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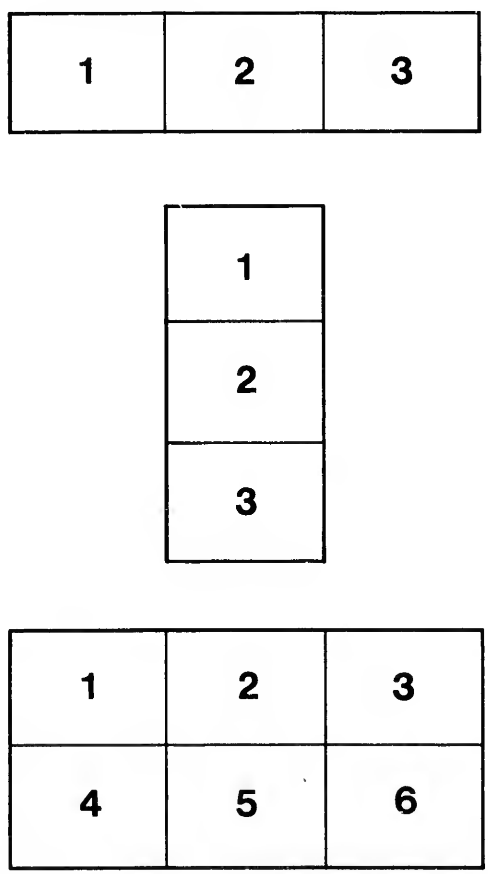

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RAILWAY

CONSTRUCTION AND WORKING.

COMPRISING THE FOLLOWING PAPERS:

I. THE CONSTRUCTION AND OPERATION OF RAILWAYS IN COUNTRIES WHERE SMALL RETURNS ARE EXPECTED.

BY ROBERT GORDON, M. INST. C.E.

II. THE LAYING-OUT, CONSTRUCTION AND EQUIPMENT OF RAILWAYS IN NEWLY-DEVELOPED COUNTRIES.

BY JAMES ROBERT MOSSE, M. INST. C.E.

III. THE ROCKY-MOUNTAIN DIVISION OF THE CANADIAN PACIFIC RAILWAY.

BY GRANVILLE CARLYLE CUNINGHAM, M. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPERS.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E.,
SECRETARY.

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THE INSTITUTION OF CIVIL ENGINEERS.

Sect. I.—MINUTES OF PROCEEDINGS.

16 March, 1886.

EDWARD WOODS, Vice-President,
in the Chair.

(*Paper No. 2104.*)

"On the Economical Construction and Operation of Railways in Countries where small Returns are expected, as exemplified by American practice."

By Robert Gordon, M. Inst. C.E.

A Paper was read lately by Mr. Edward Bates Dorsey, Member of the American Society of Civil Engineers, before that Society, in which he stated, that while the 18,681 miles of railway in the United Kingdom in 1883 had cost over £40,000 per mile, there were at the same date 110,414 miles completed in the United States, at a cost averaging £12,400 per mile, the cost of operation for the former being about £2,000 per mile, while for the latter it was £880 during 1883. The ton-mileages of the two systems were 9,589,786,848 and 44,064,923,445; and passenger-mileages 5,494,801,496 and 8,817,684,503 respectively. The average rates charged were 0·01 and 0·0012*d.* per ton-mile and 0·01165*d.* and 0·0121*d.* per passenger-mile respectively. Owing to differences of method in rendering accounts the mileage rates of working could not be compared for the whole; but by selecting the Baltimore and Ohio Railroad, which is the extreme type amongst the great trunk-lines of the American method of construction, with high summit-level, steep gradient and sharp curves, he found that the extra cost of working due to these difficulties was only [illegible] per cent.

Assuming the above figures to be fairly accurate, some corrections should be made before finally deducing a comparison. In the first place the greater portion of the English lines have double tracks, while the larger part of the American mileage is single. Again, while most of the land belonging to the American railway companies cost them nothing, and in some cases the capital accounts are reduced by sales of the land received under State grants, it is computed that in England fancy prices above the market value of the land have added to the average cost of the railways from £4,000 to £5,000 per mile. On the other hand, inflation and watering of stock are computed to have added from £2,000 to £3,000 per mile to the actual cost of American roads. The actual charges for construction are thus brought down to, say, £35,000 per mile in the United Kingdom, and to £10,000 in the United States. Making all allowances for the differences in the value of the properties and surrounding conditions, it is evident that railway construction must be carried out more economically in America than in England and in Europe generally.

Mr. Dorsey claims that a railway can be constructed on the American system at from one-half to one-fourth the cost of the English system, and be in working order in from one-half to one-fourth the time. In the rapid opening out and development of flat countries, and especially in aiding military operations of a transitory character, these qualifications, if well-founded, are of the highest importance. An examination of the principles and of the details of the American practice, where they differ from the English, may throw light on these points, and show whether it may not be possible to introduce modifications into English practice abroad, which shall render it equally capable of satisfying the requisite conditions for securing remunerative returns and outlay in a short time.

The essential differences between American and English practice originate in the universal use by the former of the bogie-truck, with short rigid wheel-base and flexible connections between the wheels and bodies for all rolling stock, as compared with the general use of longer wheel-base and more rigid connections by the latter. The developments from this initial difference cover an immense field, and all that can be attempted in this Paper will be to select the more prominent peculiarities of the American system, so far only as they may relate to economy and efficiency of results. Notices and illustrations will be given of standard types, when these exist, as used in the latest ordinary practice; and a few examples of the extreme difficulties overcome in the alignment of roads will be added. A discussion of the principles regulating such alignment will close the Paper.

It should, however, be remembered that the working of the railway-system in North America has been undergoing a great revolution within the last few years, owing, firstly, to the introduction of steel rails and rigid fish-plates, which have been found able to bear weights and wear-and-tear much heavier than the iron ones for which they have been substituted; and, secondly, to the very severe competition between the leading trunk lines for the east and west heavy freight-traffic, which has tested the powers and the endurance of rails and rolling-stock alike to the utmost. Bridges have been strengthened or rebuilt; loads of 40,000 to 50,000 lbs. are carried on the old cars which used to take only 20,000 lbs.; newer and stronger designs are still being produced—the 28-foot freight car is giving place to one of 36 or 37 feet in length; and while every effort is being made to keep down the dead-weight of cars to below 20,000 lbs., paying loads of 60,000 and 70,000 lbs., and even more, are regularly given to them.[1] No limit can yet be assigned to what the immediate future will show in this direction, but that the problem of freight-transport is in a transition stage is to be noted.

Against this, again, another and very powerful movement is operating. There is a strong tendency in America, in industrial processes, to adopt types capable of automatic reproduction in identical forms wherever possible. Several points of the railway-system come within the scope of this tendency. It is probable that by the end of 1886 nearly all the broad-gauge lines in the United States will be brought to the standard gauge of 4 feet $8\frac{1}{2}$ inches. For some years past the Louisville and Nashville Railroad (2,100 miles long) has been prepared, so that, by turning down the blank collars in the axles, all the rolling-stock can be reduced from the 5-feet gauge at a short notice. It is the practice to run cars belonging to one line over almost every other line, the owners often not regaining possession of their stock for months or years. Numerous small but important variations in the size and shape of wheels and of rails have thus acquired prominence, and the Master Car-Builders Association, and kindred societies such as the Master Mechanics and others of the employées of the different companies, are trying to introduce uniformity of form and size in the tops of the rails and in the treads and flanges of the wheels; and a standard freight-car-truck is also the object of much solicitude.

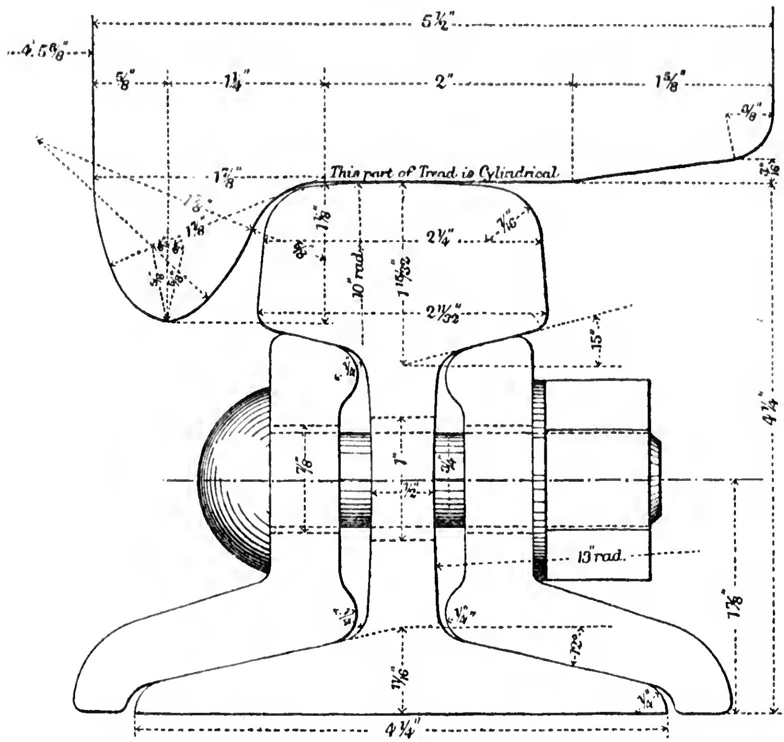
Up to the present time the only standard article universally accepted is the freight-car-axle, shown in Plate 1, Fig. 1. In 1884 its diameter was increased from $3\frac{7}{8}$ inches at the centre to $4\frac{1}{4}$ inches, and from $4\frac{3}{8}$ inches to $4\frac{5}{8}$ inches near the wheels. Its finished weight is about 400 lbs. A 33-inch chilled cast-iron wheel,

[1] Mr. Whitney says ("Railroad Gazette," 20th March, 1885), "The recent freight-car has a capacity of from 40,000 to 60,000 lbs., and it is frequently loaded to 70,000 lbs. or more. Trains on heavy grade roads are, say, sixty or seventy cars, and they are run at a minimum speed of about 18 miles per hour, and frequently "make up time" at 30 miles or more.

as hitherto generally used, is also shown, with the shape of tread and form of head of rail proposed for general adoption (Fig. 1). These forms and sizes are still under consideration; but it is probable that, with some slight modifications, they will be accepted as the universal standard throughout North America.

The increased burdens on freight-cars have severely tried the cast-iron wheel; and while those produced by the best makers

Fig. 1.

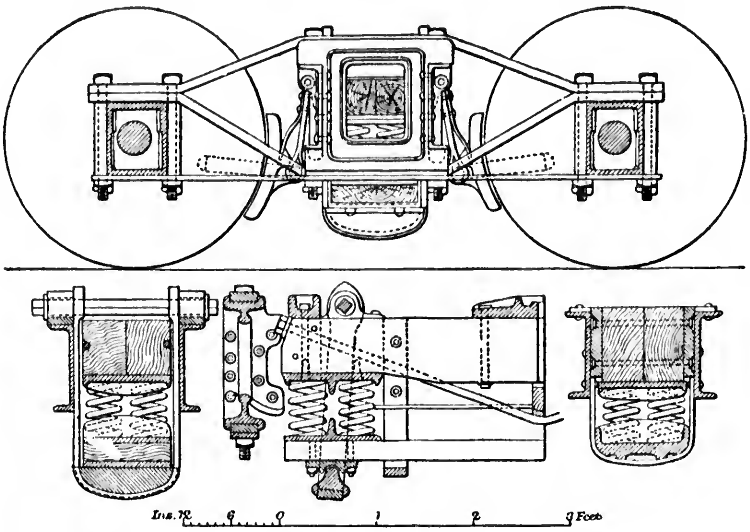


Standard wheel-tread and Head of Rail.

still yield good results of from 40,000 to 70,000 mileage averages, the general average has been reduced considerably, and on the Boston and Albany Railroad has fallen from 50,000 to 29,000 miles. There has, therefore, been a tendency of late years to resort to steel-tired wheels, some of which have an average life of over 300,000 miles, and in the end prove more economical than the cheaper cast-iron.

The most important step yet aimed at is the establishment of a standard freight-car-truck. Under the guidance of Mr. M. N. Forney, efforts have been made for some years to secure this result; and with the active concurrence of many experienced builders, there is a prospect of the design, Fig. 2, being adopted. This truck has a wheel-base of 5 feet. Its framework is of the so-called diamond type, the name being taken from the shape of the sides. The car body is loosely connected to it by a centre-pin held vertically in the middle of the bolster, on which it can turn a complete circle. The bolster itself rests on springs, and may be either rigid laterally, or have a swing-motion. Diversity of opinion exists as to the value of this motion for freight-cars, but it

Fig. 2.



Standard Freight-Car Truck.

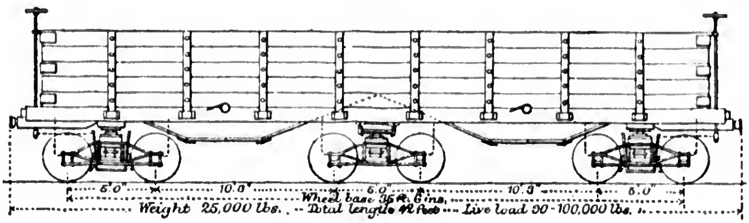
is universal for passenger-cars (Plate 1, Fig. 2), and it is estimated that one-half of the freight-cars have it. In passenger-car trucks the bolster and spring-plate are carried on side equalizing bars, which rest on the axle-boxes, and further lessen shocks from the road-bed by additional springs. In principle all the trucks, whether for cars or engines, are the same, and aim at giving the greatest amount of ease of motion compatible with safety. This flexibility, with the short rigid wheel-base of 5 feet, is characteristic of the American freight-car in contrast with the absence of flexibility and long rigid wheel-base of 8 or 9 feet in an English goods-wagon, and these qualities enable the former to work well on rough roads with sharp curves that the latter could not run upon.

In Plate 1, Figs. 3 and 4, are given respectively the latest designs of Mr. Ely for the Pennsylvania Railroad (4 feet 8½ inches gauge), and of Mr. Congden for the Union Pacific narrow gauge (3 feet.) The former is for cars to carry 60,000 lbs. It is built entirely of iron, Mr. Ely being of opinion that the limits of safe strain for wood have been passed. The Union Pacific narrow-gauge truck is to carry cars with 40,000 lbs. burden, or the same as the standard-gauge car-trucks of the same company. Its wheel-base is 4½ feet, or 6 inches less than that of the standard truck. With the exception of the bolster and spring-plate, which are of wood, all the parts of the standard truck are of iron; and it will be possible to substitute iron, as in the Pennsylvania truck, for the wood. In this case every separate part may be reproduced with the utmost accuracy; and, if a standard of strength and quality of metal can be secured, there will be a complete interchangeability of the different items, and a consequent reduction of cost both in the material and in the labour of putting the parts together.

It is impossible to exaggerate the extreme importance of this in an economical direction. The truck itself is less a design than the product of evolution from a myriad of variations of design worked out in millions of examples. It is the crystallized embodiment of experience under a multiplicity of requirements; and, once finally chosen, it is likely to remain for the next quarter of a century without change except in improvements of detail. It is estimated that about 800,000 freight-cars are in use in the United States alone. Delays and complications arise through want of uniformity in the size and strength of the parts in making repairs, and the immense advantage to accrue from a universal standard must bring about a very rapid conversion of the whole to the new pattern. It is obvious that the facility of reproduction of each part by special machinery on such a scale must minimize the cost so much that even if it were possible to work out a better design (unless an entirely new departure), the present one must dominate and supersede all others, exactly as the standard gauge of 4 feet 8½ inches has driven out others; and wherever competition is open in other countries the proved qualities of small cost and great efficiency must give it the preference over all rivals. In the Author's opinion this standard freight-car-truck, having established itself by the survival of the fittest, is likely to become the initial point and unit of reference for ordinary railway-work in new countries in the future, and it remains for manufacturers to study how far they can give the highest excellence of quality to each part at the least cost.

Though designed to carry 40,000 lbs. in each car, it will probably be often burdened to twice that amount, as the tendency is unmistakable, and cannot be restrained, to increase the proportion of paying-load to dead-load in the cars. The only limit on each line is the power of the bridges to sustain the trains, or rather the increased weight of the engines now made. As a rule only two trucks are used to each car, but latterly a third truck has been introduced under the centre of the car body (Fig. 3). This gives support just where the trussed framework of the bodies is weakest, owing to the door-aperture being there. Plate 1, Figs. 7 and 8, give drawings of late designs of freight-cars in general use. The hopper gondola-car of the Pennysylvania Railroad is designed to carry 60,000 lbs., and weighs only 19,800 lbs. By dispensing with the hopper it becomes a plain gondola-car; and if the sides are re-

Fig. 3.



Three-truck Freight-car.

moved it is a common flat-car. The box car of the West Shore Railroad is heavier than usually designed, as it weighs over 24,000 lbs. to carry 50,000 lbs. The stock-car and refrigerator-car for meat and garden products are similar to this in structure, but have special fittings.

The Author does not consider that any claim can be made for exceptional economy in the conveyance of passengers in America, nor is it more efficient than in England. An ordinary passenger-car and an emigrant-car of the latest type are shown in Plate 1, Figs. 5 and 6. The wheel-base ranges up to 7 feet for four-wheel trucks; but larger cars have six-wheel trucks with over 10-feet wheel-base. The usual length of car is from 50 to 60 feet, carrying 50 to 70 passengers in ordinary cars, with a total load of 40,000 to 60,000 lbs.; but some parlour-cars take only 20 to 30 persons, with a total load of over 80,000 lbs. Special accommodation is given, but, as economy is the object of study, that does not enter into consideration. The peculiarities of the cars, with end-platforms and steps, through communication and accessible conveniences, are well known.

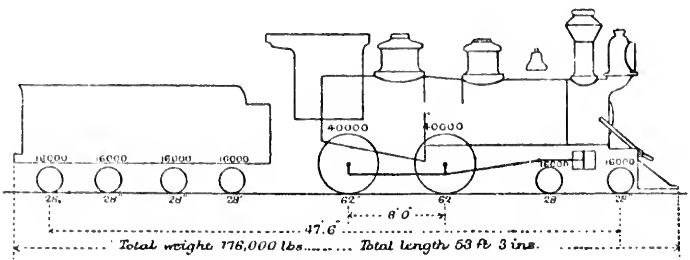
All rolling-stock is connected with central couplers, and attempts are being made to secure uniformity in these for all the lines, but up to the present little has been done, though standard draw-bars and links have been proposed. Committees have been formed to deliberate on the best kind of automatic couplings; but as there are from 3,000 to 4,000 of these offered, a decision seems difficult. In the meantime the Miller and the Janney, with combinations of both, are extensively used for passenger-cars, and are recommended for freight-cars. Standard switches and frogs are strongly advocated.

The practice is becoming general, and opinion is universal in favour of automatic brakes being applied to freight-cars, preference being given to separate application on every wheel. The Westinghouse air-brake is extensively used, but its expense of about £10 per car, besides the cost of the engine on the locomotive, is against its universal adoption, though its efficiency is well known. Brakes costing £3 per car, and others £2 per car, are advocated, but they have not proved efficient enough to secure wide support.

A separate Paper would be necessary to discuss the differences between English and American locomotives, but as the sole essential difference, if it can be said still to exist, is the universal use of bogie-trucks with the shortest possible rigid wheel-base for the drivers in the latter, so far as the economy of construction and working of roads is affected, a mere enumeration of the others will suffice at present. In the American locomotive, Plate 2, Fig. 1, the solid bar-frame is retained, generally forged throughout, and it is rigidly connected to the boiler, forming with this a complete truss. This is in marked contrast to the English plate-frame, complete in itself, connected comparatively loosely by a few bolts to the boiler, which rests upon it as on a cradle. Opponents of the latter allege that there are not sufficient diagonals or lateral stiffness to prevent deformation under side-strains, and trace the breaking of crank-axles and of coupling-rods to this cause; while it is certain that frequent total failures of the American frames occur, particularly at the welds. Outside cylinders are universal in American practice, with steel fire-boxes, cast-iron wheels, and equalizing bars for all the wheels. In engines with long wheel-base alternate sets of wheels have broad treads without flanges, and are called blanks. Minor differences from English practice, such as the cow-catcher, the spark-arrester on the smoke-stack, the enormous lantern, the bell, and the commodious cab for the attendants, with a more ornate general appearance, are to be observed in American locomotives.

Of late years in the best English practice the principle of flexible wheel-base in locomotives has been adopted, so far that the American bogie, or the Adam's bogie, or some equivalent like Mr. Webb's radial axle-boxes, is in general use; while on some lines equalizing bars are also used. The permanent way of English railways does not necessitate the practice being carried so far as in America; but having admitted the desirability of a flexible wheel-base, there is no reason why manufacturers of locomotives should not push it to the fullest extent of which it is capable in preparing engines for economical railways abroad. No English engineer will admit that in excellence of material or

Fig. 4.



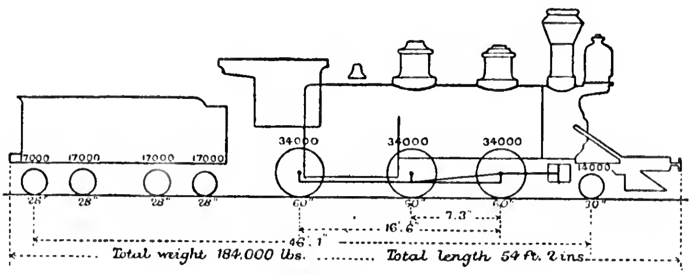
American.

workmanship, or skill in design, the locomotives made in this country are behind any in the world; but it is none the less obvious that unless they are adapted for rough and cheap roads, and made capable of working easily upon them, they will be driven out of the field by competitors fulfilling those requirements.

Sketches in outline to a scale of $\frac{1}{200}$ are given, with a few data of late practice in American locomotives, showing the principal types in use. Engines with a single pair of drivers are used, but only rarely; the ordinary passenger- and light goods-traffic being mostly worked by the so-called "American" engine (Fig. 4), with four drivers coupled, and a four-wheel bogie. The Baldwin Locomotive Works, which may be taken to represent the best American practice, make this engine with wheels up to $5\frac{1}{2}$ feet diameter, and a rigid base of $8\frac{1}{2}$ feet, the weight of ordinary sizes in working order being from 56,000 to 80,000 lbs. The "Mogul" type has six drivers coupled, the central pair blank, usually from

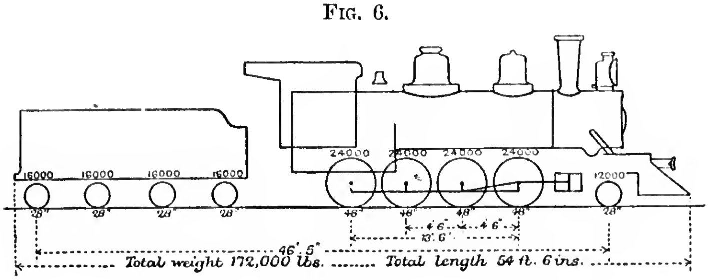
4 to 5 feet in diameter, and 14 to 15 feet length of base; the weight usually ranges from 40,000 to 90,000 lbs. in working order. The one shown in Fig. 5 is exceptionally large and heavy, and was made for the Philadelphia and Reading Railroad. It has a pony-truck of two wheels, with a radius-bar. The Mogul is used for freight trains on ordinary gradients. So-called "Mixed" freight-engines, or Moguls with four-wheeled trucks, and a somewhat shorter driver-base, are also used; and six-coupled drivers without bogies are used as "Pushers" on the Pennsylvania

FIG. 5.



Mogul.

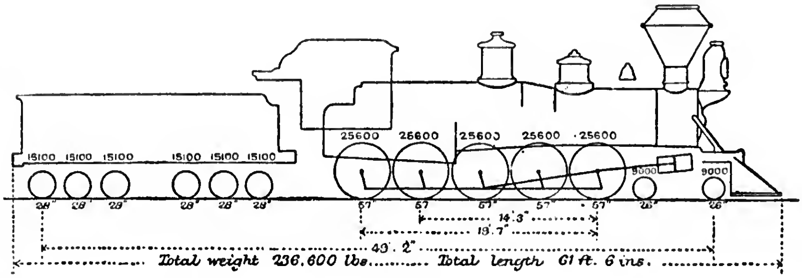
FIG. 6.



Consolidation.

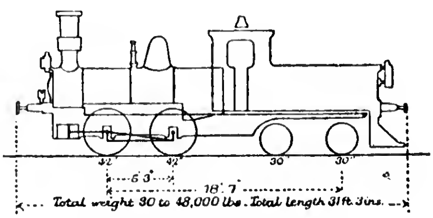
Railroad, in rear of heavy trains going up steep gradients. "Consolidation" engines of eight coupled drivers are used as "Headers" on mountain lines and undulating country. The wheels usually range, on standard-gauge roads, about 48 or 50 inches in diameter, with not over 15 feet rigid base, the central pairs being broad blanks. From 85 to 90 per cent. of the weight, which usually ranges on standard gauge from 80,000 to 120,000 lbs. in working order, is thrown on the drivers. Of late years the "Decapod," or ten-wheel coupled drivers, and bogie-truck on two or four wheels, has been developed both for narrow-gauge roads of 3 feet and for standard-gauge roads.[1] The figures given in the sketch are those of "El Gobernador," made for the Southern Pacific Railroad, the largest engine in the world, where it is used for taking 500-ton trains up grades of 116 feet to the mile. The last sketch (Fig. 8) is of the "Forney" type, where the tender is carried in the same framework with the engine, on a four-wheel bogie, and four coupled drivers of short base. This is run with the chimney in the rear. The engine is much used on suburban lines, and on the Elevated Railroad in New York, taking trains round curves of 90-feet radius, and giving much satisfaction. Its weight is 32,000 to 36,000 lbs.

