No. 1,166.—“On Light Railways in Norway, India, and Queensland.” By CHARLES DOUGLAS FOX, M. Inst. C.E.

THE subject of the construction of Light Railways is one of daily increasing importance. In Great Britain, the trunk lines have been made with a view to carry an immense traffic at high speeds; and, in most instances, in a massive manner well suited to their purpose. Other countries have followed this example; and throughout Europe, first-class railways may be found, with ruling gradients of 1 in 100, minimum curves of 20 chains radius, and rails weighing from 60 lbs. to 84 lbs. per yard; worked by locomotives having from 10 tons to 16 tons on a pair of wheels, and weighing from 30 tons to 45 tons each. But, on the other hand, railways have been constructed, especially in America, to be worked by locomotives equally heavy, although with general works, and especially permanent way, unsuited for such traffic; and thus have arisen heavy working and maintenance expenses, and numerous accidents.

A demand is now arising for railway intercommunication between places not of sufficient importance to justify the cost of a first-class railway; especially in colonies and other countries, where such communication is required for the purpose of attracting population, and where, for many years, the traffic is sure to be of a comparatively light character.

By the term “Light Railways,” the Author would wish to be understood such as, either being branches from existing trunk lines, or being intended for districts requiring the development of their traffic, should be constructed in a thoroughly substantial and durable manner, equal in their details as to quality to the best trunk lines, but with every part made only of such strength as to carry loads represented by the rule, that no pair of wheels should be allowed to have more than 6 tons upon it. This would enable these lines to carry the rolling stock of all other railways of similar gauge, with the exception only of the locomotives.

The first railways constructed upon this principle, which have come under the Author's notice, are those of the Norwegian Government; the designs for which were prepared, and the works

¹ The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

[1866-67. N.S.]

carried out, under the guidance of Mr. Carl Pihl, the State Engineer. The Author visited these lines in 1864, and was struck with their efficiency and economy. With the exception of the line from Christiania to Eidsvold, which was constructed some years since by Mr. G. P. Bidder (Past-President Inst. C.E.), and the branch therefrom to the Swedish frontier—both of which are of the 4 feet 8½ inches gauge, that being the gauge adopted in Sweden—the railway system of Norway is upon the light principle, and of the 3 feet 6 inches gauge. The two lines visited by the Author may be taken as types of the system. The first, from Grundset to Hammar (Plate 4), on the Miösen Lake, a distance of 24 English miles, passes through an easy undulating country, has ruling gradients of 1 in 70, with curves of 1,000 feet radius, and has cost, including rolling stock and stations, £3,000 per mile. The second, from Thronthjem to Stören (Plate 4), a distance of 30 English miles, passes through a difficult country. The earthworks are heavy, including several rock cuttings and embankments of bad clay. There are twelve large bridges on the length of 30 miles, three of them of great height and length, the largest being the Sloppen Bridge over the River Nid. This is 620 feet in length, and has five principal spans of 70 feet each. The piers are 100 feet high, making the total height of the viaduct 110 feet. Up to high-water level the piers are of masonry, to resist the ice, but the rest of the bridge is of timber. The timber trusses are 10 feet in depth, and 11 feet apart, and are constructed upon Warren's principle. These structures are so carefully put together, that there is scarcely any vibration during the highest wind. The gradients on this line are chiefly 1 in 100. There are, however, 5 miles of 1 in 52, and in the opposite direction from the summit, 4 miles of 1 in 42, followed by 4 miles of 1 in 65 and of 1 in 100. Frequent curves are found throughout the line, but especially on the heavy gradients, where they are chiefly reverse curves, ranging from 700 feet to 1,000 feet radius. There are two terminal stations, six intermediate stations, and three stopping places, with workshops and engine and carriage sheds at Thronthjem. The total cost of the line, including rolling stock and stations, has been £6,000 per mile.

The permanent way upon these lines consists of flat-bottomed rails, weighing from 37 lbs. to 40 lbs. per lineal yard, fished at every 21 feet, with plates 11 inches long, and secured by dog spikes only to transverse sleepers, 2 feet 6 inches apart from centre to centre; no fang-bolts, or joint-plates being used. The sleepers are of pine, 6 feet 6 inches long, by 9 inches by 4½ inches in section, uncreosoted, and half-round, laid the round side up, and adzed, to increase the bearing of the rail, to 5 inches. An inward cant of 1 in 20 is given to the rail. The ballast occupies a space of 8 feet 6 inches wide, and 1 foot 8 inches thick, and is of good quality.

