unless the topography absolutely forbids, the grades are designed as in Fig. 210, in which the heavy traffic is in the direction A B C D, the grades with the traffic being -0.5 and those against being $+0.3$.

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