FIG. 7.



Decapod.

FIG. 8.



Forney.

Contrary to what might be expected from the ingenuity and adaptiveness of the Americans, the tendency in railway construction and operation is less in the development of new principles and designs, in order to secure greater economy and efficiency, than in improving and perfecting the older types and practices, and bringing them to standard forms for universal adoption. So that, in wishing to benefit by the results attained, it will be sufficient to examine the extreme limits reached, and to study the latest modern practice.

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[1] The rear pair of wheels is allowed to move laterally on curves.

Thus, even the most economical roads must use the ordinary freight-car of 20,000 lbs. weight, and load it to the limit allowed by the bridging. In designing new roads with the utmost attention to economy, the best practice tends to make the bridgework strong enough to carry a train of locomotives such as are to be generally used on the roads; and, following this out to its legitimate conclusion, the freight-cars should be loaded to their utmost capacity to secure the greatest proportion of paying load to dead load within the limit of equal weight per lineal foot of cars for weight per lineal foot of locomotive. This is already being approximated to on the best lines using the heaviest engines. On the new road now in course of construction in South Pennsylvania, the bridges are designed to carry a train with two coupled "Consolidation" engines, each weighing with tender 171,000 lbs., with 24,000 lbs. on each pair of drivers; or one "Decapod" of 195,000 lbs. with tender. The iron bridgework of the Canadian Pacific, as designed by Mr. Shaler Smith, is to carry a train of locomotives, of "Consolidation" type, with 21,260 lbs. on each pair of drivers; and a total weight with the tender of 166,820 lbs. on a length of 56½ feet, or nearly 3,000 lbs. per lineal foot. The Atchison Topeka Railroad bridgework has been designed by Mr. A. A. Robinson to carry a train of "Consolidation" engines, with 24,500 lbs. on each pair of drivers, or 160,000 lbs. on a length of 57½ feet. The Pennsylvania Railroad Company requires similar tests for its bridges, where two "Consolidation" engines, followed by a train weighing 3,000 lbs. per lineal foot, are to be carried according to Mr. Wilson's designs. And in the general practice of the best makers and designers, weights ranging from 3,000 lbs. per lineal foot for first-class bridges to 2,000 lbs. per lineal foot for lighter lines, following two of the heaviest engines employed on the road, are used for calculating the strains. If the present freight-cars of 20,000 lbs. weight are loaded to 70,000 and 80,000 lbs., as is sometimes done on the Pennsylvania and other first-class roads, this limit is nearly reached already with 36 or 37 feet cars; and with twelve-wheel, centre-trucked cars, where a still higher proportion of paying load is sought for, it will soon be reached.

Already, trains averaging one hundred loaded cars are taken over the Pennsylvania Railroad. On steep gradients they are conveyed by two "Consolidation" headers, and one pusher. Probably they take some 3,000 tons of paying load per trip. It is in this direction of enormous paying train-loads, carried on a minimum of dead weight, that economy is sought on the trunk-lines in the heavy east-and-west traffic, and the best authorities look forward to a steady though gradual increase in rail-weight and in paying load on twelve-wheeled cars on all these lines.

Up to the present steel rails weighing 82 lbs. per yard are the heaviest used in America, a portion of the New York Central Railroad having been laid with them. As the cross-ties or sleepers are invariably closer together in American than in English practice,[1] this implies a greater strength of way than the same weight in England. The rails are mostly 30 feet long, and at least sixteen cross-ties of 8 feet to 9 feet in length, 8 inches in width, and 6 to 7 inches in depth, are generally laid to each length on the stándard gauge. Oak or other hard wood is principally used, and this averages eight to ten years' life. The flat foot of the rail is from 4 inches to 4½ inches broad, so that, with the larger number of sleepers, the bearing-surface is much greater on the wood than in English practice; and this again has a broader spread on the earth, securing more elasticity to the roadway.[2] Where timber is cheap, and good ballast scarce, the number of cross-ties is increased. The principal trunk-lines have been using steel rails weighing 65 to 67 lbs. per yard, a few having rails of 69 lbs., and, when traffic is not great, of 60 and 61 lbs. per yard; while for branches and lighter lines rails of 55 and 56 lbs. are used, standard-gauge roads rarely having anything lighter than this. Narrow-gauge roads of 3 feet width, like the Denver and Rio Grande, are supplied with rails of 40 lbs. There is a decided set of opinion amongst the best American engineers against light rails either for narrow-gauge, or so-called light railways. Economy is to be sought for elsewhere than in either rolling-stock or permanent-way, meaning by this the rails and sleepers. An extensive prejudice exists against gauges less than the standard, which experience has proved to be the most suitable for all traffic except in extremely difficult mountain regions.

It remains to seek for the economy of construction of American railways in the small outlay in first cost of grading, alignment, and heavy works, and in the gradual adaptation of the roads to the traffic requirements. A glance at the hypsometrical map of the American continent, and the network of lines running over every

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[1] From 18 to 23 inches apart in American against 33 to 36 inches apart from centre to centre in English, or from two-thirds to half the distance.

[2] The bearing-surface of the rails on the sleepers averages (2,800 × 8 inches × 4½ inches =) 1,322 square feet; and of the sleepers on the ballast (2,800 × 8 feet × 8 inches =) 15,000 square feet per mile.

part of the United States, shows that no exceptional facilities have been naturally offered for the roads; and a closer examination of what has actually been done proves that extraordinary difficulties have been surmounted by first-class lines and light lines alike.

The United States is divided physically into two immense plateaus of equal extent by the 99°th meridian, that to the east rising from sea-level to an average elevation of less than 1,000 feet, while the western one rises to a mean height of over 5,000 feet above the sea. The latter forms the base of the Cordilleras, which is broken up into the minor ranges of the Cascade, the Wasatch and the Rocky Mountains, which last spread out in Colorado, in a table-land from 5,000 to 10,000 feet high, with peaks rising to over 14,000 feet, and passes from 10,000 to 12,000 feet above the sea. Here are found the narrow 3-feet gauge roads of the Denver and Rio Grande, and of the Union Pacific Railroads. Both to the north and the south the ranges trend lower to where they are crossed by the great transcontinental or Pacific roads. The descent from the western plateau to the eastern is generally easy, though considerable irregularities are met in the foot-hills where branches of the great Granger or north-western roads penetrate. These railways, which have been much extended of late years, are in their later examples thoroughly representative of the best and most economical system of American construction, and a short account will be given of one of them.

If the whole eastern plateau were sunk 1,000 feet, little of it would remain above sea-level but a series of islands running north-east and south-west where the Appalachian range is now. This at present has a few peaks over 6,000 feet high to the extreme north and south; but its ridge is much lower, being crossed by the Baltimore and Ohio Railroad at a summit elevation of 2,706 feet, to which it ascends by continuous grades of 1 in 45, over 11 miles long on the one side and nearly 17 miles on the other, combined with curves of 600-feet radius, with other portions still more severe. The Pennsylvania Railroad crosses the same range at an elevation of about 2,160 feet, with gradients originally of 1 in 37 and 1 in 49, combined with curves of 345-feet radius. Regrading and realignment has much improved this part of the line, over which very heavy freight-trains are regularly worked. The Erie Railroad was originally laid out with extreme care to secure the best gradients and curves over the whole line; to get over a summit of 1,374 feet, heavy expenses were incurred in making the maximum gradient 1 in 88. The policy of this has been challenged, as the cost averaged £44,440 per mile, and the line has been in a chronic state of bankruptcy ever since.

The New York Central Railroad has a maximum gradient of 1 in 56, with sharp curvatures; but its late rival, the West Shore Railway, which like it follows the Hudson river, and has a low summit to cross, secured west-going gradients of 1 in 264, and east-going ones of 1 in 176, with curves of 1,146, 1,274 and 1,432-feet radius, but at the cost of bankruptcy and absorption by its rival.

On other important lines in the same regions steep gradients and sharp curves are freely used. The Lehigh Valley Railroad has maximum gradients of 1 in 42, and one uniform slope 12 miles long of 1 in 55, of which only 2 miles are straight; curves of 574 and 718-feet radius being combined with it. Trains weighing 400 tons are run up this slope at the rate of 12 miles an hour. On the Cumberland and Pennsylvania Railroad gradients of 1 in 34 combined with 300-feet curves are regularly worked with 160-ton trains. There are altogether about nine trunk-lines connecting the Atlantic sea-board with the interior, and on over 14,000 miles of these, far more than half the traffic of the United States, is conveyed, and half the revenue earned; on most of these, severe inclines and sharp curves have been profitably worked for many years owing to the facilities offered for economical construction by the use of the short wheel-base and flexible connections of the bogie-truck. On going completely through the statistics of railroads given in the United States Census Report of 1880, there is found hardly a line of importance which does not show a free use of gradients of 1 in 100 and above it.

The Pacific roads all have steep gradients freely where required. The Southern Pacific has several miles with 1 in 46; the Union Pacific 1 in 59; the Central 1 in 46 or 116 feet per mile, which is also used by the Canadian Pacific in one continuous slope 18 miles long, with frequent curves of 574-feet radius. On the Switch back of the Atchison Topeka and Santa Fé Railroad, where it crosses the Sangre-di-Christo range, trains weighing 200 tons, exclusive of engines, were run at the rate of 6 miles an hour up a gradient of 1 in 16·6 combined with curves of 359-feet radius. So far as the first-class and trunk-roads are concerned it therefore appears that a maximum curve of 1 per cent. may be ordinarily resorted to, while greater difficulties are overcome by gradients even higher than 2 per cent.

For the most economical railways of standard-gauge the steepest gradients are resorted to, and in this the American practice agrees with the theoretical studies of Mr. de Freycinet, who in his work on Economical gradients,[1] came to the conclusion that standard-gauge lines of moderate importance, when crossing rolling country, would reach the most economical gradient in 4 per cent.[2]; but for slightly uneven and partly plain land 1·8 per cent. is the most economical gradient. The most eminent and experienced American engineers, however, attach more importance to the free use of curvature, even of great sharpness, in attaining economical construction for cheap lines. A Table is given below of curves actually employed in 4 feet 8½ inches roads:—

	Feet radius.
New York, New Haven, and Hartford	410
Lehigh and Susquehanna	383 320 309
Baltimore and Ohio	400 375 300
Virginia Central	300 238
Pittsburgh, Fort Wayne and Chicago	216
Brooklyn, Bath and Coney Island	55 to 125
Metropolitan Elevated	90 and 103·5
New York "	46, 100, 125, and 150

More than eight hundred trains run daily over the last two lines, on which there are also gradients of 1 in 50.

For narrow-gauge lines no finer specimens can anywhere be found than in Colorado, where the Denver and Rio Grande and the Union Pacific branch-lines climb mountains and traverse cañons with precipitous rocky sides with the utmost boldness and success. It is impossible to do justice to the engineering skill shown on them in a short Paper; but it may be mentioned that the former line has opened out the wild but rich mining regions with 1,650 miles of 3-feet gauge line in the last few years; while the other is still spreading many hundred miles of the same gauge through similar country. Plate 3, Fig. 2, gives a sketch of the principal heavy gradients of the Denver and Rio Grande Railway, from which it will be seen that while there is one gradient of 1 in 22 there are several long ones of 1 in 25,

[1] Les pentes economiques.

[2] The Mexican Railway has many miles on 4 per cent. gradients, and the Peruvian Railway has nearly 50 of the same in a continuous line on the standard-gauge lines. Mr. Wellington says that a reduction to 300-feet radius brings the cost enormously below what a 600-feet radius would give in very rough country; and for ordinary undulating country curves of 478 to 573-feet radius are found expedient.

combined with curves of 240-feet radius; and in one case of 193 feet. When the Author passed over the line in 1884, however, some of the more severe curves were being re-laid with radii of 383 feet as a maximum. Passenger-trains are run over these passes, sometimes of seven or more cars, with double-headers of one Mogul and one Consolidation engine; but freight-trains, with maximum loads of 246,000 lbs., are taken over by three Consolidation engines, of 16- by 20-inches cylinders, each engine weighing 70,000 lbs. On inquiring regarding the relative merits of headers and pushers on this line, the Author was told, "On our heavy grades and sharp curves we never put an engine behind as a pusher, as, in case of accident, the damage to property would be doubly increased by the pusher going through the hind end and setting it on fire, &c., as on a mountain road like ours short stops are very frequent on account of rock and land slides falling on the track. We can generally get through an accident to a passenger train, ditching the engine, baggage, and mail-cars, leaving the coaches on the rails with the occupants somewhat shaken up, but none the worse for their experience; whereas if there were a pusher on, the passengers in the rear coaches would, in nine cases out of ten, be crushed or scalded." The Author went over some 1,200 miles of the railway, and in the more dangerous parts of the main-line found the utmost precaution taken, patrollers watching it incessantly and meeting each other over short lengths.

One of the finest pieces of alignment visited by the Author was on the Union Pacific Railway, on the narrow-gauge line between Georgetown and Graymount, where the bed of a narrow valley rose more rapidly than the maximum gradient allowed on the line and the ascent is made in a continuous loop, returning over the line by a high bridge as shown in drawings.[1] Curves of 193, 206, 240, and 280-feet radius are freely used in accordance with the best American practice.[2]

The Chicago, Milwaukee, and St. Paul Railway Company owns

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[1] Kindly supplied by Mr. Blinkensderfer, Chief Engineer.

[2] This invariably allows compensation when the curve falls on a gradient by lessening the inclination as the sharpness of the curve increases. Some difference of opinion exists amongst the authorities as to the amount of reduction required, but the average given is 0·05 per 100-feet per degree of curvature. This means the angle subtended at the centre of the curve by a chord of 100 feet, the universal method of expressing curvature in America.

	1°	5°	8°	10°	12°	14°	16°	18°	20°
radius	5,730 ft.	1,146 ft.	717 ft.	574 ft.	478 ft.	410 ft.	359 ft.	320 ft.	288 ft.

and operates nearly 5,000 miles of line, and is thus the largest private railway concern in the world. It has neighbouring rivals, however, in the Chicago and North-Western Railway, and the Chicago, Burlington, and Quincy Railroad, both of which nearly equal it in mileage and in revenue, and cater for the same business. In 1883 it carried 4,591,000 passengers a total of 235,579,000 miles, and its freight traffic was 1,177,000,000 ton-miles; the rates being 1·26*d.* and 0·695*d.* per passenger-mile and per ton-mile. Its equipment consisted of 657 locomotives, about 500 passenger and other coaches, and 19,734 freight-cars, &c. It owns coal mines, from which it takes some 500,000 tons annually, and is very completely furnished with most expensive terminal facilities in the great cities, and with several workshops (Plate 3, Figs. 4 and 5), warehouses, elevators, and docks. Steel rails are being rapidly substituted for iron where these still exist. The Author went over many hundred miles of the line, visiting the principal stations, workshops, bridges, &c. (Plate 2, Figs. 7, 8, 9, 10, 11), on the invitation of the Chief Engineer, Mr. Whittemore, then President of the American Society of Civil Engineers, of whom he asked for detailed information regarding its construction.

Mr. Whittemore, who has been in charge of the line for forty years, replied as follows, November 25th, 1884:—Regarding "the American plan of constructing railways at a cost that would be remunerative in a new country, and thus make them agents of civilization and a profit to the nation, by necessity we in America build and operate railways with safety (and on our line certainly with profit) that cost, fully equipped for the required traffic, not to exceed £3,000 to £4,000 per mile. To do this we use often sharp curves, steep inclines, and structures of wood. In the first instance our lines are located with a view of cheap construction.

The practice varies, however, and Mr. A. A. Robinson, who has had great experience on steep gradients, gives as follows:—

			Per 100 feet per degree.
Rate of maximum grade	0 to 1 in 166·0	compensation	0·06
" " "	1 in 166 " 1 " 62·5	"	0·05
" " "	1 " 62·5 " 1 " 33·3	"	0·04

Mr. Blinkensderfer gives 0·03 to 0·07 in the same limits; while Mr. Wellington allows 0·06 on all maximum curves. The practice also of widening the gauge on curves varies much. Some engineers allow only the same play of ½ inch, that is given on straight lines; while others increase it ½ inch and more on curves. But opinion is unanimous in requiring a tangent between reverse curves, and sharp curves are eased off at both ends. In some cases also gradients are eased at the approaches.

We do not suppose that the line will be called upon to pass over from four to six trains per day, counting both directions, and from the income of these loads our revenue must come. In the course of time, as the revenue of the country increases, and as business demands, the lines are gradually improved, inclines lowered, curves made easier, permanent structures introduced suited to the economic demands of increased traffic, and at this point we find ourselves glad to make use of the experience of our English brethren. Thus it is estimated that could the Pennsylvania Railroad (one of our standards of excellence) cut out 1 mile of its road at an expense of £100,000 it would be policy now to do so; yet if in its inception this had been attempted, bankruptcy would have followed. We of America have much to learn and copy from England as to the construction of the perfect railway, yet should we be guided entirely by them in all our work of this character, our progress in the new regions would be at once arrested. The history of our line is peculiar. An organization commenced with but 45 miles, and by consolidation with a purchase of bankrupt lines, grew into large proportions. In 1878 our funded debt, all classes of stock and bonds, amounted to about £7,600 per mile. Since then we have constructed the following mileage—

1878 . . .	226 miles.	1882 . . .	219 miles.
1879 . . .	155 „	1883 . . .	205 „
1880 . . .	326 „	1884 . . .	40 „
1881 . . .	442 „		
	Total		1,613

all standard gauge, at a cost, equipped for business, of from £3,000 to £4,000 per mile, so that now our funded debt is, I believe, slightly less than £6,000 per mile on the 4,800 miles owned and operated by the company. At least three-fourths of the distance of 1,600 miles were into unsettled country and in advance of civilization, which however pushed forward within one year after building, and all the lines paid expenses of operation within one year after completion. As the demands of remunerative business warrant, permanent improvements in the railway are made. Whenever 40 per cent. of the gross earnings will pay interest of funded debts, then generally the balance left over, after paying operation, is expended in such improvements. In the first instance, all our bridges are constructed of wood. In the 1,600 miles of line built since 1877 we probably did not have to exceed 3,000 cubic yards of masonry. The earthwork required in building will probably average about 15,000 cubic yards per mile.

The timber-work for pile and trestle-bridges and culverts, exclusive of truss-bridging, will be about 1 foot board-measure to a cubic yard of earthwork. This does not include piles, which are paid for by the lineal foot. Truss-bridging amounts to about one 100-foot-span to each 10 miles. On our entire line we have about 94 miles of all kinds of bridging (pile, trestle and truss), or 2 per cent. of its entire length. Our timber-work costs about £6 per B. M. Piles driven about 30 cents per lineal foot, and truss-bridging, 100-feet spans, £5 5*s.* per foot, and 150-feet spans, £6 15*s.* per foot. At present we lay no iron rails. Trunk lines have 67 lbs. steel per yard. Minor lines have 60 lbs., and light-traffic lines 56 lbs. steel per yard. Cross-ties 6 inches by 7 inches, and 6 inches by 8 inches, 8 feet long, about 2,800 per mile. We now purchase only angle fish-plates 37 to 40 lbs. per pair, and spikes ½ lb. each. Our standard wooden bridges, pile, trestle and truss, etc., are shown (Plate 2, Figs. 4, 5, 6, 7). The average life of our wooden culverts and pile- and trestle-bridges is from eight to ten years, and truss-bridges nine to eleven years. In new structures we make the limit in tension 10,000 lbs., but in hanger-bolts liable to shock bring this down to from 4,000 to 5,000 lbs."

Replying to an inquiry whether the link-and-pin bridges in iron and steel in universal use in America would not allow designs to be prepared so as to admit of additional members being added as the freight tonnage increased, he says: "I would not like to attempt to design a bridge with provision for additional strength, as you propose. There would not be so much difficulty in providing for additional tension-members as for those of compression. I take it that it would be better to give the strength in the first instance."[1]

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[1] The Author laid this problem before other distinguished bridge engineers, that is: Could not the American iron bridge be so designed for economical railways as to allow of its being strengthened afterwards by additional members for increased traffic? This would dispense with the costly process of replacing light and temporary wooden bridges after eight or ten years of service, and be especially useful in countries where timber is not cheap. The replies were generally unfavourable. Mr. C. S. Maurice, of the Union Bridge Company, thus writes: "I can answer your question in a general way, by saying that iron bridges have not been built or designed in this country with this end in view. The problem which you raise has been met in practice by the construction of cheap wooden bridges known as 'Howe Trusses,' having a life of six to ten years on new lines of light traffic, and replacing them with iron bridges of standard proportions when the development of business would warrant the outlay. In some instances iron bridges which were deficient in section have been remodelled and strengthened so as to bring them up to present requirements, and in other cases bridges which were insufficient for the traffic of

Mr. Whittemore has very kindly given several drawings of works connected with the line, including the newly-designed workshops near Milwaukee (Plate 3, Figs. 3 and 6) and other places. The managers of these large railway-systems find it preferable to distribute a number of shops over the line to having them concentrated. Every branch of construction of cars and locomotives, as well as repairs, is carried on in them; but the system is general in the United States of having, as far as possible, separate articles made in special factories to standard forms and strengths, and this is found to be at once cheaper and better than each place making everything for itself. Mr. Whittemore, in sending the plans, says: "I wish to say that we see many of our faults, and wherein we can learn much from our English brethren. Before designing our shops we sent one of our best men (an Englishman) to England, and I personally examined the best shops in this country, and from the knowledge thus gained evolved ours. I could not prevail on our people to make use of cranes to the extent used in England, and in this we are at fault." For comparison, the new shops of the Chicago, Burlington and Quincy Railroad at Burlington are shown, as designed by Mr. Rhodes. The great length of engines with tenders necessitates enormous turn-tables and beds, for which 65 feet is becoming requisite.

On the Chicago and Milwaukee principal lines, or on from two-thirds to three-fourths of the system, the stations average 3 to 4 miles apart, and on the rest about 7 miles apart. There sidings are laid for passing trains, when, as in most cases, it is a single track.[1] On the Chicago and North-Western Railway the propor-

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a 'main line' have been utilized on 'branches,' where only light rolling-stock was used. In the former case, however, no provision was made in the original designs for increasing the sections, and the change has been made by substituting entirely new compression-members and floor-systems. It would be a very simple matter to design our pin-bridges so that additional *tension-members*—lower chords and diagonals—could be added at any time, but I hardly think it could be practicable to carry out the same idea with the *compressive-members* and cross-floor beams."—Athens, Penn., Dec. 28th, 1884.

[1] The problem has been raised: What is the maximum capacity of a single track? To this much attention has been devoted, but the numerous varying elements make it impossible to give a general answer of value. Mr. Thompson, of the New York, Pennsylvania and Ohio Railroad, deduced that ("Railway Gazette," 1884, p. 43) for trains running an average of 20 miles an hour, the most economical speed for freight, the maximum is reached with stations and passing-places 3·7 miles apart, when, with an allowance of six minutes detention for each train crossed, and eight minutes extra for each passenger-train passed, it is found that the limit is reached when the time of detention equals that of running

tion of side-track is 9 per cent., and on an average there are twelve trains both ways daily; the Cleveland, Columbus, Cincinnati, and Indianapolis Railway, with 30 per cent. of side-track, accommodates twenty-four trains daily; the New York, Pennsylvania and Ohio Railroad, with 35 per cent. of side-track, thirty trains both ways. The Pennsylvania, with 70 per cent. of side-track, passes fifty-one trains, passenger and freight, over its trunk lines both ways daily; and the Erie, with forty-five trains, has 90 per cent. of side-track.

As the result of his observations on several thousand miles of North American railways of all classes, from communications with distinguished American engineers, as well as from the study of papers published by technical societies and periodicals concerned with the subject, the Author has come to the following conclusions: 1st. That there is no difference in the principles underlying the American practice in the location of light railways and that of the most expensive and perfect railway for heavy traffic; and that while the former is to be looked upon as an imperfect stage of development of the latter, due consideration is usually given and provision made for the growth and improvement of the line to a better condition as traffic increases, with the least possible fundamental alteration in the line or its belongings. The highest engineering skill is as much or more required in laying out a cheap and light line as a heavy line. 2nd. The latest and best American practice rejects the use of very light rails and permanent way for an economical railway. It must be prepared for the ordinary passenger and freight cars of the country to pass over it, the only difference being that lighter loads would be carried on the light line. To fix the ideas, without attaching precise value to the figures, it might be expressed by saying that whilst 3,000 lbs. per lineal foot of train appears to be the maximum load of a freight-train on a heavy road at present, 2,000 lbs. per lineal foot is the limit of the light railway; and the bridge-work would be calculated for these loads respectively. Steel rails, weighing not less than 55 lbs. per yard, with rigid connections [sufficiently

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in the twenty-four hours, which gives sixty trains per day both ways. For fifty trains and over, the track should be doubled between the termini and the next stations. In practice it is found that grades limit the number of cars run in a train, so that, if forty loaded cars be the ordinary number on the level, only twenty are taken over undulating country by a single engine. Actually on Mr. Thompson's division, 98 miles in length, the standard engine takes nineteen cars, the Mogul twenty-three cars, and the Consolidation thirty-three cars each per train.

long to rest on three sleepers], and sleepers, not less than two thousand eight hundred per mile, with 15,000 square feet of bearing surface on the ballast, should be used. 3rd. The nature and amount of traffic to be provided for being fixed, a variety of opinion and practice appears to exist as to the mode of working it. Thus some advocate light engines and a larger number of trains in order to facilitate and encourage the growth of traffic, while others prefer heavier engines and fewer trains, with greater loads as being the more economical. In practice matters are settled very much by the conditions to be fulfilled. In the Far-West, where distances to be traversed are great and traffic is as yet small, sometimes one or two trains only are run each way per day; and here are found some of the heaviest engines in use in the country both on standard- and narrow-gauge lines, with trains loaded to their fullest capacity.[1] While in the newer countries of the Mid-west, where settlers are more numerous and movements brisker, it is good policy to run light trains oftener. The question is of importance in determining the weight and the character of the locomotives which with the previous data fix the conditions of the alignment. 4th. The practical recommendations of the alignment may be thus briefly summed up:—When no extra cost is involved by it, the same grading and curvature that could be given to the best railway the country admits of should be used for the economical line. In undulating country the surface line should be approximated to, and all undulations of not more than 13 feet may be adopted with ordinary gradients without

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[1] Professor A. Frank draws the conclusion from numerous experiments in Europe by Wöhler in 1879 and himself in 1882 (Minutes of Proceedings Inst. C.E., vol. lxxv., p. 348), that it is desirable on economical grounds to give to each engine the heaviest train it can draw, not only because it is better employed, but because the useful effect increases with the work done. The engine must not be overloaded so as to cause too much priming, &c. Again, a succession of rising and falling gradients have a very small effect on the work done, provided that the speed in descending has not to be checked by brakes. The load to be put on an engine must be calculated with reference to the steepest gradient it has to surmount, and the maximum resistance it may encounter on that gradient. It has been proved that the useful effect is practically independent of the speed, and this result has important consequences. As the speed diminishes the resistance of the air diminishes in a much higher proportion, and the traction power at the same time increases. Hence, lowering the speed is very effective in overcoming great resistances, but a limit is set to this by the adhesive force between tires and rails.