The crossings are reversible, and the switches self-acting. The permanent way, after having stood the test of several Norwegian winters, forms a very smooth road. Its repairs employ one man per mile. The general works are thoroughly substantial, the bridges and stations being of pine timber. The lines are 14 feet wide at the formation level.

The locomotives are nearly all alike, with the exception that some have the Bissel bogie, and others Adams' radial axle boxes. They were constructed partly by Messrs. R. Stephenson and Co., and partly by the Avonside Engine Company. They have outside cylinders, 10 inches in diameter, with a length of stroke of 18 inches, and six wheels—four driving-wheels 3 feet diameter, coupled, and two leading-wheels 2 feet in diameter. They are tank engines, and are fitted for burning coal, and have a working pressure of 120 lbs. Their weight in working order is 14 tons. The train by which the Author travelled weighed, with the engine, 118 tons, and ran considerable distances at 30 miles an hour, with smoothness and steadiness. The ordinary speed required by the traffic does not, however, exceed 15 miles per hour, including stoppages. In ascending the incline of 1 in 52, an assistant engine was attached, increasing the gross load to 133 tons, or $66\frac{1}{2}$ tons of gross load per engine, which was taken up with ease at about 12 miles to 15 miles per hour. The passenger carriages are 19 feet long, on four wheels, without bogies, and 6 feet 6 inches wide, by 9 feet 9 inches high outside. The goods wagons are 21 feet long, and 6 feet 3 inches wide. A single central buffer is adopted, forming also the drawbar. The under-frames are of wood.

These lines, which run through thinly-populated districts, already more than pay their expenses, and the results have been so satisfactory, that this system is being rapidly extended.

The railway from the Arconum Junction of the Madras Railway to the town of Conjeveram, 19 miles in length, and of the 3 feet 6 inches gauge, was constructed by Sir Charles Fox (M. Inst. C.E.), and Mr. G. Berkley (M. Inst. C.E.), as Engineers, and by Mr. B. Holloway, as Resident Engineer, for the Indian Tramway Company, Limited. It has now been in operation eighteen months with most satisfactory results.

The line, which runs over a flat country, is formed chiefly of a low embankment, with frequent culverts for drainage, and with two iron bridges, on screw piles, of considerable size, to cross rivers exposed to heavy floods. The works are substantially executed. The permanent way consists of flat-bottomed rails, $35\frac{1}{2}$ lbs. to the yard (Figs. 1 and 2), properly fished, and secured by dog spikes to transverse teak sleepers, 2 feet 6 inches apart from centre to centre, and

well ballasted. The locomotives and other rolling stock are nearly similar to those used on the Norwegian lines, adapted however to

Fig. 1.

Indian Tramway. Section at Joint; Rail $35\frac{1}{2}$ lbs. per yard.

Fig. 2.

Indian Tramway. 9 inch pile.

the difference of climate. The cost of this line, which was constructed by the Company's officers, was £3,200 per mile, including telegraph and stations, or £3,900 per mile including all management and rolling stock. Although the traffic does not require a greater working speed than from 12 miles to 15 miles per hour, the trains have at times been run, with perfect safety, at upwards of 40 miles per hour, including stoppages. During the Festival Days, in May, 1866, twenty-two thousand persons travelled on the line.

The relation of the cost of working to the gross receipts does not exceed that of an ordinary line.

The Government railways of the colony of Queensland—to which Sir Charles Fox (M. Inst. C.E.) and the Author are the Consulting Engineers—form at present the most extensive system to which this principle has been applied. These lines have been laid out by Mr. A. C. FitzGibbon (M. Inst. C.E.), the Engineer-in-Chief to the Colonial Government, who, upon his arrival in the colony, found that the chief want of the country was means of intercommunication, and that it would be better supplied by constructing light, but substantial, railways, than by continuing to spend something like the same amount on roads. Careful surveys were accordingly made, and it was found, that whilst the country both above and below the Main Range of hills was of an easy character, yet to surmount this range, cut up as it is by numerous and deep ravines, would require works of no ordinary character, and such as, for a line with ordinary curves and gradients, would be simply prohibitory in cost. The matter excited much interest in the colony; and the Government having, upon the advice of their Engineer, determined upon adopting a system of light railways, with a gauge of 3 feet 6 inches, much opposition was raised, resulting in the final adoption of the Government plans.