It would thus appear that independent of questions of policy, the most economical mode of operation would be with the heaviest engines the line would incurring any expense to avoid them.[1] Above that height an expenditure of from £20 to £100 for each vertical foot in height may be incurred to avoid the undulation. Where it is necessary to resort to stiff gradients they should be eased off at both ends; and for speeds of 15 to 20 miles an hour the introduction of breaks in the gradient of 5 vertical feet in height, to allow the engine to get up momentum, are advisable.[2] But where it is possible to get round an obstacle by curves these should be preferred to gradients. In the very roughest country a reduction of curve-radius from 600 to 300 feet greatly reduces the cost while in ordinary rough country 10° and 12° curves (573- and 478-feet radius) furnish the most expedient minimum curves. Local traffic and towns should be served by increasing the length of the line. Trestling should be used everywhere instead of heavy masonry or earthwork of above 10 to 15 feet in height. Split stringers, sills and caps, without mortices, where every piece can be taken out and renewed without much trouble, should be used. Terminal and station facilities should be of the cheapest kind. Level-crossings are everywhere used, even in the largest cities, in the United States. Fencing is often dispensed with, except in cattle-grazing districts.

All these matters are differences of degree and detail rather than of kind or of principle between light lines and heavy for a railway; and the general problem the American engineer sets before himself is—not which is the best possible constructed line for serving any probable traffic permanently between two places—but, of all possible lines passing through a given country, which is the one that, in a series of years after construction (taken sufficiently long to include the period of renewal of temporary works) will give at the same time a minimum of interest of first cost, and a minimum of cost of operation of the traffic likely to be developed during that period? And as the American ideal railway transcends everything yet reached in any country, and the best work yet accomplished is looked upon as a temporary or transition stage of progress, all solutions of the problems are given in a more or less tentative form as regards the data employed and

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bear, likely to be required within the first few years, and worked up to the fullest capacity with the fewest number of trains, and this actually seems to be the method employed for freight- transport and mixed-trains in the Far-west of North America.

[1] Mr. A. M. Wellington: Transactions of the American Society of Civil Engineers, vol. xiii., 1884, p. 197.

[2] "Railroad Gazette," March 27, 1885.

figured conclusions, while the principles remain true throughout all varying applications.

It is impossible to do more than give a slight sketch of these principles, and a very few of the data, in this Paper, and the Author would refer amongst others to the following writers who have treated these subjects at length. Mr. Hermann Haupt, Professor G. L. Vose, Mr. William H. Searles, and Mr. A. M. Wellington.[1] Mr. Searles gives his results mostly in a mathematical form, which permit a clear view to be taken of the more salient points. Mr. Wellington's valuable book is now out of print, but he is engaged in preparing a new edition with later data and results. A very short and imperfect notice of the results will now be given.

Mr. Wellington begins by analyzing the cost of working thirteen of the principal railways, and of all the lines of the three States of Ohio, Massachusetts, and New York. Since he wrote, the Census Report of 1880 on Transportation has been published, which gives the operating expenses of all the railways in the United States for the previous year. Treating the abstract of this in the same manner, the following results are obtained. (See next page.)

The actual cost of operation in the census year 1880 was, for freight-trains \$0·98 per train-mile; for passenger-trains, \$0·76 per train-mile. Mr. Wellington assumes the average cost of all trains to be \$1 per train-mile, a convenient unit generally adopted. Comparing the results in the last column with those obtained by him in 1877:—

——	Engines.	Cars.	Trains Wages.	Train Expenses.	Maintenance of Way.	Total.
Average of thirteen railways . . .	30·7	14·4	17·6	62·7	37·3	100
Average of railways of three States .	28·8	14·5	17·9	61·2	38·8	100
Average of all railways in the United States	25·3	13·8	28·4	67·5	32·5	100

Applying these data to the consideration of a division 100 miles long, it is shown that for small variations of length the total

[1] Haupt: "Van Nostrand's Magazine," vol. ii., p. 593 ;Vose: "Manual for Railroad Engineers and Engineering Students," 1881; Searles: "Field Engineering," chap. iii.; "Theory of Maximum Economy of Grades and Curves," 1883; Wellington: "The Economic Theory of the Location of Railways," 1877.

TABLE.

Operating Expenses U.S. Railways, 1880.				Per cent.
Description.	Amount.	Per cent.	Per cent.	
	Dollars.			
Fuel for locomotives	32,836,470·47	9·31	..	
Water-supply	2,388,866·66	0·68	..	
Oil waste, &c.	3,754,671·25	1·06	..	25·31
Repairs of locomotives	21,830,963·43	6·19	..	
Locomotives, total	60,810,971·81	..	17·24	
Repairs, passenger cars	10,558,823·99	2·99	..	13·79
„ freight „	22,595,553·09	6·40	..	67·5
Cars	33,154,377·08	..	9·39	
Wages, &c., locomotive service	27,239,567·54	7·72	..	
„ passenger	12,002,415·65	3·41	..	28·40
„ freight	28,935,135·96	8·21	..	
Wages, supplies, &c.	68,177,119·15	..	19·34	
Train expenses, grand total	162,142,468·04	..	45·97	
Repairs, road-bed and track	39,603,076·09	11·23	..	
„ renewal of rails	17,243,950·43	4·89	..	
„ „ ties (sleepers)	10,741,577·06	3·04	..	32·50
„ bridges	9,009,097·20	2·55	..	
„ fences, crossings, &c.	1,480,925·69	0·42	..	
Maintenance of way	78,078,626·47	..	22·13	
Train expenses and maintenance of way	240,221,094·51	..	68·10	100
Repairs and buildings	7,644,121·24	2·17	..	
Telegraph expenses	3,576,476·45	1·01	..	
Agents and station service	36,767,299·20	10·42	..	
Station supplies	2,871,932·69	0·81	..	
Station, &c., service	50,859,829,58	..	14·41	
Salaries of officers and clerks	12,215,850·06	3·46	..	
Legal expenses	2,457,904·98	0·70	..	
Taxes	13,283,819·10	3·77	..	
Insurance	926,633·77	0·26	..	
Stationery and printing	2,692,011·00	0·76	..	
Outside agencies and advertising	4,737,310·56	1·34	..	
Contingencies, &c.	21,328,325·70	6·04	..	
Loss and damage	3,456,264·49	0·98	..	
Expenses not above specified	621,077·00	0·18	..	
Establishment, &c.	61,719,196·66	..	17·49	
General control expenses	112,579,026·24	..	31·90	
Total expenses	352,800,120·75	..	100·00	

cost of operation is very little altered, especially if no alteration is made in the number of stations or stoppages. For each additional mile the extra expense of operation does not exceed 42 per cent. of the average cost per mile. For longer distances a larger percentage must be allowed; but, for those in practice, 50 per cent. is found to be sufficient. In projecting a new line the capitalized value of reducing the length 1 mile would be, at 5 per cent. interest, for each daily drain (round trip), £1,100. Against this, however, is the set-off that sometimes local traffic is better served by a longer line, and the expense is recouped by mileage rates. If 1 mile of line could be cut out of the Pensylvania Railroad, where it has fifty-one trains each way daily, the saving in operation would justify an outlay at the above rate of £56,100.

The testimony as to the extra cost entailed in operating trains on curves varies very widely; but it is claimed that besides allowing much sharper curves to be worked, the use of the bogie-truck reduces the expense to one-half of that found to exist with the long rigid wheel-base of European lines. Mr. Wellington is of opinion that the extra cost due to the curves is comprised within two items, the wear and tear of track, and the additional fuel used in hauling round the curves. He estimates from the data at hand that the extra wear of rails is less than 10 per cent. per degree of curvature, and track-maintenance and ties average 4 to 5 per cent. increased expenses for the same; or for 1 mile in length of continuous curve of 11° 20′ (512-feet radius) 100 per cent. extra wear and tear on the former, 50 per cent. for the latter.

The extra cost for haulage is estimated to lie between 1 lb. per ton per degree of curvature for slow speed, and ½ lb. for higher, but no satisfactory conclusion has been reached on these points.[1]

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[1] Mr. Wm. F. Shunk gives experiments on the Tyrone and Clearfield Railway, where with a rolling friction of 7 lbs. per ton to a train 350 feet long, a curve of 10° entailed a farther friction of 4·6 lbs. per ton; and a 12° curve with a train 720 feet long gave a resistance of 9·4 lbs. per ton. It was his opinion that the length of a train modified the resistance. Mr. O. Chanute considers that the resistance is inversely as the radius; and gives the formula—

$$\text{Resistance due to curvature in lbs. per 2,000 lbs.} = 0 \cdot 6 \times \frac{5{,}730}{\text{radius in feet}}.$$

This differs from the results of Von Röckl's experiments (over 2,000 in number) in Europe, who gives

$$\text{Coefficient of resistance due to curvature} = \frac{0 \cdot 6504}{\text{radius in metres} - 55} = \frac{0 \cdot 20}{\text{radius in feet} - 17} \text{ nearly.}$$

Mr. Wellington estimates the fuel consumption to be increased by 60 per cent. on a length of curvature offering the same resistance as a mile of level straight track, which is found to be 600°. The cost per train-mile per degree of curvature is thus 0·0375 when the train-mile costs 100; or per year per daily train it comes to 24·375; and, equating the value of curvature and distance, it is found that the operating cost of 1° of curvature is equal to that of 4·7 feet of distance, or 1 mile of distance equals 1120° of curvature. In estimating therefore the comparative values of two different lines between the same points, the sums of the interest on first cost in each case, and of the operating cost of the probable number of trains so far as affected by distance and curvature, can be stated and balanced.

The expense of gradients is a more complicated question, as it involves not only considerations respecting the maximum or ruling-gradient, but the direct cost of overcoming the total rise and fall in the line. The two problems presented are not only separate but different in their nature. The first limits the weight of train that the engines can draw on the line, the second is an important factor in the operating expenses. Every foot of rise implies a foot of fall, excepting the difference between the termini of a line; and the sum of the ascents and descents may be called the summit-elevation. It is obvious that when a train goes a round trip, each foot of summit-rise implies 2 feet of ascent and 2 feet of descent, thus entailing twice the cost of terminal elevation. Any two lines may therefore be compared directly by taking the total rise and fall in each and dividing by two. Using the ordinary formula for train-resistance[1] it is found that at a speed of 15 miles per hour 22-feet rise per mile, and at a speed of 30 miles per hour 31 feet per mile, doubles the resistance. Taking an average speed of 20 miles per hour, a gradient of about 25 feet per mile may be

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Mr. Searles takes the resistance to average ½ lb. per degree of curvature. Mr. Wilder, on the Erie Railroad, found by experiments with his dynamometer on trains in regular work on the whole length of that road, that with a friction on level straight lines of 3¾ lbs. per ton the curves added $\frac{4}{10}$ths lbs. per ton per degree of curvature to the resistance.—Mr. Reuben Wells, of the Louisville and Nashville Railroad, estimates that the power consumed in drawing a train over 100 miles of road, with modulus of curvature equal to 10°, would haul the same train over 110 miles of tangent. The modulus of curvature is equal to the average angle turned through in running 1,000 feet.

[1] Mr. D. K. Clark gives resistance $= \frac{v^2}{171} + 8$. Mr. Searles gives resistance $= 5{\cdot}4 + \left(0{\cdot}06 + \frac{0{\cdot}0006 \text{ weight of engine}}{\text{total weight of train}}\right)v^2$.

taken as doubling the resistance, and used for estimating the operating cost. The following ratios of extra expense over that on a level line are then found for each 25 feet of rise and fall. Repairs of engines and cars, none, though 10 per cent. may be allowed; repairs to rails and track, 10 per cent.; the two items together increasing the rate of train-mileage 4 per cent.; fuel, 60 per cent. increase, the fuel saved in descending not compensating for the extra cost in ascent. The total extra cost per train-mile is 8 per cent. when the train-mile cost is 100; and the yearly cost per daily train, round trip both ways, becomes 208 for each foot of summit elevation ($2·08 when the train-mile is valued at $1). The capitalized value of saving 1 foot of rise and fall on gradients over 40 feet per mile, and not exceeding the ruling gradient, is $41·60 at 5 per cent. interest; and 1 mile of distance is equal to 131 feet of rise and fall in operating expenses; or 1 foot rise and fall to 40 feet of distance, or to 8°·5 of curvature.

Ruling-gradients limit the weight of trains which the locomotive can haul, and it is usual to consider each division of a line separately, and adapt it as far as possible to the same method of working throughout. The length of engine-stage varies in the United States from 50 to 200 miles or more, and may average about 75 miles; and it is found most economical to concentrate any exceptional features of a line, such as extremely sharp curvature or very steep gradients, in as few engine-stages as possible, and to operate these with special or heavy engines with many drivers, or with assistant engines. Each division of the line will therefore have its own ruling-gradient adapted to the conditions of the country and to the nature of the traffic, which is sometimes much heavier in one direction than in the other. In this case the ruling-gradients are so adjusted that the same engine-effort is required to haul the light train with empty cars the one way as the heavy train the other way.

The traction-force of engines is found to vary from one-third to one-seventh of the weight of the drivers in ordinary conditions, and may be taken as averaging one-fifth. Eight-wheel drivers usually have 60 to 80 per cent. of the weight upon the drivers, while Decapods take as much as 90 per cent. The Fairlie engine, with its whole weight on the drivers, is never used in the United States. The resistance from gravity alone is, for every foot of gradient per mile, 0·0001894 per cent. of the weight. To fix the ideas, the rolling friction may be taken as 10 lbs. per ton. Thus the total resistance per ton will be = gradient in feet per mile

$\times\ 0 \cdot 0001894 + 10$, and the ratios of load to traction-power will be as follows per each 2,000 lbs. (short ton):—

Gradient in feet per mile . .	Level.	Feet. 10	20	30	40	50	60	70	80	90	100	150	200	300	400	500
Resistance in lbs. per ton . . .	10	14	17·6	21·4	25·1	28·9	32·7	36·5	30·3	44·1	47·9	66·9	85·8	123·7	162	199
Ratio of gross load to traction . .	200	145	114	94	79	69	61	55	50	45	42	30	23	16	12	10
Per cent. increase of engine tonnage per foot change of grade	4	3·1	2·4	2·0	1·7	1·5	1·4	1·4	1·2	1·1	1·1	0·9	0·8	0·8	0·8	0·8

It is found that when the ruling-gradient changes slightly, the corresponding percentage of change in the engine-tonnage is nearly uniform per foot. But the amount of this percentage of increase or decrease in the engine-tonnage required varies considerably with each gradient, being nearly five times as much on a level as in a 150-feet gradient. The change in engine-power may be made in two ways: in the number, or in the weight of the engines used. In the first case the cost of fuel, wages, oil, &c., comes to 50 per cent. more than that of operating a single engine, while it is estimated that an engine of double weight increases the expenses by 42 per cent., though this is very uncertain. But an average may be taken of 48 per cent. increase per train-mile, consequent on a change of ruling-gradient, requiring a double engine-tonnage to operate. Or, allowing three hundred and twenty-five round trips to be made per year, the cost per daily train per mile of road would be $48 \times 325 \times 2 =$ \$312·00 when the train-mile costs \$1. The operating cost of this for an engine-stage, say 100 miles in length, will be found by multiplying this sum by the rate per cent. of change of engine-tonnage given in the last Table for each grade, and the capitalized value, say at 5 per cent. interest, by multiplying these sums by 20, which gives for each change of 1 foot per mile from level a value of \$24,960, and from 40 feet per mile of \$10,608. These values apply, however, only to trains running with the maximum loads permitted by the gradients.

The question of the use of assistant engines is of the highest practical importance, but while general rules and recommendations have been arrived at by experience, each length of line presents problems which can only be solved subject to the special conditions met with. It is, however, recommended to concentrate the maximum resistances from curves and gradients in as short lengths of the line as possible, and to work these portions with assistant engines, so arranged in number and weight as to be capable of hauling through their stage the maximum train hauled in the level. It is found that from 60 to 80 miles a day is fair work for an assistant engine, with frequent short runs, while it can do 100 miles in favourable circumstances. The work should be so adjusted as to keep them in constant employment, and their use conduces to great economy in first cost, as well as to economy of operation. The following Table is given by Mr. Wellington to show the adjustment of gradients for assistant engines, according to the average daily performance on all American railways:—

Ruling Grade worked by One Engine in Feet per Mile.	Grade at which the same Train can be drawn by the aid of					
	One Assistant Engine			Two Assistant Engines		
	Of equal weight on Drivers.	Heavier by		Of equal weight on Drivers.	Heavier by	
		20 per cent.	40 per cent.		20 per cent.	40 per cent.
Level	24	29	33	46	54	62
10	42	48	53	70	80	90
20	59	66	72	92	104	116
30	76	84	91	113	126	138
40	92	101	109	133	147	160
50	107	117	126	152	167	180
60	122	133	142	169	185	199
70	136	148	158	185	201	216
80	150	162	173	201	217	232
90	164	176	187	216	232	247
100	177	189	201	230	247	261
110	190	202	214	..	..	..
120	203	215	227	..	..	..
130	215	227	239	..	..	..
140	227	239	251	..	..	..
150	238	250	262	..	..	..

The above Table is calculated on the assumption that the rolling-friction on the level is 10 lbs. per ton; for lower frictions the gradients are proportionately lessened. Also it is understood that all gradients must be properly compensated for curvature. The use of the assistant engines as headers or pushers can only be determined by the conditions of the traffic; but those who believe that the length of a train on a curve determines the amount of extra friction prefer pushers in order to lessen this. Assuming the cost of operating an assistant engine to be 47 cents per train-mile, the additional cost per year for daily trains will be $47 \times 2 \times 325 =$

\$305·50, when the ordinary train-mileage is \$1. The capitalized value of this, at 5 per cent. interest, is \$7,110.

Lastly, as the heavy traffic on through-lines is often much greater one way than in the other, special attention is given to balancing the resistances on the whole line, so as to ensure that the full engine-power required to take the loaded trains one way shall be required to take back the empty cars and partially-loaded trains the other way. This is done by adjusting the ruling-gradients and curves on the principles already mentioned; but with special reference to the weight of trains and the power of the engines employed; although it is perhaps the most important consideration affecting the whole alignment, it is, when all the other conditions are duly arranged, the easiest to accomplish. The whole of the preliminary problems taken together contain the solution of this final problem, and should be so considered throughout.

In conclusion, the Author cannot refrain from expressing the diffidence he feels in dealing with this important subject, especially in its present transition stage, and he has only ventured to do so in the hope that the statements made may be accepted as opening out inquiries regarding matters of great interest, in which further information and enlightenment is desired.

The Paper is accompanied by numerous illustrations, from which Plates 1, 2 and 3, and the Figs. in the text have been engraved.

(*Paper No. 2098.*)

"The Principles to be Observed in the Laying-out, Construction and Equipment of Railways in Newly-Developed Countries."

By James Robert Mosse, M. Inst. C.E.

Railways in undeveloped countries present the following contrasts to railways in those that are settled. In England, and more or less in Europe, they have been constructed solely as private commercial enterprises, whereas in new countries they are more commonly undertaken by the State, either wholly or in part. Each system has naturally its advantages and its evils. State interference, which might be very prejudicial in England, is essential in new and poor colonies, where public works, which at first could not pay commercially, are nevertheless indispensable to the development and prosperity of the country. In other words if public works be undertaken, they must be in some manner assisted by the Government; and if so, they will, in the Author's opinion, be constructed more substantially, and be worked more advantageously to the community, when owned by the State than when in the hands of a private company. In the first case the advancement and prosperity of the country is the chief object in view; in the second, it is the commercial profit of the shareholders.

In England railways have been undertaken one after the other, where the population and business required better means of communication; as for instance, from Liverpool to Manchester, afterwards to Birmingham, and then to London; whereas in North America and in Australia, railways have been projected on a far larger scale, not so much to give facilities for existing business as to favour the growth of population and commerce. Take, for example, the chief southern and western railways in the United States. The line from Mobile through Cairo to Chicago, some 845 miles long, and the three lines to the Pacific, and then take in Canada, the Intercolonial Railway from Halifax to Quebec, 687 miles, the Grand Trunk, from Quebec to Sarnia, say 673 miles, and especially the Canadian Pacific, from Montreal to Port Moody, a distance of some 2,900 miles. This latter railway, constructed solely to open up the far west of Canada, is particularly worthy of record; the company formed to made and work it has been assisted by a donation of £5,000,000 sterling, and by a grant of twenty-five million acres of land from the Dominion of Canada. The railway lands extend in breadth 24 miles on each side of the line, the Government and the Company owning alternate lots; and free grants of 160 acres are given to any one who will settle on and cultivate them. There can be no doubt of the wisdom of this policy, and that Canada will soon reap a rich reward for her expenditure on this work. Similar principles prevail in Australia, in other colonies, and in India. The locomotive is not so much the transporter of commerce as the pioneer and the developer of civilization.

The different circumstances existing in an undeveloped and in an old settled country naturally cause a contrast in the class of works; the requirements of the former are less than those of the latter; the one is poor, the other rich, and the works must, as far as practicable, correspond with the circumstances in each case. It should, however, be remembered that the large geographical features of many countries as compared with England, for instance the mountain ranges and the large rivers of Canada and India, often necessitate heavier works than usually prevail in this country.

Class of Railway.

In a level country, with small population and little traffic, due allowance being made for its subsequent increase, a light railway will suffice. But in a hilly country where steep gradients are imperative, or with a large anticipated traffic, heavy engines become indispensable, and they in turn require a strong permanent way and heavy bridges. In fact the class of railway to be made must from the first regulate the design of every portion of it; everything should be rigidly in keeping, and though economy must be studied, and the capital available for the railway forms an important factor in the design, the general suitability of the work for its requirements is equally important.

Laying-out.

As regards the principles of laying-out a railway, the line should be suited to the country; the practical question being the shortest and most level route available between any given points. With Ordnance maps, or with a fairly open country, this exploration and survey are comparatively easy, but where dense forests prevail, the case is far more difficult. The Author knows of no better method of conducting a railway survey through woods than that practised in America. The party generally consists of four surveyors with from twelve to twenty men as chain-men, axemen, carriers of baggage, &c.; they are furnished with tents and provisions, and where practicable with two or more horse teams. The surveyors include the chief of the party, the theodolite man, the leveller, one man taking cross-sections, and one spare surveyor.

After obtaining what knowledge of the country is practicable from its general features and from the course of rivers, the chief reconnoitres with an aneroid and a compass some 2 or 3 miles in advance of the party, and he then directs the courses to be taken with the trial lines. The theodolite man then cuts these courses in straight lines (not trusting to the compass) puts in pegs every 100 feet, enters in his note-book the courses, width of rivers and streams, and sketches the general topography of the country. The third surveyor records the levels, and the fourth man follows the level, taking at every 100 feet length cross-sections with a clinometer graduated to percentages of inclination, so that if the index mark 6, and the distance be 400 feet, the difference of level between the two points would be 24 feet; and a figured sketch of each cross-section is then entered in the note-book. By this system, the line cut through the forest is levelled and cross-sectioned on the same day; in fact the ground covered by the cross-sections is thoroughly ascertained. Where the forest is not too thick, an average of $1\frac{1}{4}$ mile of line can be thus surveyed in one day, provided the axemen and chainmen are experienced. In the United States all field-work done during the day is plotted the same evening, so as to guide the next day's operations, a practice which, though very laborious, effects great saving in time. After thus finding by trial lines a good route, the railway, as termed in America, is "located," that is pegged out at distances of 100 feet, and when necessary this "location" is similarly improved until a satisfactory route has been found. As a rule American engineers are very skilful and particular in making these "locations." They always use a chain of 100 feet, and their tapes are divided into feet and tenths.

Gradients.

Cases occasionally occur where a summit-level, with a given maximum rate of inclination, regulates the route irrespective of the suitableness or otherwise of the intermediate ground. A case of this nature exists on the Midland line of the Mauritius Railway, which has a rise of 1,817 feet in 16 miles, with some intermediate gradients of 1 in 27; and another instance is to be found in the Nanu Oya extension of the Ceylon Railway, where "with the exception of pieces aggregating $1\frac{1}{4}$ mile in length, the gradient of 1 in 44 prevails for $18\frac{1}{2}$ consecutive miles," and on another portion of this line the same gradient is continued for $9\frac{1}{2}$ miles; the total rise of the extension amounts in about 40 miles to 3,380 feet, the Nanu Oya station being 5,293 feet above the sea. In these cases, ground had evidently to be found to suit the maximum gradient permissible, instead of the gradient being made to suit the ground, and thus give the least amount of earthwork.

The maximum gradient, which should in general be adopted on a railway to be worked by ordinary locomotives, depends upon the character of the country, the capital available for the construction of the line, the amount of traffic anticipated, and on the speed required.

From the Author's experience in working for five years the steep gradients on the Mauritius Railway, he came to the conclusion, that, as far as practicable, a gradient for locomotive-traction should not exceed 1 in 40; although he has since seen such rough country in Ceylon, that economy would compel him to adopt a gradient of 1 in 30, to be worked if necessary by two locomotives.

Where a rising gradient is required for several miles, for instance of 1 in 60, it is safer to adopt a steeper gradient, say, 1 in 55, with lengths where practicable comparatively level, rather than that the whole line (stations excepted) should be of one uniform inclination. In the former case, a runaway train would be brought under control on the level, which it might not be in the latter; and the knowledge that at a particular spot a runaway train will stop, gives to the drivers and guards greater coolness under such circumstances.

Curves.

However desirable it may be to adopt easy curves, economy on all mountain railways necessitates sharp curves; and the question is then to decide upon the minimum curve which is safe and workable without excessive wear. In America, with a gauge of 4 feet $8\frac{1}{2}$ inches, curves of from 330 feet to 400 feet radius are traversed by carriages carried on four or six-wheeled bogie-frames, hauled by four-wheeled coupled engines having a wheel-base of 6 or $6\frac{1}{2}$ feet, and supported upon a bogie-frame in front. American locomotives are made with greater play, they therefore go more easily round curves, and they adopt themselves better to the great inequalities of the permanent way caused by the climate, than would be the case with English locomotives. During a Canadian winter the only way of keeping the rails level is by "shimming up" or packing them with pieces of wood from ½ inch to 3 inches in thickness, and these packings must be constantly changed, for the rails will vary in level 6 inches in a night, and in cases of extreme frost after rain, they will sometimes rise 12 inches in as many hours. It is consequently a common practice to tap the ice in the side-drains with a crow-bar, so that by letting out the water the rails may come more to a level. A curve of 1° at the centre on a chord of 100 feet, which is equal to a radius of 5,730 feet, is ordinarily said in America to produce friction or resistance equal to a rise of 1¼ foot per mile on a straight line, that is, a gradient of 1 in 4,224, the gauge being 4 feet 8½ inches.

On the Intercolonial Railway, with a gauge of 4 feet 8½ inches, Mr. Sandford Fleming, C.M.G., M. Inst. C.E., decided that the maximum gradient, which on the straight, or on a curve of not less than 5,730 feet radius, was fixed at 1 in 100, should on a curve of 2,865 feet radius be reduced to a grade of 1 in 111, and on a curve of 1,910 feet radius to an inclination of 1 in 125, the latter being equal to a reduction of 10·60 feet per mile as compared with the gradient of 1 in 100 on a straight line. This agrees fairly with Professor Rankine's rule. On the Nanu Oya extension of the Ceylon Railway (gauge 5 feet 6 inches), opened for traffic on the 20th of May, 1885, a large portion of the curves varying from 6 to 9 chains radius are on the gradient of 1 in 44, which prevails for many consecutive miles, and on the few exceptional curves of 5 chains radius the gradient has been reduced to 1 in 50¾, equal to a reduction of 16 feet per mile.

Gauge.

This question has been often discussed, and the Author will only record his opinion that in general the gauge should not be less than 4 feet, nor wider than the Irish gauge of 5 feet 3 inches, the mean of these widths being practically the standard gauge of 4 feet 8½ inches. It has already been shown that the width of the gauge *per se*, other items being unaffected by it, can make but little difference in the total cost of a railway.

Construction.

Whatever be the class of railway adopted, a fair margin of safety against contingencies should always be provided. Both for economy in first cost, and for convenience in working, the design of the works should be ample and the execution substantial; nothing can be more unsatisfactory than additions required on account of an insufficient design, nor more costly than alterations necessitated by bad materials or workmanship.

Earthwork.

The dimensions and the slopes of cuttings and embankments depend chiefly upon climate, rainfall, and the nature of the ground. For instance on the Intercolonial Railway of Canada, in wet soil the earth cuttings for a single line of rails are 32 feet wide at the base, with ditches on each side 4 feet deep below formation level, whereas in a milder climate a width of 20 feet would suffice; slopes of cuttings can also be made much steeper in temperate climates than in those where frost often causes them to slip to a slope of 4 to 1.

Where land is cheap, but plant expensive and scarcely available, earthwork is done more speedily by carrying the excavation to spoil, and by making up the embankment from side-cutting, than by the use of wagons. This practice, and the ploughing and scraping on the Canadian Pacific and on the West Shore Railways, are very common in America; and the wagons there used are generally "side-tipping cars," as more suitable for forming the narrow embankments required for a single line of way.

On some railways in the United States it was formerly customary to pay per cubic yard both for excavation and embankment, leaving it optional with the contractor either to transport the material, or to form the embankment from side-cutting, a practice still followed with coolies and basket-work in India.

On the Southside Railway in Virginia, the side slopes were pegged out with a level at distances of 100 feet, depending on the rise or fall of the ground above or below the centre line, so that the average depth of cutting (or height of embankment) on each cross-section might be accurately determined. The cubic content of earthwork according to the width of formation and the ratio of the slopes was then obtained from tables calculated for each tenth of a foot in depth. To the cubic content corresponding to the average depths thus found, an addition was made from an "error table" to give the true prismoidal content. Thus, take a cutting of 20-feet base with slopes 1 to 1, say 2 feet deep at one end, and 30 feet deep at the other, length 66 feet.

	Cubic yards.
Then content for mean depth of 16 feet =	1,408
Add for error 30 feet − 2 feet = 28 feet =	160
True cubic content	1,568

The error E in cubic yards always additive $= \dfrac{L \times D^2 \times R}{27 \times 3}$;

where L = length of excavation in feet;

D = half difference of the depths of cutting at each end of the excavation in feet;

R = ratio of the slopes.

In the above case; instead of in feet—

$$\frac{66 \times 14^2 \times 1}{27 \times 3} = 160 \text{ cubic yards.}$$

These tables are more detailed than those of the late Mr. G. P. Bidder, Past-President Inst. C.E., being calculated for each tenth of a foot in depth.

Waterway.

The provision necessary for floods forms one of the most important items in the construction of railways, and to obtain information as to flood-levels in an unsettled district is often extremely difficult. The requisite waterway depends chiefly upon the general features of the country, and the rainfall, especially upon the maximum fall per day during the wet season.

In England falls of 3 inches in depth per day are most unusual; but in many parts of the tropics, having a rainfall ranging from 100 to 200 inches per annum, falls of 10, 12 and even 18 inches in twenty-four hours have to be provided for.

To avoid the trouble and expense which sometimes arise in repairing "washaways," and providing additional bridges, after a railway has been opened for traffic, ample waterway, having a safe margin for all contingencies, should always in the first instance be provided. The Author allowed a margin of 5 feet in height to the underside of the girders, above the highest known flood-level; and as regards width, he considered it better to err on the safe side.

Bridges.

The choice of a suitable site, for crossing large rivers within certain limits, often forms the chief point in the selection of a railway route. The principal desideratum is a solid foundation with a shallow depth of water. Where elaborate appliances are costly, and where skilled labour is both uncertain and expensive, simple measures suited to the customs of the country will generally be found preferable. Thus in India, the well-system is understood and easily worked by natives, and in North America, with timber abundant and cheap, piling and timber flooring are more frequently adopted than cofferdams and concrete.

Where stone is distant from the works and haulage expensive, small rivers and streams are often crossed in the first instance by timber-work, the stone being brought to the spot after the line has been opened for traffic, when either an arch can be turned, or ironwork substituted for timber. Whether timber structures should in any case be erected, their life being only some ten years, must depend upon the class of railway to be made, upon the capital available, and upon the individual local circumstances; but if put up as a temporary measure, the Author knows of no plan of timber bridge, for spans up to 150 feet, so simple, cheap and efficient as the common Howe truss. The difficulty and cost of transport are generally so great, that for all bridges the chief desideratum is the lightness of each piece, especially when it has to be carried by hand; and as regards ironwork, the difficulty of getting good riveting done by natives induces the Author to prefer the "pin-connected" system as in the Warren girder, and those generally adopted in the United States, even although the bridge be not so stiff as when riveted.

Culverts and Stream-Diversions.

Where the Intercolonial Railway of Canada passed over short but deep ravines, it was common, in 1870, to divert the stream from the upper toe of the embankment, and to pass it on that level under the embankment through a tunnel, frequently formed in rock, rather than to build a culvert at the lowest part of the ravine, and the tunnel was not only cheaper, but more expeditious in making, than the culvert, for the former could at any time be excavated by common labour, whereas the latter could only be built by masons in the summer.

This practice has been extensively followed on the recent Ceylon railway extensions, passing chiefly through sidelong ground as steep as 3 or 4 to 1. The streams were frequently diverted, as high as practicable, through the solid ground, sometimes to near the mouth of the adjacent cutting, where they were crossed by 6-feet rolled girders resting on abutments, say 20 feet long; whereas an arched culvert, some 150 feet in length, would have been necessary at the bottom of the ravine. Great care was taken in making the stream-diversions of ample cross-section, both as to width and slopes, as well as in protecting the toe or steps of the culvert on the lower side from being undermined or injured by heavy floods; and when streams were thus diverted, the ravine on the upper side of the embankment was, in order to prevent water from lodging, filled up to formation-level with surplus excavation, either from the adjacent cutting or stream-diversion. This system has proved very satisfactory.

Masonry.

The choice lies between light ashlar masonry and flat-bedded rubble, well bonded, forming in the aggregate a larger mass. The Author has seen, in the United States, piers supporting timber bridges, built of superior ashlar, fully 80 feet in height, and only 4 feet thick at the top, with a batter $\frac{1}{2}$ inch to the foot on each side; but in general thicker masonry of a rougher class, built in Portland cement mortar, is preferable. In the tropics it is most difficult to get the stones well wetted and cooled before being bedded. They are mostly of a temperature that gives the mortar no chance of properly setting. For this reason concrete should be mixed with more water in the tropics than in temperate climates, and though abutments and arches of cement concrete are successfully used in temperate latitudes, they are subject to much greater risk, and are therefore not so suitable for hot or for cold climates.

Permanent Way.

The rails (of steel) may vary from 40 to 75 lbs. per yard, with fish-plates, fastenings, dimensions of sleepers, depth of ballast, &c., all corresponding to the rail used. A rail weighing less than 60 lbs. to the yard is, however, seldom advisable. For newly developed countries the flat-bottomed rail, in lengths of 21 feet, is the easiest to lay, having fewer parts to transport and fix. There should be at least seven sleepers to each rail, which should be fixed at the joints, and at least to one intermediate sleeper, in the middle by fang-bolts, the other sleepers having strong dog-spikes; guard-rails should also be used on all curves of 10-chains radius and under. The Author considers that in cold climates, on account of the frost, and in the tropics, because of the heavy rains, only small broken stone, 10 inches in depth, should be used for bottom ballast, the top layer, 8 inches deep, being of good gravel; and that the boxing should cover the sleepers, so as to protect them from the sun. A strong permanent way, with first-rate ballast, ensures great economy in future maintenance. Green native sleepers both in Canada and in India, are in general very perishable, and in the tropics it is preferable to import creosoted Baltic fir sleepers.

STATIONS.

However amply stations may have been originally designed, increasing traffic has required them to be so continually enlarged that it would be difficult to find any station at this date with the accommodation provided forty years ago. A station too large for future requirements has been rarely if ever seen; hence ample provision, especially in land, should be made in the first instance. For a single line in newly developed countries, the Author recommends a siding and platform being placed on each side of the main line at every station, so that three trains may pass there at the same time. Each passenger-platform should in general not be less than 300 feet in length, for the trains being few are often long. The length of the sidings will depend upon the anticipated traffic; but in Canada, passing-sidings to hold two trains were, as a rule made not less than 2,000 feet long. The goods-shed and sidings should be placed on one side, so as not to interfere with the passenger trains. Having personally experienced great inconvenience in conducting traffic with insufficient station accommodation, the Author would emphasize the necessity and economy of providing an ample design in the first instance. The buildings should be simple, and placed so as to be capable of enlargement, and there should be plenty of space in the station-yard for additional sidings, as otherwise the enlargement of stations becomes most difficult and expensive. Though the design should be extensive, only such portions as are necessary need from time to time be carried out.

EQUIPMENT.

Perhaps more than any other item, the equipment depends upon the nature of the railway and the traffic; for the steeper the gradients, and the heavier the traffic, the greater must be either the number of the locomotives or their weight. It is true economy not to overwork rolling-stock—especially engines; of which to meet repairs, and ordinary contingencies, there should be a margin of, say, 25 per cent. With the exception of Canada and Australia, where locomotives are manufactured, the engines and ironwork for rolling-stock, are mostly imported into the Colonies from England, the woodwork being very well made there from the most suitable native timber, from pitch-pine in America, and from teak in India and elsewhere in the East.

The rolling-stock provided for the Nanu Oya extension of the Ceylon Railway, having a gradient of 1 in 44, with curves from 5 to 8 chains radius, the gauge being 5 feet 6 inches, is as follows:

Locomotives from Messrs. Kitson and Co., cylinders 17 inches in diameter; length of stroke, 26 inches; driving-wheels, six coupled, 4 feet 5 inches in diameter; wheel-base, 9 feet 6 inches; but as the leading pair of driving-wheels are flangeless, the fixed wheel-base may be said to be only 4 feet 5 inches. The bogie has four wheels of 3 feet diameter, with lateral play in the centre, the wheel-base being 6 feet. The firegrate area is 23½ square feet; the total heating surface, 1,247 square feet.

	Tons.	Cwt.
Weight on leading wheels coupled	11	7
„ driving „ „	12	12
„ trailing „ „	11	7
„ bogie „	10	0
Total weight in running order	45	6

The side-tanks of the engine contain 600 gallons. The tender, 1,800 gallons. Total, 2,400 gallons.

The engines are provided both with a steam- and with a hand-brake. Ten were ordered for working the extension of about 40 miles. The Resident Engineer, Mr. Edward Strong, M. Inst. C.E., reports as follows: "These engines work remarkably well, with practically no flange wear—they are a perfect success for working on 5-chain curves."

Carriage and Wagon Stock.

The carriage and wagon underframes are of iron: the former 40 feet long by 8 feet 4 inches wide, the latter 31 feet long by 7 feet 9 inches wide.

Both these carriages and wagons are supported on a four-wheeled bogie at each end, the wheels being 3 feet 6 inches in diameter, and the rigid wheel-base 6 feet. They are all fitted with Clark's chain-brake, which can be worked either from the tender or from the brake-van. The ordinary four-wheeled goods' wagons, having a rigid wheel-base of 7 feet 6 inches, run round 6-chain curves so easily, even on a gauge of 5 feet 6 inches, that the purchase of many additional wagons supported on bogie-frames is not considered probable.

The locomotives working on gradients varying from 1 in 27 to 1 in 40 over a rise of 1,817 feet on the Mauritius Government Railways, are six-wheeled coupled side-tank engines, 3 feet 6 inches in diameter, with cylinders 16 inches in diameter, having a length of stroke of 22 inches, and a rigid wheel-base of 15 feet. Their weight with fuel and water is 37 tons each.

There are also some eight-wheeled coupled saddle-tank engines with wheels 4 feet in diameter and rigid wheel-base of 15 feet 6 inches; but the joints of the coupling-rods connecting the leading- and trailing-wheels with the driving-wheels, are fitted with a ball and socket, so as to allow the requisite play in going round curves. The cylinders of these engines are 18 inches in diameter, length of stroke 24 inches, they weigh in running order 48 tons, and worked very satisfactorily.

The rolling-stock, to be adopted on any particular railway, must depend entirely upon its character and requirements both present and future; but as a guide, the particulars of rolling-stock on some railways in newly developed countries the greater portion being in North America), have been tabulated from official reports. The following are the results:—

Miles open	140,756	
	No.	Average No. per Mile.
Locomotives	27,958	0·1986
Passenger vehicles	33,662	0·2389
Goods „	831,163	5·905

Taking the locomotives as 1, the passenger vehicles are as 1·2824, and the goods vehicles as 29·739.

The Table in the Appendix is interesting as showing that, whereas in general the number of passenger vehicles exceeds by about 50 per cent. the number of locomotives, the reverse is the case in the Southern and Western States of America, which are thinly populated, and that the total average is as above-stated.

The large number of goods vehicles 5·9 per mile, or a proportion of 29·74 goods to 1·282 passenger vehicles, shows how much heavier and more important in newly developed countries is the transport of goods than that of passengers; for the latter can ride or walk on bridle-paths, whereas the former, except at prohibitive cost, can only be conveyed on good roads, by water communication, or by railways.

Conclusion.

In consequence of the want of capital, it was customary in the United States up to the year 1860, if not later, to open railways at the least first cost, regardless of the large and expensive additions that would ultimately be required, as well as of the increased working-expenses entailed in the meantime. In the Author's opinion this policy was bad both in principle and practice; such additions can seldom if ever be made without inconvenience to the traffic, and at far greater cost than if executed in the first instance. The capital of American railways has from time to time been so largely increased, that the present great depreciation in value of the original stock is not surprising; and the Author considers that these works would not only have been better, but more remunerative, had they been constructed upon sounder principles and with greater stability.

[Appendix.

APPENDIX.—PARTICULARS of ROLLING STOCK on SOME RAILWAYS in AMERICA and in the COLONIES.

Authority.	Name of Railway.	Miles open.	Locomotives. Number.	Passenger Vehicles. Number.	Goods Vehicles. Number.	Per Mile of Railway open. Locomotives.	Per Mile of Railway open. Passenger Vehicles.	Per Mile of Railway open. Goods Vehicles.
Poor's Manual of Railroads in the United States, 1884	New England States in 1853	6,323	1,819	3,055	40,212	0·2876	0·4831	6·359
	Middle States "	17,532	7,351	7,950	300,587	0·4193	0·4534	17·145
	Southern States "	18,866	2,514	2,276	53,427	0·1332	0·1206	2·832
	Western States "	70,345	11,418	9,663	340,079	0·1623	0·1374	4·834
	Pacific States "	7,486	721	903	14,356	0·0963	0·1206	1·918
Report dated 13th June, 1885.	Canadian Pacific	2,794	304	282	7,543	0·109	0·101	2·762 [1]
State Report 30 June, 1884	Intercolonial of Canada, Halifax to Quebec	847	163	241	4,348	0·192	0·284	5·133 [2]
Administration Report on Railways in India, 1883–84	Indian 5 feet 6 inches gauge	6,866	1,871	4,571	35,787	0·272	0·665	5·122
	India metre gauge	3,252	664	2,253	12,204	0·204	0·692	3·697
Administration Report, 1883, and subsequent information.	Ceylon Government	182	58	174	539	0·318	0·956	2·961
Annual Rpport for 1874	Mauritius "	66	27	87	331	0·409	1·318	5·005 [3]
" 31 Dec., 1882	Queensland "	896	71	104	1,011	0·079	0·116	1·128 [4]
" 31 Dec., 1881	New South Wales "	995	233	530	4,849	0·234	0·532	4·871
" 31 Dec., 1882	Victorian "	1,355	228	456	3,951	0·168	0·336	2·916
" 30 June, 1881	South Australia "	624	85	138	2,153	0·136	0·221	3·449 [5]
" 31 March, 1883	New Zealand "	1,358	204	580	6,154	0·150	0·427	4·532
, 31 Dec., 1882	The Cape "	969	227	399	3,632	0·234	0·412	3·748
Totals		140,756	27,958	33,662	831,163			
Average of totals						0·1986	0·2389	5·905
Proportion of totals			1·00	1·2824	29·739			

Remarks.—[1] Only partially open for traffic. [2] Opened about 1876. [3] Goods traffic heavy during crop season.
[4] Report states, "We have been extremely short of engines all through the year."
[5] Report states that more locomotives are required.

(*Paper No. 2094.*)

"On the Construction of the Canadian Pacific Railway (Rocky Mountain Division) during the Season of 1884."

By Granville Carlyle Cuningham, M. Inst. C.E.

When the work of constructing the western division of the Canadian Pacific Railway was suspended for the winter in December 1883, the rails had reached a point about 4 miles short of the summit of the Rocky Mountains. This point is 960 miles west of Winnipeg, and 120 miles west of Calgary, the last station on the plains, where the line enters the mountains by the Bow Pass. From here two possible routes are available for further progress westwards; one following the Bow Pass to its summit, and thence descending by the Howse Pass into the Columbia Valley; the other diverging from the Bow Pass, reaching the summit of the Rocky Mountains at the commencement of the Kicking Horse Pass, and following this, entering the Columbia Valley at a point about 12 miles to the south of the mouth of the Howse Pass. The first route presented comparatively easy grades and curvature, but crossed the summit at 1,000 feet greater altitude, thus bringing the line into much deeper snow in winter; and it was 30 miles longer than the second. The second route, though of a lower altitude and shorter distance, would entail very heavy work at the head of the Kicking Horse Pass, in order to maintain equally good gradients. After considering the problem, the Directorate decided to adopt the shorter route by the Kicking Horse Pass, and to use a steep gradient at its commencement, in order to temporarily avoid the heavy work that will be required on the permanent line, and thus to effect the connection with the railway on the Pacific coast by the autumn of 1885.

Route.

The route follows the valley of the Kicking Horse River, from its commencement near the summit of the Rocky Mountains, to its entrance into the valley of the Columbia River, a distance of about 45 miles. The Columbia Valley is from 6 to 8 miles wide, and is heavily timbered. It is the westerly limit of the Rocky Mountain range, which it divides from the Selkirk range.

The general direction of the valley is north, for some 80 to 100 miles, when the river makes a bold sweep round the northern end of the Selkirks, at what is called "the Big Bend," and thence flows southwards, on the western side of the Selkirk range, to Oregon territory and the Pacific Ocean. The railway, entering the Columbia Valley at the point above mentioned, follows it northwards for a distance of about 30 miles, until the mouth of the Beaver River, flowing out of the Selkirks, is reached. Here the line turns west, ascends to the summit of the Selkirks by the Beaver Valley, and thence descends, by the valley and cañon of the Illecilli-wact, to the second crossing of the Columbia River. From the second crossing it ascends the Eagle Pass, through the Gold range, and passes by the valley of the Shoo-swap Lakes to Kamloops, to which point the rails from the Pacific coast have been laid. The distances, measured from the summit of the Rocky Mountains, and the altitudes above the sea, at various points along this route, are as follow:—

	Distance.	Altitude.
	Miles.	Feet.
Summit of Rocky Mountains	..	5,296
Mouth of Kicking Horse Pass	44½	2,539
First crossing Columbia River	62	2,521
Mouth of Beaver River	73¾	2,340
Summit of Selkirks	94½	4,300
Second crossing Columbia River	139½	1,600
Kamloops	270	..

Geological System.

The geological system through which the line passes is the Lower Carboniferous. At the upper portion of the Kicking Horse Pass, hard crystalline limestone is found, in several instances of a quality so pure and homogeneous as to form marble of some commercial value. Lower down the pass, the shales of the system appear in every variety; sometimes dark hard slates, sometimes soft laminated clays.

With the exception of the hard limestone at the head of the Kicking Horse Pass, none of the rock, between that point and the mouth of the Beaver, is of quality good enough for building purposes. Generally the mountains rise directly from the valleys, at a very steep slope, without any intervening foot-hills, and continue with an even inclination to their summits, often from 5,000 to 6,000 feet above the valley. The lower half is covered with a comparatively thin layer of soil, resting on the smooth and slippery surface of the shale, and bearing a thick growth of timber and underbrush; the upper half is bare, affording, by its rugged surface, a gathering-place for the heavy snows that fall in winter. The consequence of this mountain-formation, combined with the friable and treacherous shale rock, is that "land-slides" are no unusual occurrence. The wash of a stream at the mountain's base wears away the clay bank, and the support for a large stretch of soil on the steep mountain-side being thus removed, a slide takes place, and acres of ground are left stripped of the covering soil and trees; while snow and ice, gathering on these steep mountain-sides, are liable to descend in spring, or during a winter thaw, with great force, bringing down boulders and trees in their course.

Climate.

The climate has much to do with the difficulties of railway construction in any country. In 1884, in the district under consideration, snow lay deep in the bush at the summit of the Rocky Mountains into the month of June. The Kicking Horse Lake, at the head of the pass, was not free from ice until the middle of the same month. Rain fell almost incessantly during July and August, which, combined with the melting snow on the mountain-tops, kept the rivers and streams in high flood. On the 28th of September, 1884, a depth of 4 inches of snow fell in the valley at the summit, and by the middle of the following month the Kicking Horse Lake was again frozen over, to remain so throughout the winter. In the Columbia Valley, owing to its lower altitude, a better condition of things prevailed. The snow was all gone by the end of March, and did not again fall, to remain on the ground, until the middle of December. Between these extremes the climate varied with the altitude, between the Rocky Mountain summit and the mouth of the Beaver. In the winter of 1883–4, a register of the temperature was kept in the Columbia Valley at the mouth of the Kicking Horse River. On the 30th of December, 1883, the thermometer registered $-40°$ Fahrenheit, and on the 9th and 10th of February, 1884, a temperature of $-38°$ was recorded. In the interval of time between these two lowest extremes, the average temperature was $-12°$. During the winter of 1884–5, in the Columbia Valley, the temperature fell to $-42°$ on the 24th of December, and from the 15th of the month up to that day the average was $-26°$. At the summit of the Rocky Mountains, during the same period, a temperature of $-48°$ was registered. It will be easily understood, with such a low temperature as this, how much difficulty may be caused by ice piling in the rivers about bridge-piers; by springs that force their way out of the sides of cuttings, and freeze as soon as they begin to flow; and by accumulations of ice that form on the mountain-sides, until they fall by their own weight.

Natural Products.

The natural products of the district lying between the Rocky Mountain summit and the mouth of the Beaver, capable of use in railway construction, are very few. Throughout the whole length, timber is to be had sufficient for ties, sleepers, and temporary bridges, trestles, and culverts. At the summit of the Rocky Mountains, on the margin of the Kicking Horse Lake, a steam saw-mill was erected by the end of July, for cutting up the timber growing in the immediate neighbourhood into bridge- and trestle-timber. This timber is chiefly white spruce, unusually sound, and, though not of equal strength with the ordinary American pine, is admirably adapted to the purpose for which it is required; being obtainable easily, and in large quantities, it was of much value in expediting the work. Further down the pass, better and larger timber was got, and in the Columbia Valley fine specimens of the Douglas pine (*Pina ponderosa*)—a very hard and strong wood—were used in bridge- and culvert-building. Everything else that was required on the work had to be brought in from the East for very long distances. The thick growths of moss on the ground, produced at the summit, doubtless, by the continuous wet weather during the period of vegetation, prevented any growth of grass that might be used as fodder for horses or cattle; and the totally uninhabited state of the country was a sufficient reason for the absence of artificial grasses or cereals in the Columbia Valley, where they might grow if cultivated. The importation of food for horses and cattle, as well as for the men employed, was a serious undertaking, and one which necessarily added much labour to the work.

General System.

The following brief description is necessary in order to understand the manner and the difficulties of carrying on the work. In the first place, it was necessary to construct a wagon-road along the general line of the intended route, so that contractors with their men, plant and material, might be placed on the work at various points, and for the supply of provisions and necessaries. Hitherto the passes and valleys traversed by the surveyed line had been reached only by narrow trails, affording sufficient, though often dangerous, accommodation for pack-ponies, but inadequate to the requirements of railway work. The construction of this road was pushed on as rapidly as possible in advance of the work, in many places merely enough being done, in the way of clearing timber, to admit of the passage of wagons through the bush. Contractors were then brought in and established in their camps on the portions of the line allotted to them. The contracts varied in length from 1 mile to 4 or 5 miles, according to the nature of the work and the capacity of the contractor. As each portion was finished, the contractor was moved on further to the front; and in this manner a stretch of about 40 miles in advance of the end of the track was kept constantly in hand. As the grading progressed, track-laying was continued, and the end of the track steadily advanced. The company's main stores were established at Laggan, about 6 miles east of the summit of the Rocky Mountains. Here an ample stock was kept of everything that could be required by the contractors or their men; such as tents, tools, wagons, harness, provisions, clothing, hay, oats, &c. These were sent out by rail to the "End-of-track store," a movable store, maintained in cars, and advanced every few days as the track was laid. From this point the goods were conveyed by wagon to the various camps. The heavy traffic which the roughly constructed wagon-road had to bear, in carrying forward supplies for four thousand men and one thousand two hundred horses or mules, combined with the copious and continuous rains, so cut up the road, that at times, and in many places, it was almost impassable. A weight of 1,000 lbs. constituted a load for a pair of horses, while 12 to 15 miles was the extent of a day's journey. The difficulty in maintaining supplies in sufficient quantities over such a road was not small, and the attendant expense was very great. The cost of conveying stores to a point 40 miles beyond the end of the track was 8 cents. (4*d.*) per lb., and this, when applied to hay and oats, made horse-food an expensive item. The opening out and construction of the road was begun at the summit in the middle of April, and by the latter part of the same month, contractors were set to work on the temporary line at the head of the Kicking Horse Pass.

Curves and Gradients.

Up to the summit of the Rocky Mountains the curves and gradients have been light: the latter not exceeding 40 feet to the mile, except in one or two instances. From this point, however, the descent of the valleys and rivers to the west is so rapid, that it was necessary to adopt a heavier maximum gradient, in order that the line might be able, approximately at least, to follow the natural descent of the ground. The gradient fixed upon as a maximum is 2·2 feet per 100, or 116 feet to the mile, or 1 in 45·45. This gradient has been exceeded only in the instance of the temporary line, at the beginning of the Kicking Horse Pass. The descent in this pass, at its commencement, is very steep; the river falls 1,100 feet in 3½ miles. To follow such a descent the gradient would have been impracticable for a railway: while, on the other hand, with the 2·2 gradient the line would have been so high up on the mountain side, and so many miles of heavy and difficult side-hill work would have been required before it could reach the valley, that much delay would have been occasioned in the work further to the west. It was therefore decided to make the descent of the upper portion of the pass on a temporary line, with a gradient of 4·50 feet per 100, or 237 feet to the mile, or 1 in 22·22. The temporary line begins at a point about 4 miles west of the summit. At first there is ½ mile on a gradient of 3·50 per 100; this is followed by 3¼ miles of the 4·50 gradient, after which 3½ miles of the 2·2 gradient takes the line down to the base of the mountain and the flats of the river. This heavy gradient winds down the mountain side, with curves whose maximum deflection on 100-feet chord is 10° (573-feet radius). Though so unusually severe, the practical working has shown that a large traffic can be successfully carried over it. Details are given further on of the working of this gradient.

In every instance where curves occur in conjunction with the maximum gradient, the grade was equated for the curve so that the resistance to traction would not be greater on the curved than on the straight part of the line. The equation used was 0·03 of a foot rise per 100 feet for each degree of curvature; so that on a 10° curve, the rise per 100 feet was reduced 0·3 per foot. A rise of 0·3 per foot in 100 is a gradient of 1 in 333, which would develop a resistance to traction of 6·73 lbs. per ton; this, therefore, is the allowance given as the equivalent in resistance of a 10° curve (573-feet radius); and close observation on the heavy grade on the temporary line showed that this was very near the truth. The locomotive, when ascending with a full train, had a tendency rather to gain, than to lose, speed on the curves. It should be stated, however, that all trucks and engines were mounted on bogies.

Grading.

The cuttings are taken out to a width of 22 feet in the bottom, with a side-slope varying from $\frac{1}{4}$ to 1 to $1\frac{1}{2}$ to 1, according to the nature of the material. The hardest rock encountered was that on the temporary line. It is a crystallized limestone. Owing to the impossibility of bringing machinery over such a road as has been described all drilling was done by hand. In the hardest of the rock two strikers and one holder could drill only 9 lineal feet in ten hours' work, the hole being $1\frac{1}{4}$ inch in diameter. The amount usually accomplished in rock of average hardness was from 16 to 18 feet in that time. The explosive used was dynamite, generally of 75 per cent. strength, which was made at a factory erected by the company at the Kicking Horse Lake. The explosive was discharged sometimes by time-fuze, and sometimes by electricity. Lower down the valley, where shale rocks were encountered, the action of dynamite was found to be too quick, as its force was spent between the layers of the rock and through fissures, and better results were obtained from black powder. In some few instances, in rock-cuttings near the dynamite factory, pure nitro-glycerine was employed with good results; but the use of this was not permitted on other parts of the line, owing to great danger attending its transportation.

The width of the banks on the top is 14 feet. They were made, whenever practicable, from the excavation hauled out from the cuttings. But a considerable portion of the line, on the flats of the Kicking Horse River, for example, and in the Columbia Valley, consist of a light bank, averaging 3 feet above the general level of the ground, formed by material collected with "scrapers" from the sides.[1]

Where the material has to be taken out of a cutting to form a bank at some little distance, wheel-scrapers are used. These are large sheet-iron scoops of about $\frac{1}{2}$ cubic yard capacity, mounted on wheels. By a simple arrangement of a crank upon the axle, worked by a hand-lever, the wheels can be raised, so that the body of the scraper drags on the broken-up soil, and fills by the traction of the horses. When full, a pressure of the lever again brings the wheels into action, and the load is run out and "dumped" in position. Wherever possible, ploughs were used to break up the material in the cuttings, so that it might be taken out by scrapers.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxvi. p. 273.

The following quantities were taken out on the different divisions of the line:—

From the summit of the Rocky Mountains to the mouth of the Kicking Horse River—44¼ miles: Solid rock, 256,834 cubic yards; loose rock, 115,371 cubic yards; earth, 988,255 cubic yards; hard pan, 136,457 cubic yards. Total, 1,496,917 cubic yards. This is exclusive of the excavation in tunnels: it gives an average quantity of 33,806 cubic yards per mile.

From the mouth of the Kicking Horse to the first crossing of the Columbia River—17¾ miles: Solid rock, 646 cubic yards; loose rock, 1,011 cubic yards; earth, 341,336 cubic yards; hard pan, 18,990 cubic yards. Total, 361,983 cubic yards. The average quantity on this division is 20,393 cubic yards per mile.

On the succeeding 11 miles from the First Crossing to the mouth of the Beaver, the average quantity was 27,500 cubic yards per mile.

Tunnels.

On the length of line constructed—73¾ miles—there are seven tunnels. Their positions, length, and general nature, are as follow:—

	Distance from Summit. Miles.	Length. Feet.	Remarks.
No. 1	8	130	On temporary line; solid rock.
„ 2	33¾	470	Clay; timber lined.
„ 3	40	337	Rock.
„ 4	40½	298	„
„ 5	42½	360	Part rock and part soft; timber lined for 200 feet.
„ 6	63½	97	Rock; part lined.
„ 7	67¼	460	Gravel and rock; part lined.
Total		2,152	

The general section adopted for tunnels is 22 feet in height, by 16 feet wide. This gives about 12 cubic yards of material per lineal foot. The great height, as compared with European tunnels, is necessary in order to meet the requirements of the Canadian Railway Act, which specifies that every permanent structure spanning a railway line, shall be of such height as to give a clear space of 7 feet between the lowest part overhead, and the top of a box freight-car; so that brakemen may not be endangered when on the roof of a car, in the execution of their duty.

Tunnel No. 1 is situated immediately at the foot of the 4·50 per cent. grade, on the temporary line. The material is hard crystalline limestone, much fissured and broken. The progress was $6\frac{1}{2}$ feet per week at each face. Gangs were kept at work night and day. All drilling was done by hand, and the explosive used was dynamite.

Tunnel No. 2 is through a lofty spur, composed of blue clay, hard packed gravel, and boulder-drift. The blue-clay seam at the eastern mouth of the tunnel is about 20 feet in thickness, resting upon fine sand, and supporting an overlying mass of boulder-drift, having fine veins of sand interspersed. It would scarcely be possible to find material more treacherous than this. Streams and springs from the mountain slope make their way down through the soil, and working out in the veins of sand, and between the boulder-drift and the blue clay, cause deep excavations, which result in sudden and disastrous "slides." Work was begun early in June, and on the 23rd of July a heavy "slide" took place at the eastern breast of the tunnel, tearing away about 30 lineal feet of the timber lining, and bringing down about 15,000 cubic yards of material, which completely blocked the mouth, entailing a long delay. Again, in the beginning of October, when the piercing of the hill was completed, and the track about to be laid through, a second "slide" at the same end of the tunnel, brought down about 9,000 cubic yards.

Throughout its whole length, this tunnel is lined with timber. Each section of the frame of the lining consists of two upright posts 14 feet in height, 12 inches square in cross section, standing on a transverse sill, and supporting a longitudinal cap: from this cap spring two inclined pieces, straining against a central straining-piece in the roof of the tunnel 7 feet in length. These sections of the frame were put in at 3 feet apart from centre to centre. At the back timber-lagging was closely packed in, 6 inches square, in lengths of 3 feet. The quantity of timber used in the lining was 780 feet board measure per lineal foot. The timber was all obtained from the bush in the immediat neighbourhood, and was hewn with the axe to the proper dimensions.

When the tunnel was opened through, it was found that the action of the air on the blue clay at the eastern end, caused it to swell, and the tremendous pressure thus exerted, crushed the timbers of the lining in the roof. The track was laid through the tunnel on the 20th of October, 1884. All the work in connection with the piercing and lining was done by Messrs. Corry Bros., of Wisconsin. This tunnel is on a 9° curve (636 feet radius).

Tunnels No. 3 and 4 are pierced through slate shale. Work was begun in July and finished in September. Messrs. Muir Bros., of St. Paul, Minnesota, were the contractors. The following are the particulars of the work:—

Average progress at every face in twenty-four hours, working eleven-hour shifts, 3 feet 3 inches; average depth of hole drilled (all by hand) in heading, 3 feet 6 inches; diameter of hole, $1\frac{1}{2}$ inch; average quantity of material moved per man employed in twenty-four hours, 1·625 cubic yard. Each shift at each face consisted of one foreman, nine drill-men, one dump-man, two drivers, and eleven shovellers.

The fifth tunnel is pierced partly through gravel and partly through shale rock; that part which is through gravel is timber-lined, in the same manner as tunnel No. 2. The sixth tunnel is only 97 feet long, and timber-lined for 30 feet. The seventh tunnel is on a 10° curve (573 feet radius); is 460 feet in length, and is timber-lined for 150 feet. The material through which it is pierced is partly gravel and partly hard shale rock. Work was begun on it at the end of July, and it was finished in time for the track to be laid through it in the middle of December.

Bridging.

As might be expected on a line traversing deep valleys and ravines, the amount of bridging constructed is extensive. There are nine crossings of the Kicking Horse River, six of these crossing within a distance of 12 miles. Such a fact as this gives most concisely an idea of the winding and difficult nature of the pass through which the line is carried. There is one crossing of the Columbia River,[1] and numerous crossings of smaller rivers and streams.

All the bridges and trestles constructed during the season were of wood. Most of the timber was obtained in the district, the main-posts, caps, sills, and such pieces being hewn on the spot; while the floor-timbers, deck-material, and lighter pieces, were sawn at the mill on the Kicking Horse Lake. The heavy chord sticks, principal truss-members, and track-stringers, were of sawn white pine imported from the east, as was also the oak used in trusses. One general design was employed for trestles: the openings were of the uniform width of 15 feet from centre to centre. Piles, usually four, were driven in a row at the position

[1] Minutes of Proceedings Inst. C.E. vol. lxxxii. p. 345.

of each "bent." When the rail-level was not more than 8 to 10 feet above the ground, these piles were cut off at from 5 to 7 feet, and a cap, consisting of a timber of 12 inches cross-section by 14 feet long was drift-bolted on to the top of them. From cap to cap the rail-stringers, consisting of pieces 9 inches by 15 inches by 16 feet long, or 6 inches by 15 inches by 16 feet long, spanned the intervening space of 14 feet. The stringers were placed so that their ends lapped past on the caps. For one span, three 6 inches by 15 inches pieces were placed under each rail; for the next span, two 9 inches by 15 inches pieces, and so on alternately. In this way a good bearing was obtained on the cap, the stringers were in the best position to support the rail, while in each span there was the same amount of timber. At the outer ends of the caps, additional 6 inches by 15 inches stringers supported the ends of the floor-timbers. These latter were 6 inches by 8 inches by 14 feet, and were placed transversely on the stringers at 15 inches from centre to centre. To these the rail was spiked. When the height of the rail-level above the ground exceeded 10 feet, or thereabouts, a "trestle-bent" was put in to support the cap. The piles were then cut off at the level of the ground, and a sill 12 inches square in section was drift-bolted down to them; on this sill were erected two vertical and two battering posts 12 inches square, and of the necessary height supporting the cap; at the meeting place of the posts with the cap, or sill, the junction was made secure by a mortise and tenon-joint, and the posts were further secured by cross-bracing of 3-inch plank. When the height of the trestle exceeded 35 feet, an intermediate sill was inserted, carrying a fresh set of vertical and battering posts, and thus the structure was carried up by "lifts" or storeys of 20-feet height each, to the required altitude. In the instance of the trestle crossing the Otter Tail Creek, this altitude exceeded 100 feet above the ground.

The general system of building trestles and bridges was as follows:—After the ground had been cleared of trees and prostrate timber, the piles were driven in position by the pile-driving gang. The main-timbers, such as sills, posts and caps, were hewn in the immediate neighbourhood, framed and erected ready to receive the track-stringers. When the track, as it was being laid, arrived at such a structure, a car, laden with the requisite number of stringers and floor-timbers, was run forward to the extremity of the rails, unloaded, and the pieces placed in position by a gang of bridgemen. This generally involved some delay to track-laying, but by proper organization and promptness the delay was small. It could usually be arranged that any large structure could be completed by the bridge-men at night. It was impossible to transport heavy bridge-timbers by wagon over the wagon-road, as had been done on the prairie sections of the line.

The Howe truss, in spans varying from 100 to 150 feet, was chiefly used. The lower six crossings of the Kicking Horse River are from 200 to 300 feet in width, requiring two trussed spans. What has been said in regard to the impossibility of bringing forward heavy timbers by wagon for trestles, applies with greater force to the long chord-timbers, iron rods and castings needed for trusses. To obviate the delay to track-laying, which would have occurred had the truss material been run forward to the end of the track at each bridge, the truss erected, and the track then laid across, it was deemed expedient to bridge the river by temporary pile-structures at the various points, and to erect the trusses at greater leisure, after the material had been brought forward by the train, and the track-laying passed on. This plan was adopted for all the main bridges, except the second crossing of the Kicking Horse River, and the crossing of the Otter Tail Creek. The former is of 150 feet span, and crosses a chasm in the upper part of the valley 75 feet in depth; while the latter is of 100 feet span in the centre of a 500-feet length of trestle, and is 112 feet above water-level. In those places it was unadvisable to put in temporary work, and the permanent trusses were therefore erected in the first instance.

The piers carrying these trusses were formed of timber crib-work filled with stone. The greatest depth of the water, in the ordinary state of the Kicking Horse River, was not more than 6 feet where the piers were placed. The depth in the Columbia River was 15 feet. The total length of bridging and trestle-work from the summit to the first crossing of the Columbia River (62 miles) is 8,039 lineal feet.

The piles were selected from trees growing in the neighbourhood, and were required to be not less than 8 inches in diameter at the small end, and 12 inches in diameter at the butt when sawn off. They were driven under a hammer weighing 2,000 lbs., and the driving was continued until there was not more than ½-inch penetration under a blow of this weight falling 25 feet. Five pile-drivers were at work during the latter part of the season. Including the delay of moving and setting up the machine, which is always considerable, the average work for each driver was ten to fifteen piles per day, in structures having about forty piles, driven an average depth of 10 feet into the ground.

Track-laying.

A single line of track has been laid. The rail is steel, of the Sandberg pattern, with angle-plate joints, and secured to the ties (sleepers) by spikes. The weight of rail to a point $3\frac{1}{2}$ miles west of the summit of the Rocky Mountains is 60 lbs. to the yard. From here through the Kicking Horse Valley, for a distance of 41 miles, the gradient and curves being severe, a rail of 70 lbs. to the yard was laid. In the Columbia Valley, to the crossing of the river (18 miles), the 60-lb. rail was adopted, and from this point on to the mouth of the Beaver (12 miles), through the Columbia Cañon the 70-lb. rail. The angle-plate connection, which has recently been adopted in Canada and the United States in preference to the old fish-plate joint, makes a very rigid and perfect track. The weight of the angle-plate joint is rather more than double that of the fish-plate, being 5·66 tons per mile with 30-feet rails, as compared with 2·51 tons. Ties were laid at the rate of three thousand to the mile, or 1 foot 9 inches from centre to centre. They were 8 feet long, 6 inches thick, and not less than 6 inches in the face, hewn on two sides. They were made from timber growing in the mountains, chiefly spruce and jack-pine.

Track-laying was begun in June, but was carried on slowly, pending the construction of the temporary line, on the heavy grade, at the head of the Kicking Horse Pass. By the 18th of June it had reached only to the first tunnel, 8 miles west of the summit. From this point, however, it was continued more evenly and steadily. The Columbia Valley was entered on the 10th of November, the Columbia River crossed on the 1st of December, and the mouth of the Beaver, at the end of the Columbia Cañon was reached on the 26th of the same month, the rate of progress being $1\frac{1}{2}$ mile per day. Here the work was suspended for the season. The distance from the summit is $73\frac{3}{4}$ miles, and the total distance track was laid, $75\frac{3}{4}$ miles.

The work was done by a gang averaging ninety men. They were carried along in a train of cars, fitted up with sleeping and boarding accommodation, so that they were always close to their work, since the train was kept at the end of the track. As the rails for laying were run to the front, they were unloaded immediately to the rear of the boarding-train, this train was pulled back, and the fresh rails, with the requisite ties, were placed on light push-cars, and hauled forward by horses to the last pair of rails in position. From this the ties necessary for a length of rails were laid out, a pair of rails was placed in position, and the car run forward, the same operation being repeated for the next pair of rails. Men coming behind put on the angle-plates, and spiked the rails to the ties. The greatest length of track laid in one day was 1·4 mile. This "record" is very small as compared with the work done on the prairie in the summer of 1883, when 6·3 miles of track were laid in one day; but on the mountain division it was impossible to obtain the same assistance from teams, conveying material to the front alongside the track, as had been given on the prairie section, and all the work of laying had to be carried on from the cars.

Dynamite Factory.

A dynamite factory was erected on the bank of the Kicking Horse Lake for manufacturing the explosives used on the work, so as to get rid of the danger attendant upon their transportation from long distances east by rail. The acid and glycerine were brought by train to the factory, which was immediately alongside the track. In the first instance, charcoal, made from the trees in the neighbourhood, was used as the absorbent; but its absorbing powers were not sufficient for the high grade of powder, while the charcoal-gas evolved on explosion rendered the air in tunnels very bad, and delayed the men at work. Latterly recourse was had to wood-pulp, brought from the east. Necessarily a much larger quantity, by weight, of raw material was brought in than would have been the case had the manufactured article been purchased from some eastern factory; but the risk of carrying large quantities of high per cent. dynamite 1,500 or 2,000 miles by rail, as well as the high rate of freight exacted by railway companies for its conveyance, more than counterbalanced the freight charges on the additional weight of raw material.

The quantities entering into the composition of 100 lbs. of dynamite of 75 per cent. strength, are as follow:—

Raw material. Lbs.		Dynamite. Lbs.	
37½	glycerine.	75	nitro-glycerine.
300	nitric and sulphuric acid.		
25	wood-pulp.	25	wood-pulp.
362½		100	

It will thus be seen that the weight of the raw material is more than three and a half times that of the manufactured article. More than 90 tons of dynamite were made at this factory during the season, and forwarded by rail and wagon where required, without accident. The factory has now been moved from the Kicking Horse Lake, and re-erected in the Columbia Valley.

As a gradient of 1 in 22 with sharp curves on the 4 feet $8\frac{1}{2}$ inches gauge is not common, some particulars in regard to its working may not be without interest. The locomotives were without any special adaptation to such a grade, being the ordinary engines of the Canadian Pacific Railway Company. They are mostly built at the Baldwin Locomotive Works of Philadelphia, and had two pairs of driving-wheels coupled, the weight on the drivers being about 26 tons, and the total weight of the engine 33 tons; the weight of the tender was 15 tons. Some were fitted with the Westinghouse brake, while others had only hand-brakes. Where the steam-brake was attached, it was used only on the tender, and was not applied to the cars. The diameter of the driving-wheels varied from 4 feet 8 inches to 5 feet. Two such engines were always worked together, both in descending and in ascending the gradient, one at the head of the train, the other at the rear. The train in descending usually consisted of from twelve to fourteen loaded cars, averaging 26 tons gross weight each; the ascending train consisted of from eight to twelve empty cars, averaging 10 tons weight each. The speed during the descent never exceeded 4 miles an hour, while in the ascent, with the rail in good dry condition and a moderate train, it was often at the rate of 6 to 8 miles an hour on the steep part of the grade. It was necessary to descend slowly, because if the train attained a speed much greater than 6 miles per hour, there was considerable danger of its getting out of control. Two "runaways" took place, while track was being laid, which demonstrated the necessity for care andext reme watchfulness. Since, however, the line has been used for bringing forward the company's supplies and material, a large quantity of freight, embracing provisions, supplies, rails, timber and dynamite, has been brought down this grade in safety. In the two months of October and November 1884, sixteen hundred and twenty-two loaded cars were taken down the grade, and fifteen hundred empties brought up; and this by four ordinary light locomotives, such as are in use in other parts of the line.

It is the intention of the company to use large and powerful consolidated engines on this part of the road, during the construction of the railway to the west. Two such engines have been built by the Baldwin Locomotive Works, and in January (1885) one of them was tried and tested on the grade, with very satisfactory results. This single engine took up a train of twelve cars, weighing 280,850 lbs. at a speed of 4¼ miles per hour. It has four pairs of 4-feet driving-wheels coupled; the cylinders are 20 inches by 26 inches; the steam-pressure in the boiler is 150 lbs. per square inch. Two trials were made, the first on the 20th of January, the second on the 28th. The first trial was with the engine burning wood, when difficulty was experienced in keeping up steam. The second was carried out with coal as the fuel, and as maintenance of steam was then perfect, the results of that test are given:—

TEST of CONSOLIDATED ENGINE on 4½ PER CENT. GRADE (1 in 22·2) in the KICKING HORSE PASS on the 28th of JANUARY, 1885.

Thermometer, 25° Fahrenheit. Rail, clean and dry.

	Lbs.
Weight of engine on drivers	102,000
„ „ on front truck	14,000
„ tender when full	50,000
Total weight of engine and tender . .	166,000
Weight of train (twelve cars)	280,850
Total weight of engine and train . . .	446,850
	Feet.
Length of grade	17,000

Time of ascent, forty-five minutes. Speed, 4·29 miles per hour. Steam-pressure at foot of grade, 126 lbs. per square inch; do. at head, 140 lbs. Consumption of coal, 2,676 lbs.; do. of water, 1,498 gallons; consumption of water per minute, 33⅓ gallons. Fuel consumed per gross ton moved 1 mile, 4·16 lbs. Resistance on grade per ton, 110 lbs. Total resistance of locomotive and train, 21,941 lbs. Equivalent in foot-lbs. in ascending grade, 372,997,000. Foot-pounds per 1 lb. of coal consumed, 139,411.

The adhesion developed in the engine was 2·9 of its weight on the driving-wheels. The coal used was not of the best quality, 1 lb. evaporated only 56 gallons of water.

There are several 10° curves (573-feet radius) of short length on the grade, but the grade is equated for the curves, and the resistance on them was no greater than on the straight parts. In descending the working of the engine was very satisfactory, and no difficulty was experienced in controlling a train of fourteen loaded cars when moving at 8 miles an hour. The engine is fitted with the Westinghouse steam-brake, which is applied to the driving-wheels and the wheels of the tender. With two engines such as this a large traffic can be successfully worked on this gradient.

A telegraph line has been constructed along the route of the railway.

The uniform rate of wages paid for common labour was $2 (8s.) per day of ten hours, and the men were charged $5 (£1) per week for board.

On a work such as has been described, carried on in an entirely undeveloped and uninhabited country, and at a distance of some 200 miles from any of the established institutions of civilized man, it was necessary to make provision for the wants and needs of the contractors and labourers in every respect. A bi-weekly mail service, by means of pony couriers, was established along the whole length of the route on which contractors' camps were placed, and beyond to the outlying camps of the surveying parties. This mail service was independent of the Government postal service, which did not extend beyond the end of the track-store. At this point the Government post-office was maintained in a car fitted up for the purpose, and which was moved on from time to time as track-laying progressed.

An efficient staff of doctors was maintained, and hospitals for the treatment of the sick and injured were erected at convenient points. All men employed were charged 75 cents. (3s.) each per month as medical dues, and for this all medicines, doctor's attendance, and hospital treatment, were given free of further charge.

A detachment of the North West Mounted Police, numbering twenty-five men, was told off for duty along the line of railway, and this small body of men, under the command of Captain S. B. Steel, was successful in maintaining law and order among the heterogeneous population, in which were representives of almost every European nation, numbering over six thousand labourers and camp followers.

The work of construction has been carried on during the winter, and at the present time (February 1885) contractors are spread over the route, from the end of track to the second crossing of the Columbia River, a distance of 65 miles. It is confidently expected that the junction with the rails from the Pacific Coast will be effected by November.

The Paper is accompanied by a small scale-map and profile, showing that portion of the line which was completed in 1884.

The whole of the works, as well as the preliminary and final surveys, have been carried on under the direction of Mr. James Ross, the Chief Engineer and Manager of Construction.

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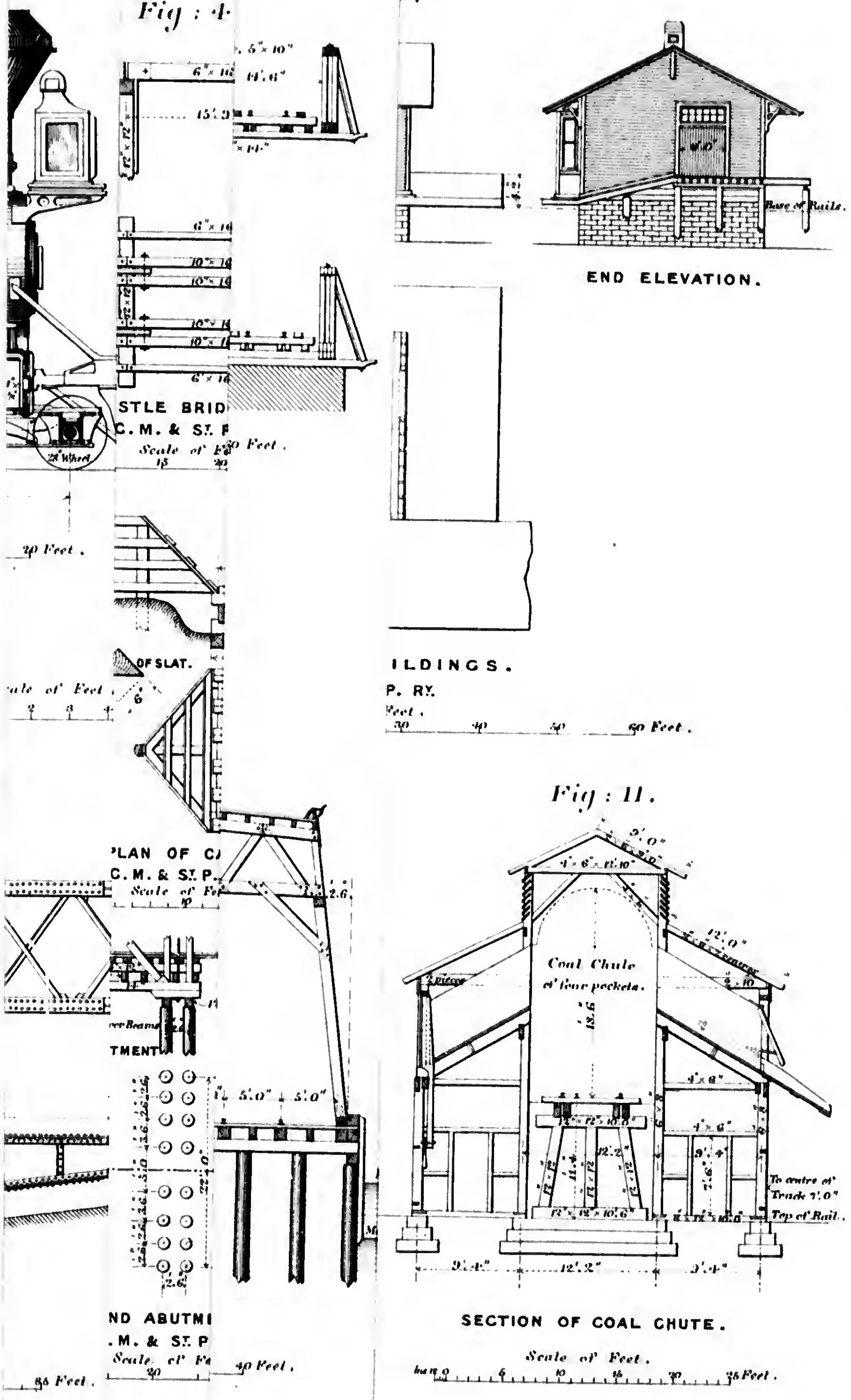
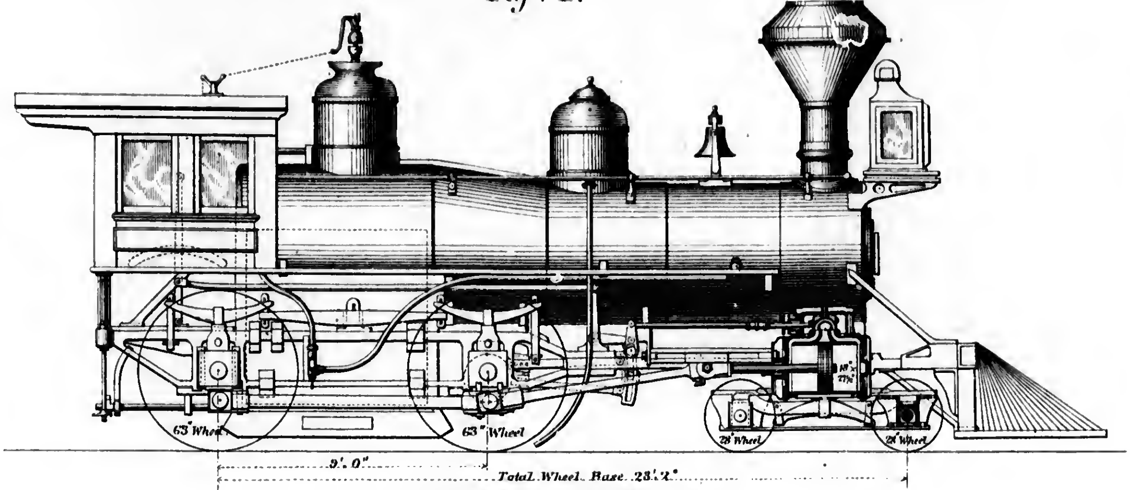


THOs KELL & SON, LITH. 40, KING ST COVENT GARDEN

Fig : 1.



STANDARD LOCOMOTIVE.

Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 10 15 20 Feet.

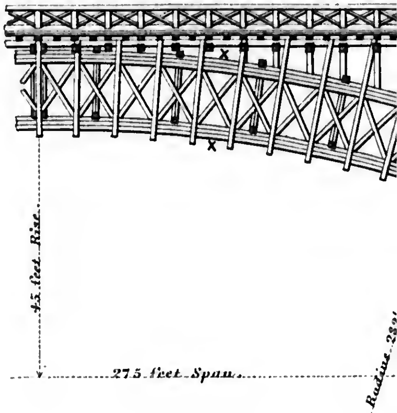
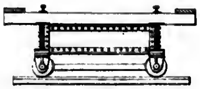
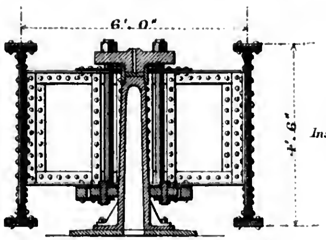


Fig : 2.



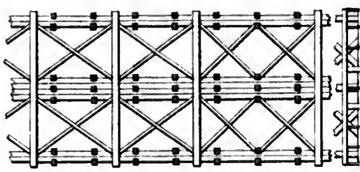
TRANSVERSE SECTION.



SECTION THROUGH CENTRE.

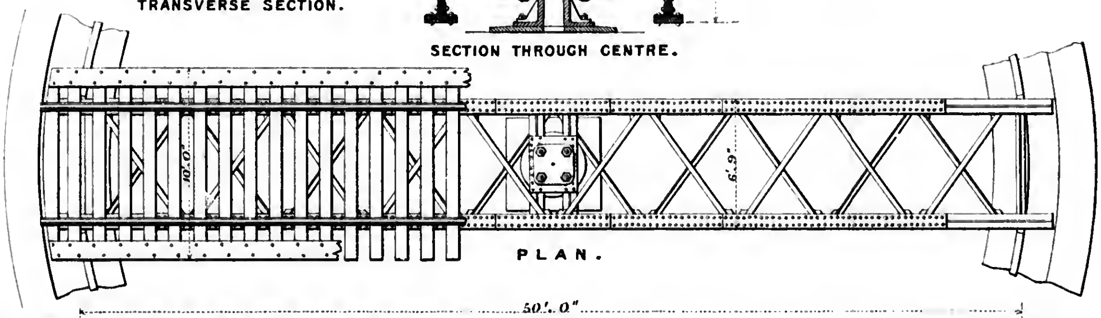
Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

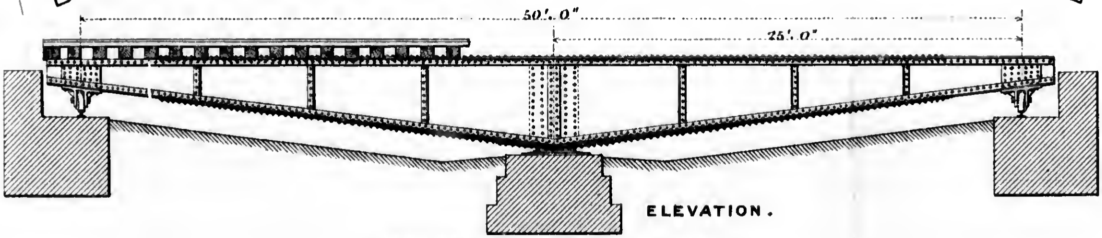


PLAN OF RIBS.

Ft 10 5 0 10 20 30



PLAN.

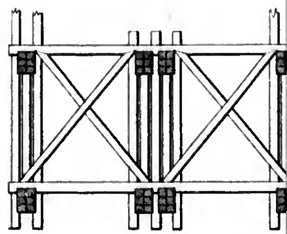


ELEVATION.

TURNTABLE. - ERIE RAILWAY.

Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 10 15 20 25 30 35 Feet.



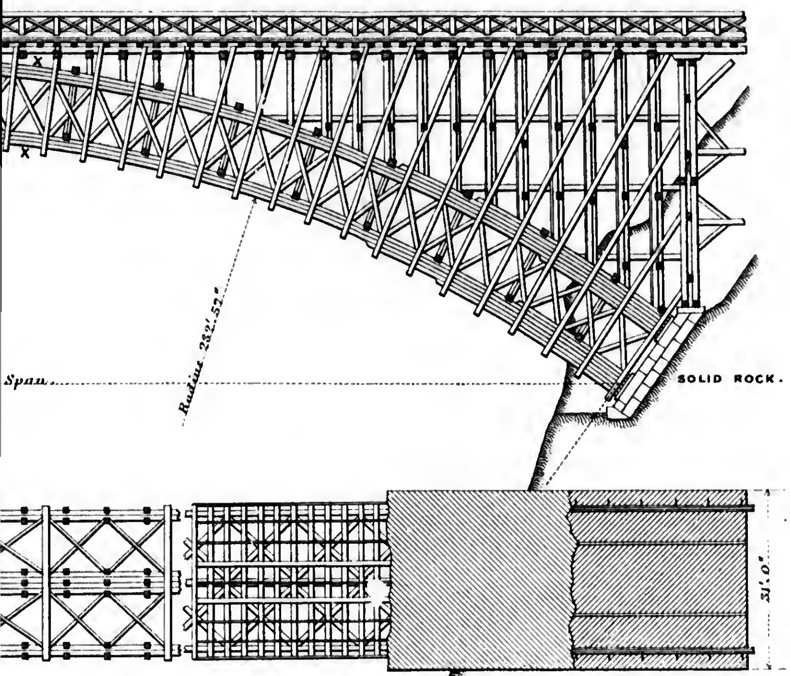
SECTION THROUGH XX.

CASCADE B

Ft 10 5 0

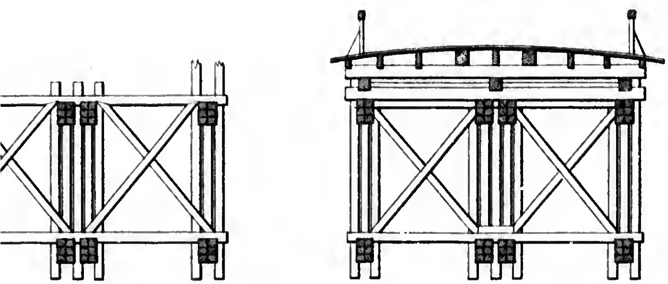
ROBERT GORDON, DEL^T

Fig: 3.



F RIBS. FLOOR BEAMS &c. FINISHED PLAN.

Scale of Feet.

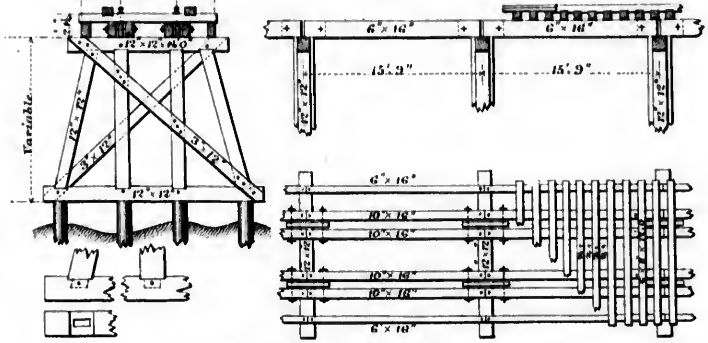


CTION THROUGH XX. SECTION THROUGH CROWN OF ARCH.

CASCADE BRIDGE. - ERIE RAILWAY.

Scale of Feet.

Fig: 4.

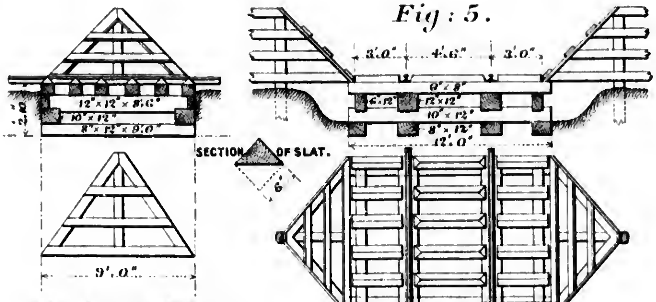


STANDARD TRESTLE BRIDGE. - 15'.9" BENTS.

C. M. & ST. P. RY.

Scale of Feet.

Fig: 5.



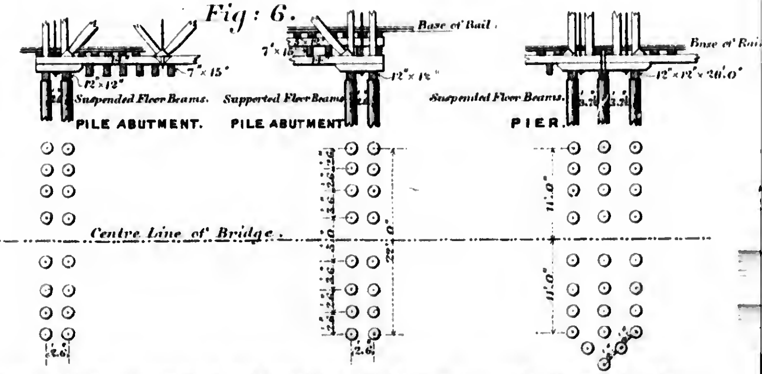
PLAN OF WING PANEL.

STANDARD PLAN OF CATTLE GUARD.

C. M. & ST. P. RY.

Scale of Feet.

Fig: 6.

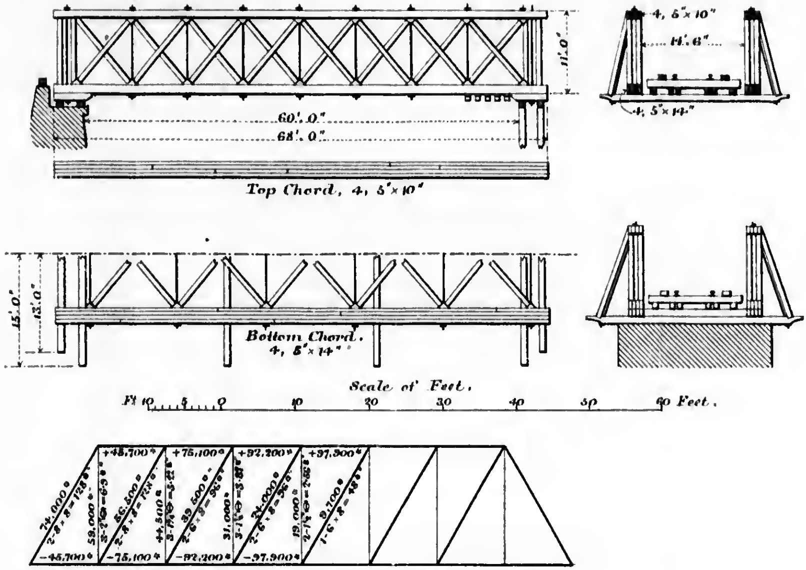


STANDARD PLAN OF PILE PIER AND ABUTMENT FOR HOWE TRUSS BRIDGES.

C. M. & ST. P. RY.

Scale of Feet.

Fig : 7.



62 feet between End Posts. — 8 Panels of 7·75'. — Depth 10' c. to c. Chords.
Max. 97,900 = 4 - 6" x 10" = 240 □".
97,000 □" tension ...... } = *4 - 6" x 14" = 210 □" net.*
26,100 □" bend^g moment }
Max. Strain on extreme fibres = 975 feet per □".

60 FEET SPAN BRIDGE.

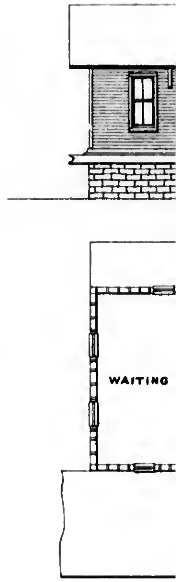
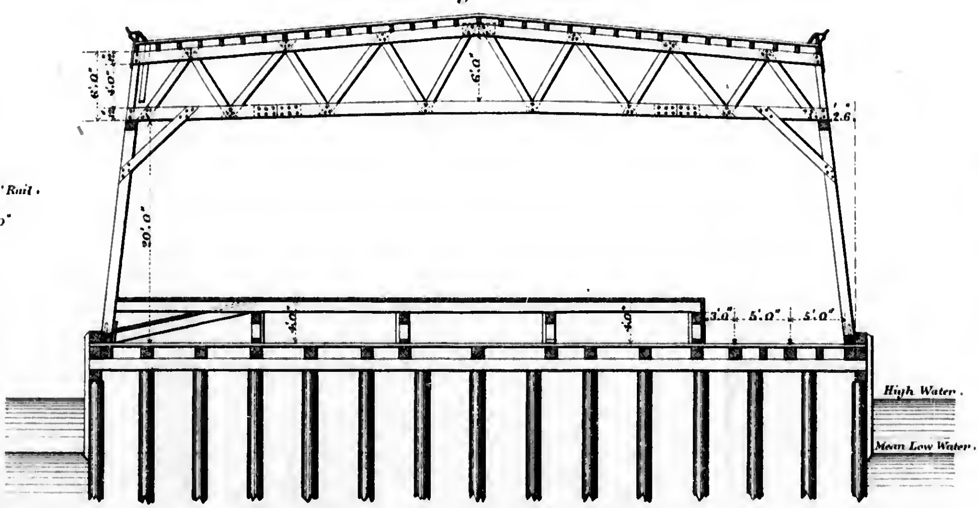


Fig : 8.



TRANSVERSE SECTION OF FREIGHT SHED.

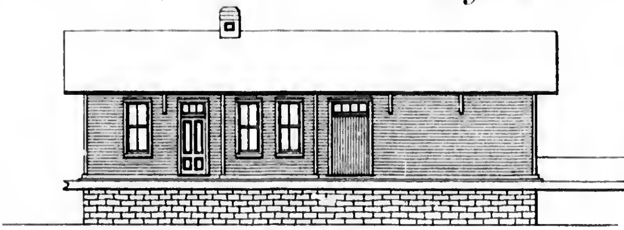
Scale of Feet.
Ft 10 5 0 10 20 30 40 Feet.

" Rail.

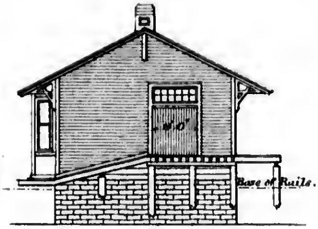
0"

I.

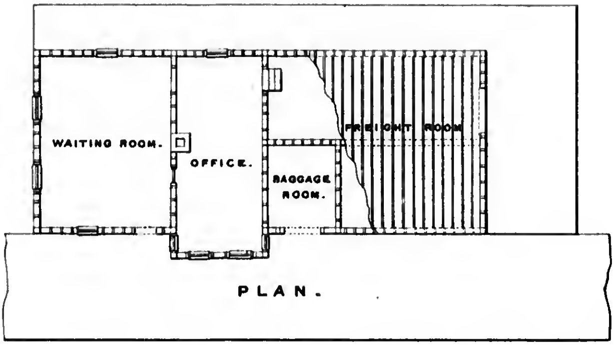
Fig : 9.



ELEVATION.



END ELEVATION.



STATION BUILDINGS.

C.M. & ST. P. RY.

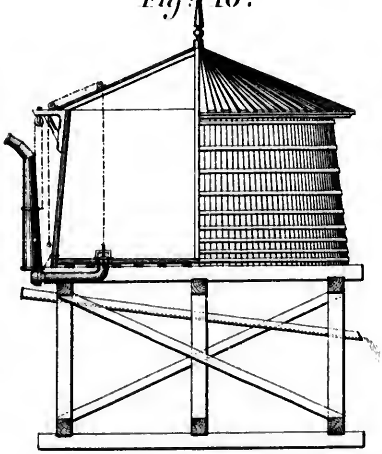
Scale of Feet.

Ft. 10 5 0 10 20 30 40 50 60 Feet.

Fig : 10.

High Water.

Mean Low Water.

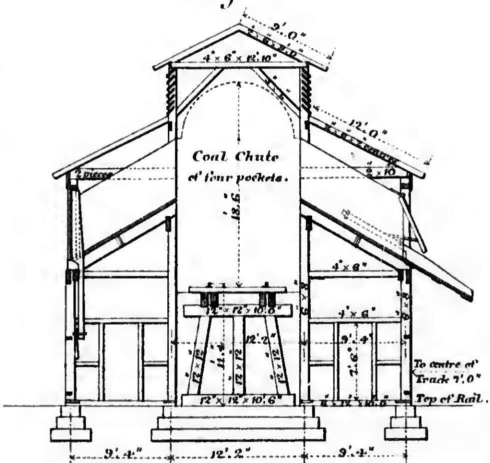


WATER TANK AND CRANE.

Scale of Feet

Ins. 12 0 5 10 15 20 Feet.

Fig : 11.



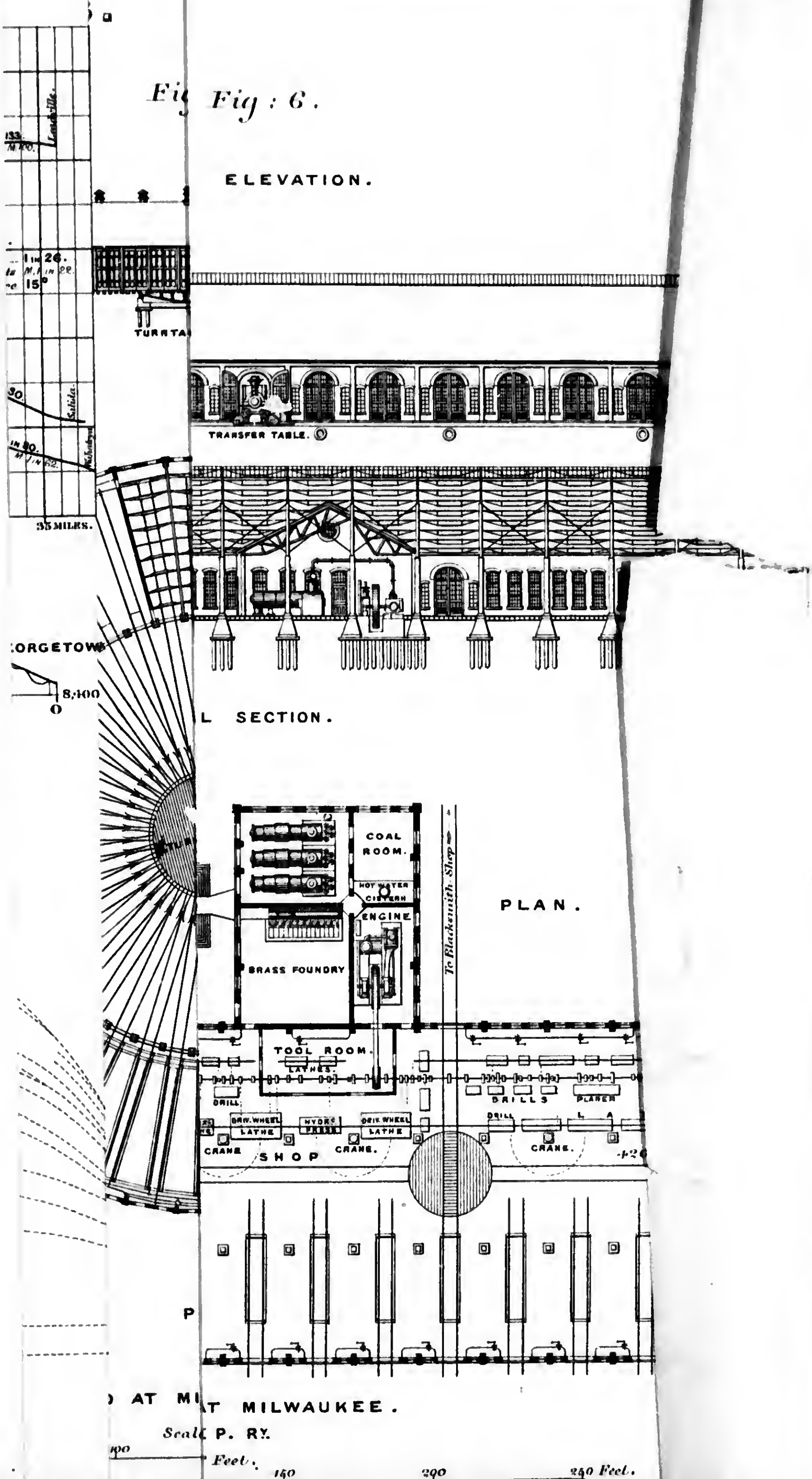
SECTION OF COAL CHUTE.

Scale of Feet.

Ins. 12 0 5 10 15 20 25 Feet.

THOS KELL & SON, LITH. 40, KING ST. COVENT GARDEN


133.
M.100.
1 IN 26.
15°
30.
ORGET

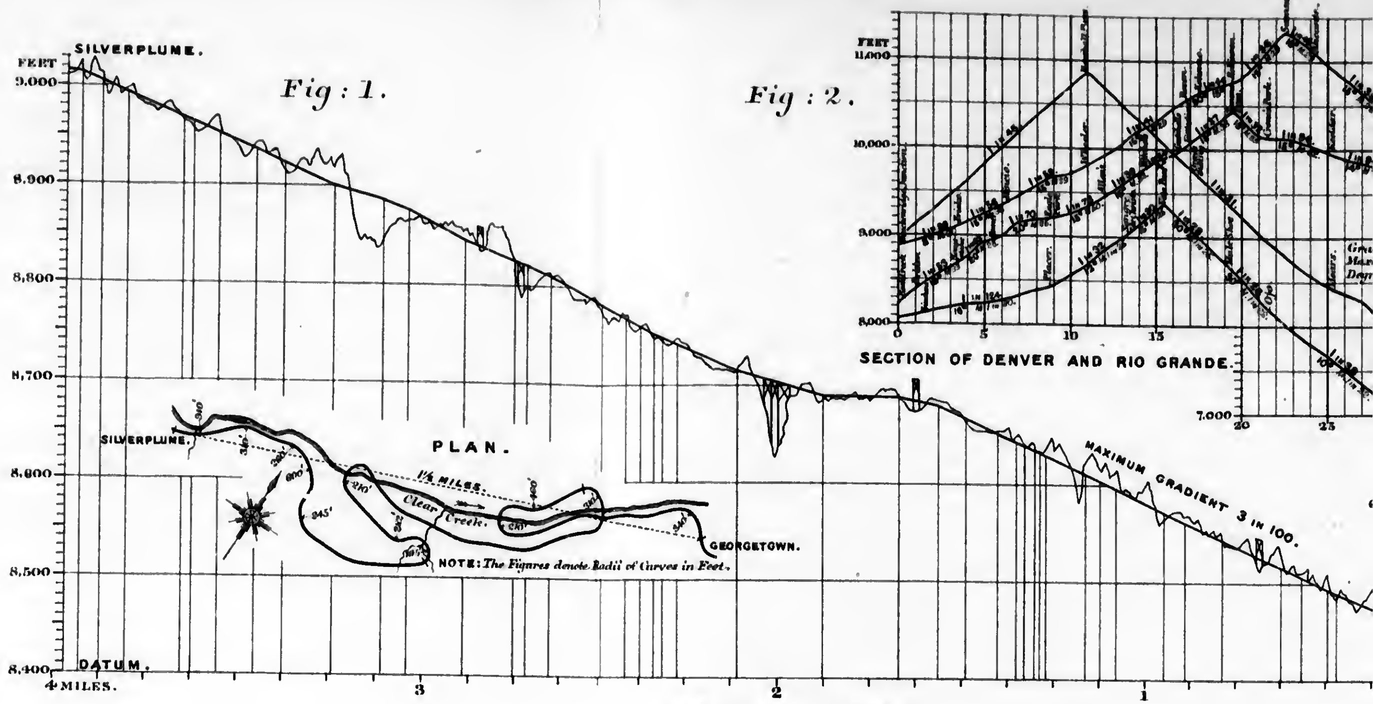


36. Part I

THOS. KELL & SON, LITH

Fig : 1.

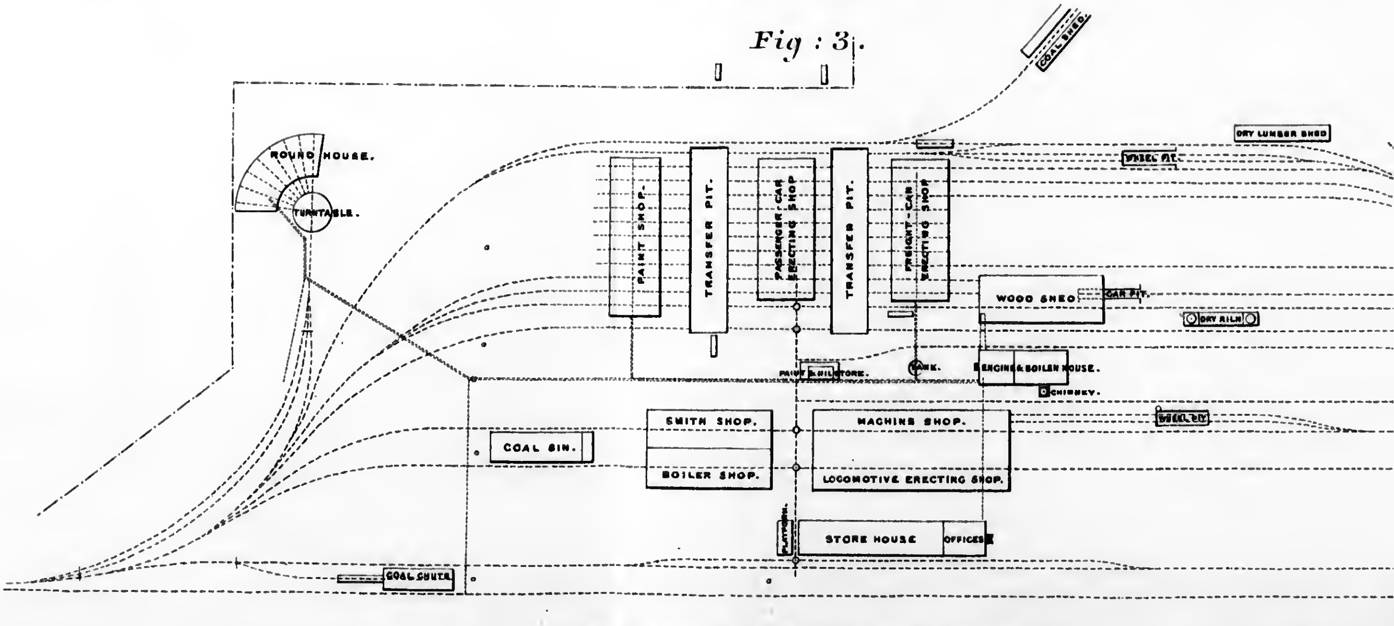
Fig : 2.



SECTION OF DENVER AND RIO GRANDE.

GREYTOWN LOOP.

Fig : 3.

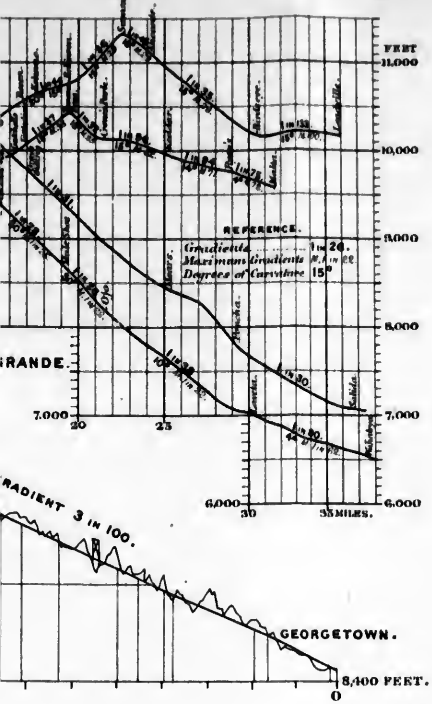


BURLINGTON SHOPS. – GENERAL PLAN.

Scale of Feet.

Ft 100 50 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 Feet.

ROBERT GORDON, DELT


FEET
11,000
10,000
9,000
8,000
7,000
6,000
REFERENCE.
Gradients .... 1 in 26.
Maximum Gradients 1 in 22
Degrees of Curvature 15°
GRANDE.
20
25
30
35 MILES.
GRADIENT 3 IN 100.
GEORGETOWN.
8,400 FEET.
0

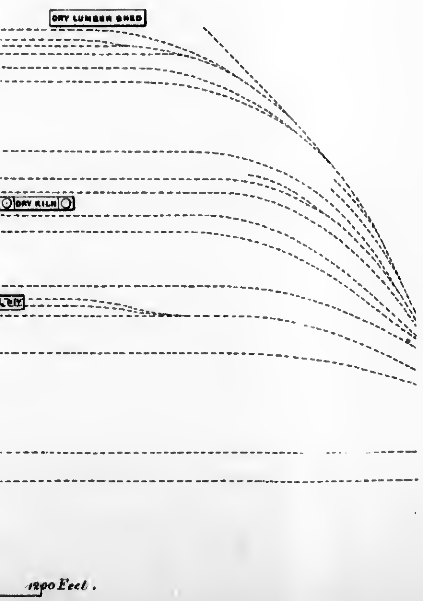

DRY LUMBER SHED
DRY KILN
1200 Feet.

Fig : 4.

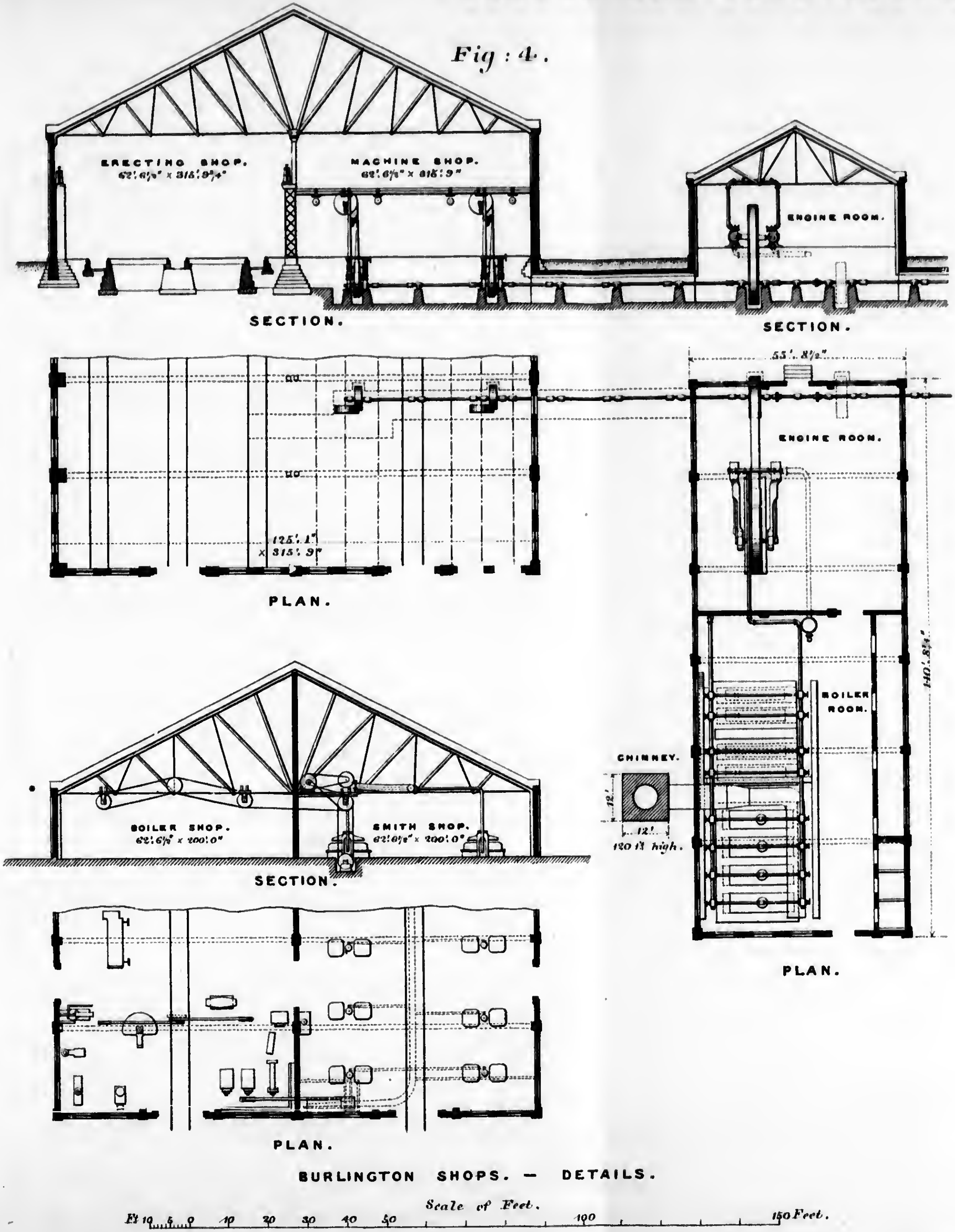
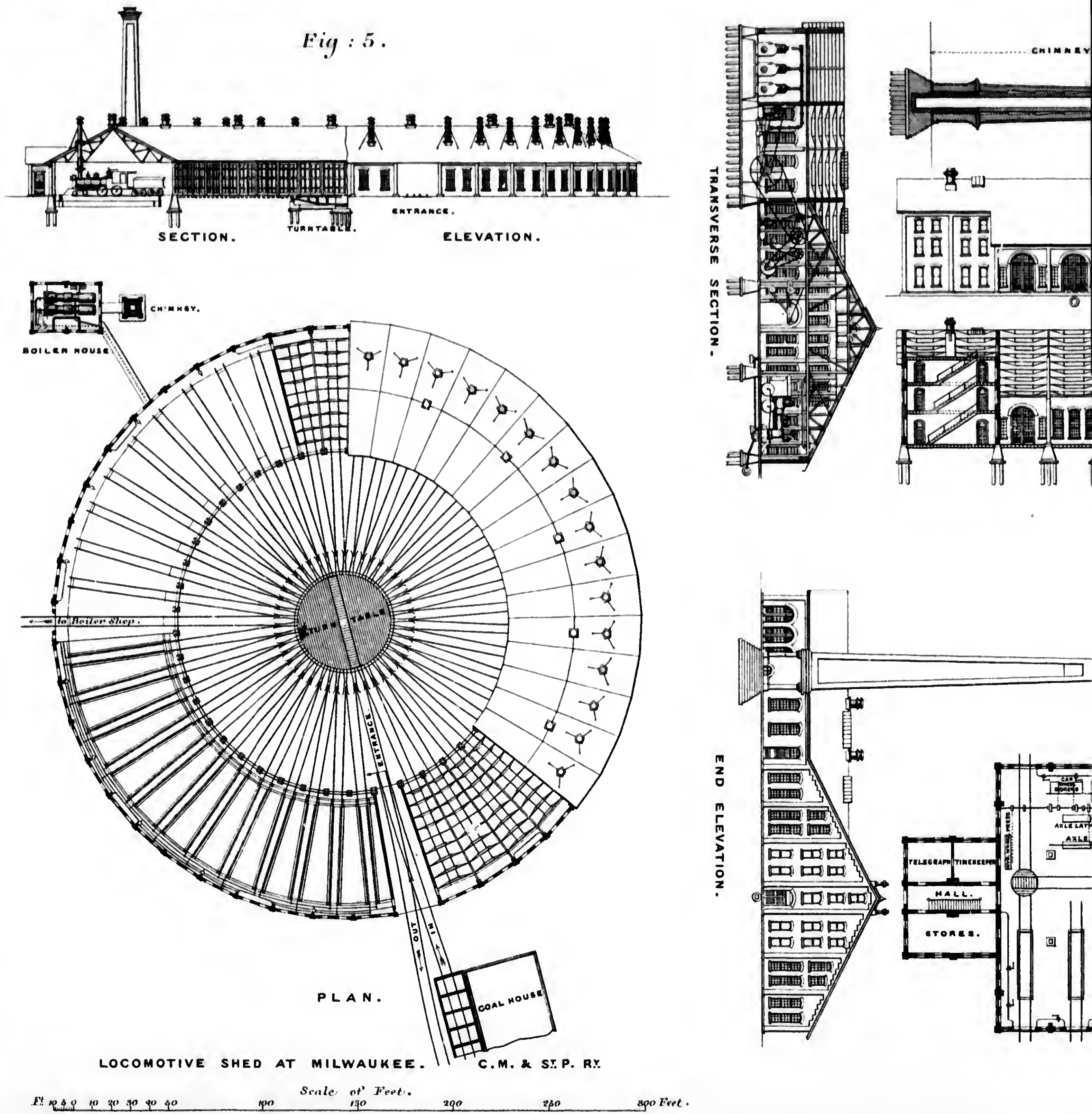
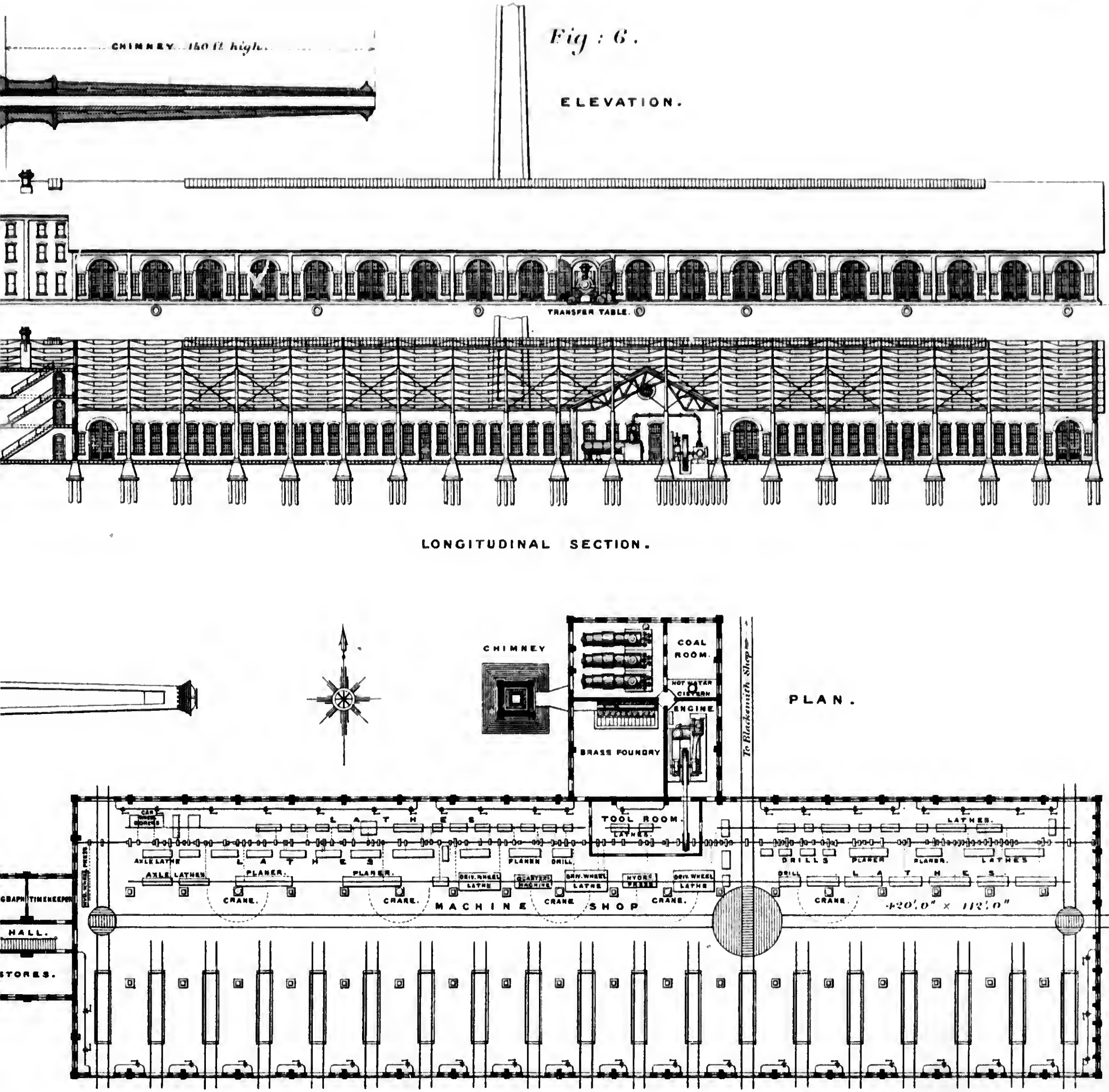

ERECTING SHOP.
MACHINE SHOP.
ENGINE ROOM.
SECTION.
SECTION.
53'. 8½"
ENGINE ROOM.
125'. 1" × 315'. 9"
PLAN.
BOILER ROOM.
CHIMNEY.
12'
12'.
120 ft. high.
140'. 8¾"
BOILER SHOP.
62'. 6½" × 200'. 0"
SMITH SHOP.
62'. 6½" × 200'. 0"
SECTION.
PLAN.
PLAN.
BURLINGTON SHOPS. — DETAILS.
Scale of Feet.
Ft 10 5 0 10 20 30 40 50 100 150 Feet.

Fig: 5.



LOCOMOTIVE SHED AT MILWAUKEE. C.M. & ST. P. RY.



MACHINE SHOP AT MILWAUKEE.

C.M. & St. P. Ry.

Scale of Feet.

Ft 10 5 0 10 20 30 40 50 100 150 200 250 Feet.

THOS. KELL & SON, LITH. 40, KING St. COVENT GARDEN.

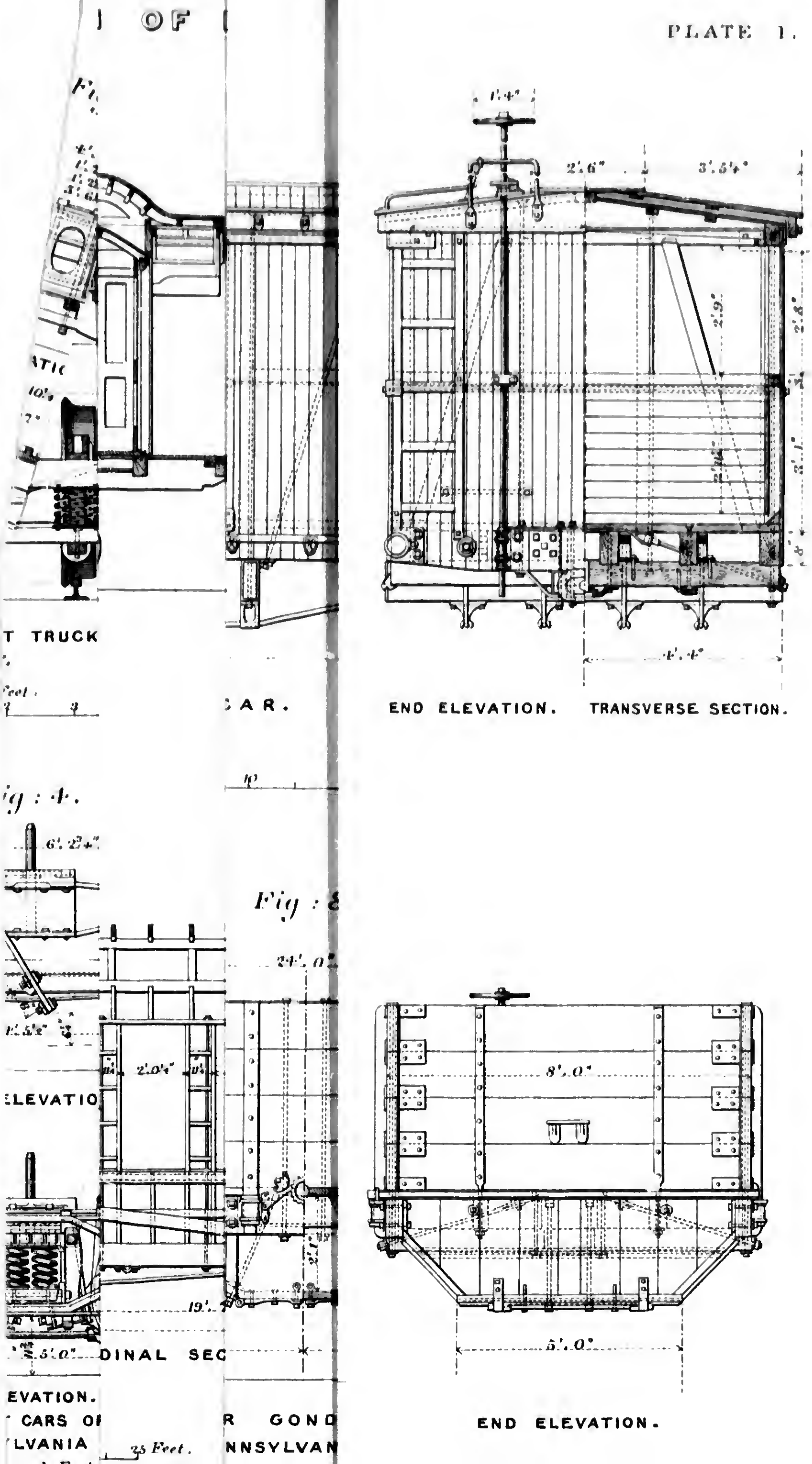
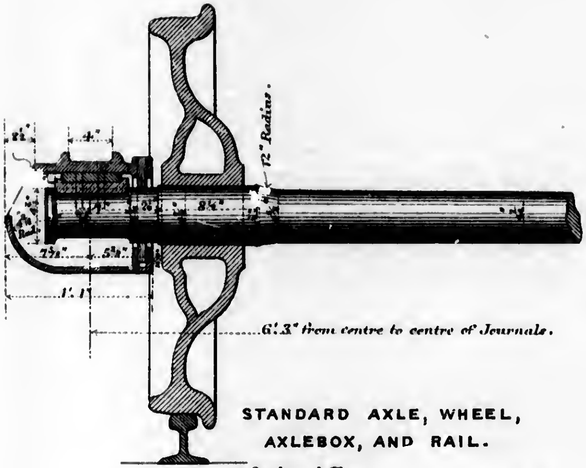

OF
T TRUCK
CAR.
END ELEVATION.
TRANSVERSE SECTION.
Fig : 4.
Fig : 8
ELEVATIO
DINAL SEC
EVATION.
CARS OF
LVANIA
25 Feet.
R GOND
NNSYLVAN
END ELEVATION.
8'.0"
5'.0"
4'.4"
24'.0"
19'.
2'.6"
3'.5¼"
2'.9"
2'.8"
3'.1"
6'.2¾"
2'.0¼"

Fig : 1.

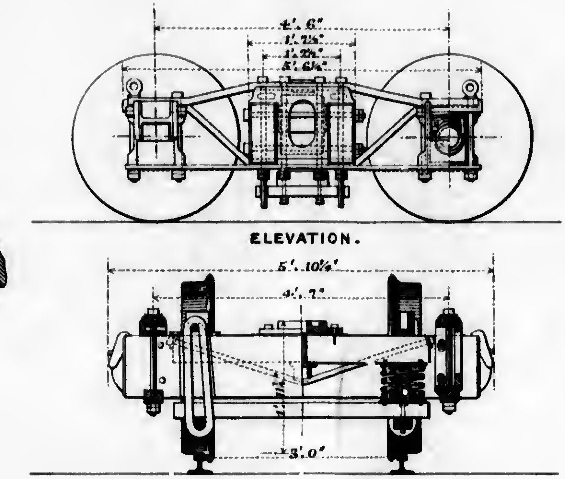


STANDARD AXLE, WHEEL, AXLEBOX, AND RAIL.

Scale of Feet.

Ins. 12 9 6 3 0 1 2 Feet.

Fig : 3.



20 TON FREIGHT TRUCK.

U. P. RY.

Scale of Feet.

Ins. 12 6 0 1 2 3 4 Feet.

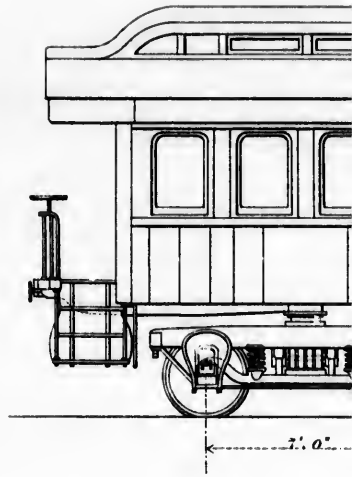
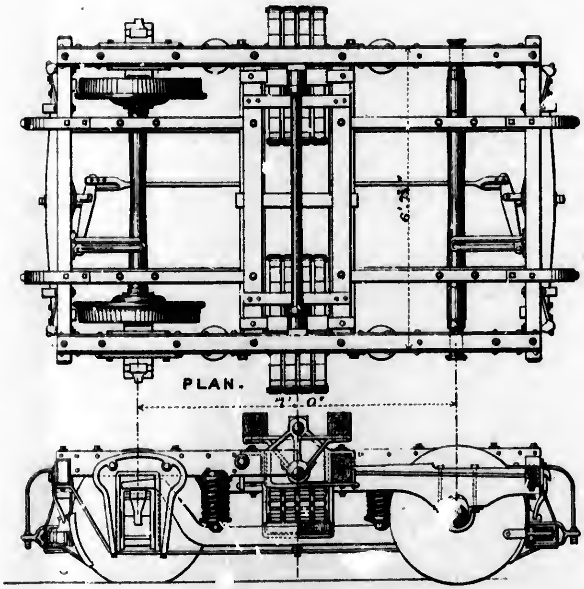


Fig : 2.



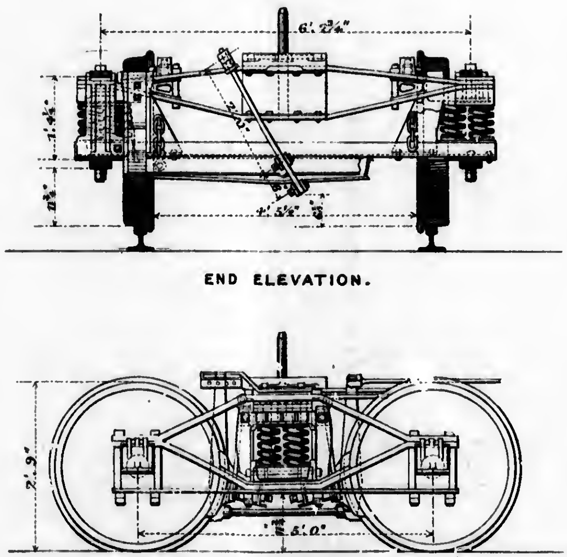
ELEVATION.

SUSPENSION TRUCK FOR PASSENGER CARS.

Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 6 7 Feet.

Fig : 4.



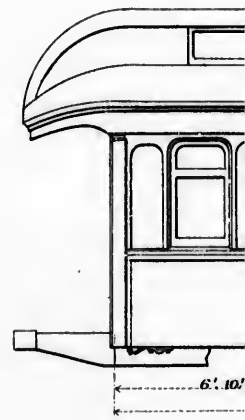
ELEVATION.

IRON TRUCK FOR FREIGHT CARS OF 60,000 LBS. CAPACITY.

PENNSYLVANIA RY.

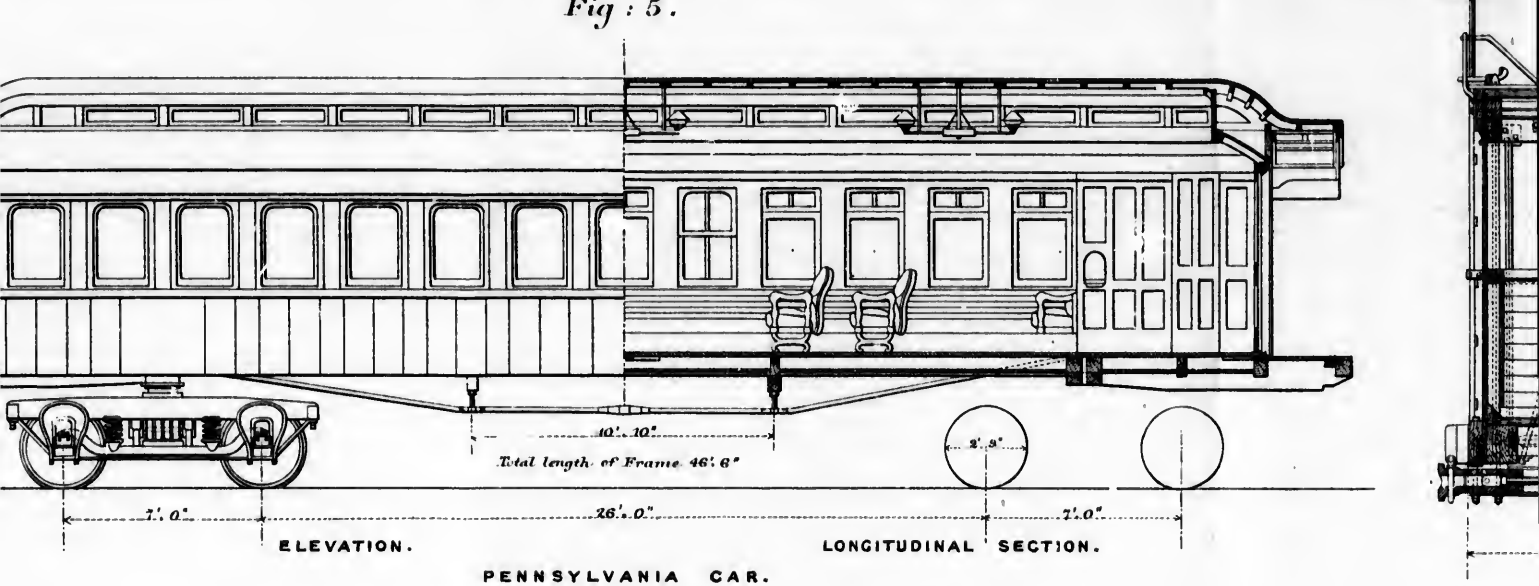
Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 Feet.



ROBERT GORDON, DELT.

Fig : 5.

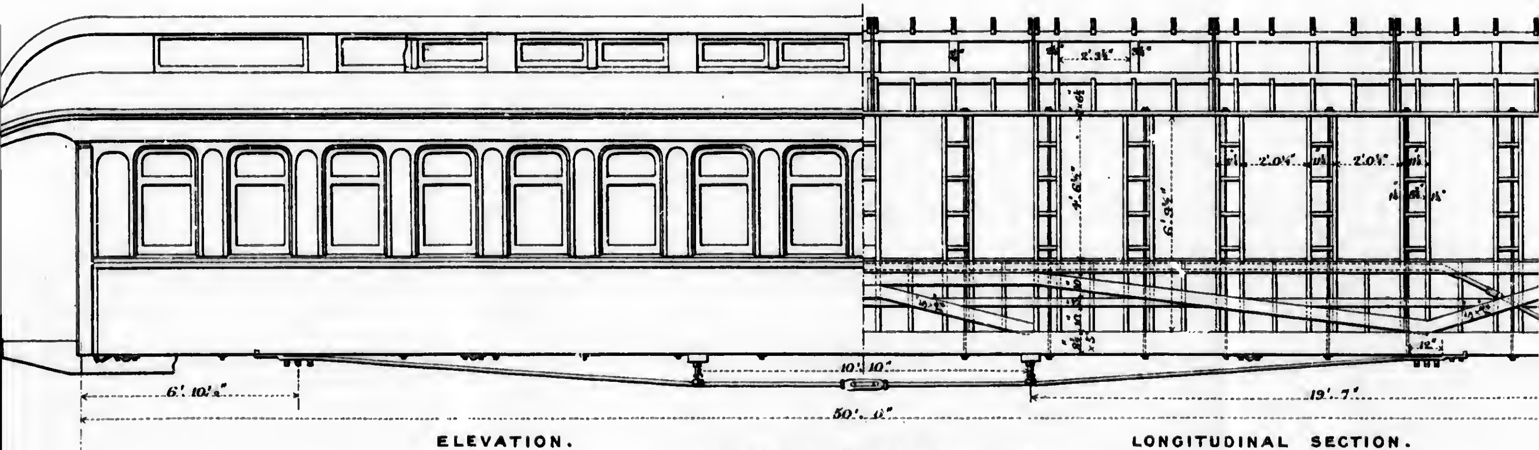


PENNSYLVANIA CAR.

Scale of Feet.

Ins. 12 6 0 1 2 3 4 5 10 15 20 25 Feet.

Fig : 6.



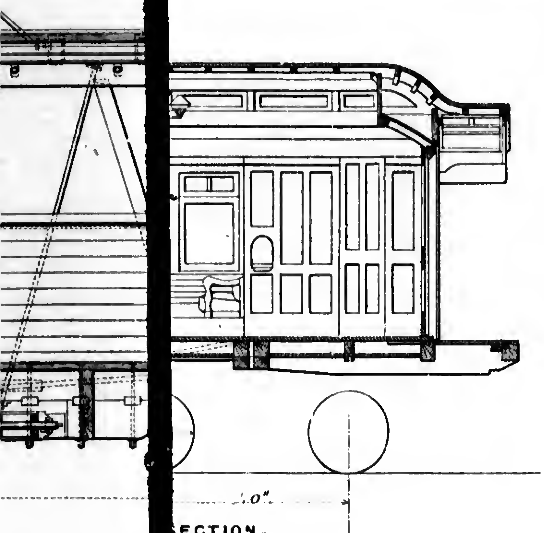
IMMIGRANT SLEEPING CAR.

CANADIAN PACIFIC RY.

Scale of Feet.

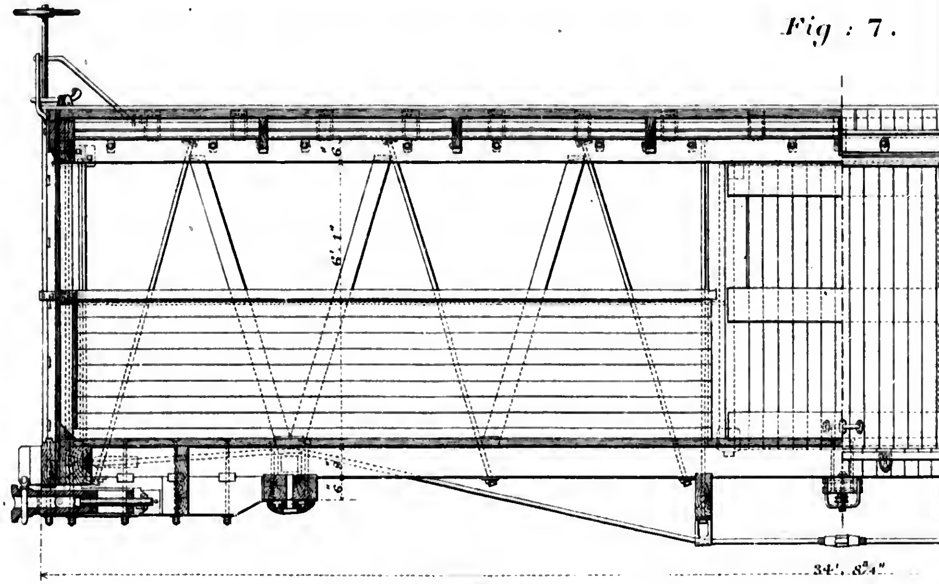
Ins. 12 6 0 1 2 3 4 5 10 15 20 25 Feet.

Fig : 7.



ECTION.

Feet.



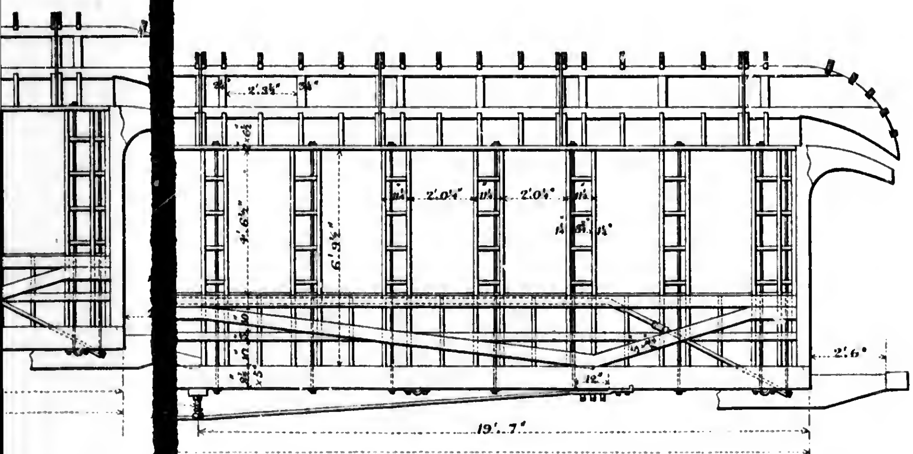
LONGITUDINAL SECTION.

STANDARD BOX

N.Y. W.S. & B. RY.

Scale of Feet.

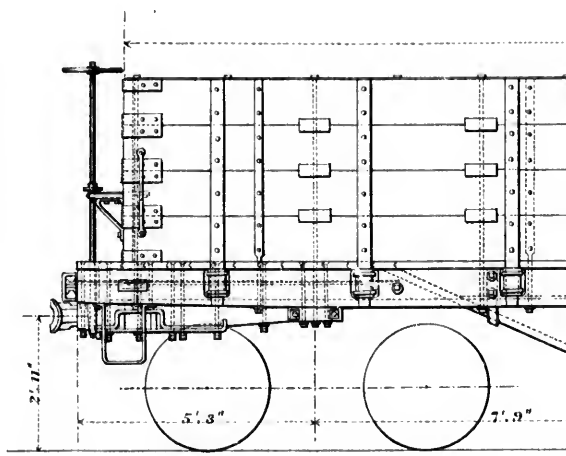
Ins. 12 6 0 1 2 3 4 5



LONGITUDINAL SECTION.

AR.

30 35 Feet.



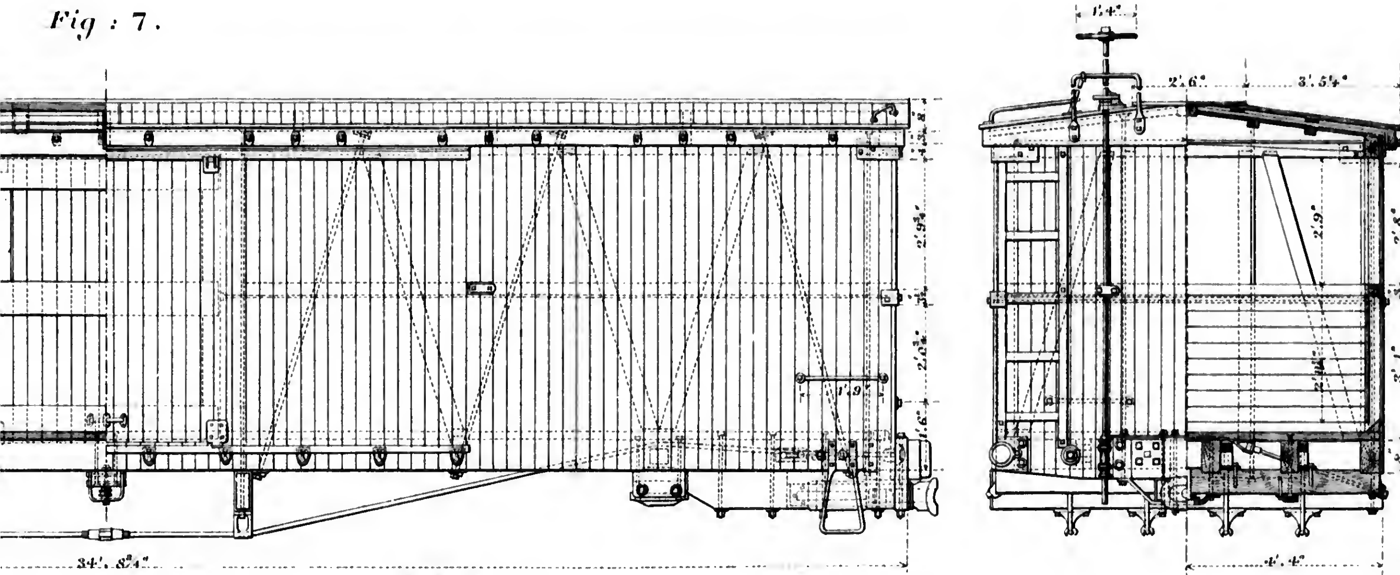
HOPPE

P

Ins. 12 6 0 1 2 3 4

Part III.

Fig : 7.



ELEVATION.

END ELEVATION. TRANSVERSE SECTION.

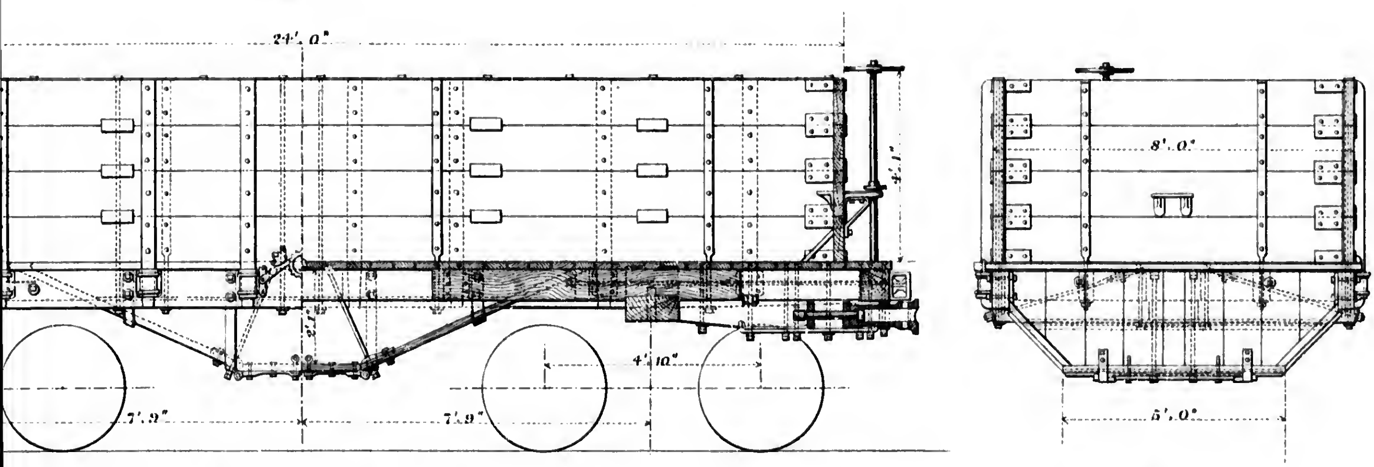
NDARD BOX CAR.

N.Y. W.S. & B. RY.

Scale of Feet.

5 10 15 Feet.

Fig : 8.



HOPPER GONDOLA CAR.

PENNSYLVANIA RY.

END ELEVATION.

Scale of Feet.

1 2 3 4 5 10 15 Feet.

THOS. KELL & SON. LITH. 40, KING ST. COVENT GARDEN.