The Southern and Western Railway of Queensland will run from the town of Ipswich to Toowoomba, a distance of 78 miles, and will then divide into two branches, one running to Dalby, a distance of 52 miles, and the other to Warwick, a distance of 62 miles, making a total of 192 miles. About 50 miles have been opened for traffic, and the remaining 142 miles are in course of construction, partly by Messrs. Peto, Brassey, and Betts, and partly by local contractors. A further length of upwards of 200 miles is under survey. The Little Liverpool incline on this line, which passes a ridge 700 feet in height, is 3 miles in length, and has ruling gradients of 1 in 50, with curves of 6 chains radius. The main incline (Plate 4), which crosses a ridge 1,400 feet high, is 16 miles in length, and has ruling gradients of 1 in 50, with frequent curves of 5 chains radius. The earthworks on this portion of the line are very heavy, with cuttings in rock, and eleven tunnels, also in rock, which have been lined with brickwork, and of which one is 27 chains in length. There are also about twenty iron bridges, with lattice girders, 12 feet apart from centre to centre, and in spans varying from 60 feet to 100 feet, with an amount of water-way almost unparalleled on a similar length of line.

One of the chief works is the bridge over the river Bremer (Plate 6), close to the Ipswich terminus, for carrying a single line of narrow-gauge railway, and a public road 25 feet wide. It has a width of

37 feet between the parapets, and consists of three spans of 150 feet each. The abutments are of stone. The piers, which are 60 feet high, consist of cast-iron cylinders 6 feet in diameter, sunk into the bed of the river, and filled with concrete. Both the main and the cross girders are of lattice construction, the former being 12 feet deep. The top flange is composed of cast iron in a tubular form, the bottom tie of Howard and Ravenhill's rolled links. The cross girders are 6 feet apart from centre to centre, 37 feet long, and 1 foot 9 inches deep. The strains upon the various parts are in all cases within the limits fixed by the Board of Trade, the rolling load being taken at $\frac{3}{4}$ of a ton per lineal foot of single line. The total weight of the superstructure is only 12 cwt. per lineal foot of the bridge, which is less than one-third the weight of bridges of similar span and width sent out to the colonies for railways of ordinary construction.

The stations on these lines are of an ornamental and somewhat extensive character. The termini at Ipswich and Toowoomba, several of the roadside stations, the engineering workshops, and the engine and carriage sheds, have been sent from England, Messrs. Fisher Brothers having been the contractors for them. They are framed in iron and wood, and covered with zinc, and are fitted with traversers, turntables, cranes, weighbridges, tanks, and pumping engines, of the same description as those used in England.

The passenger rolling stock is of the best English manufacture. The carriages are generally 32 feet long and 6 feet 6 inches wide, divided into compartments. The first-class carriages have accommodation for thirty passengers, at a cost of £17 17s. per passenger; the composite carriages, for thirty-six passengers, at a cost of £12 10s. each; and the second-class, for forty-eight passengers, at a cost of £8 10s. each, there being no third-class. The carriages are mounted upon iron under-frames, and are fitted partly with bogie trucks and eight wheels, and partly with Adams' radial axle-boxes and six wheels. The wagon stock varies in length from 14 feet upon four wheels to 20 feet upon six wheels, the latter being fitted with Adams' radial axle-boxes at each end. The bearing, buffing, and draw springs are of the best steel, a matter of importance, as tending towards the reduction of wear and tear. The tires, though originally of iron, are now being gradually superseded by those of steel, of comparatively light section, and fitted with Adams' springs, which have the advantage of allowing slip in passing curves, and of diminishing materially the blow between the wheel and the rail. Everything has been done, in designing this rolling stock, to keep down the weight of the various parts, so far as is consistent with strength and durability. The whole of the passenger stock, as well as one-half of the wagon stock, is fitted with Clark's continuous break, similar to that recommended by Mr. G. Berkley for the Ghât

inclines on the Great Indian Peninsula Railway. The cost of this rolling stock per passenger, although fitted with every luxury, shows a considerable saving over that of other railways in sister colonies.

Three classes of locomotives are used on these railways. Tender-engines are employed upon the portions of the line where the curves and gradients are easiest. These engines weigh 15 tons in working order, and are upon six wheels, of which four are 'drivers.' The driving-wheels are 3 feet in diameter, in some cases placed behind, with the leading-wheels 2 feet in diameter, fitted with a Bissel bogie, while in others the driving-wheels are placed in front, and the trailing-wheels are fitted with Adams' radial axle-boxes. The following are some of the leading features of these engines:—Diameter of cylinders, 10 inches; length of stroke, 18 inches; heating surface, 400 superficial feet; length, 19 feet 2 inches; extreme width, 7 feet; wheel base of driving-wheels, 5 feet 6 inches. The tenders are 10 feet long, on four wheels, weigh 7 tons, have 70 cubic feet of fuel space, and tank capacity for 520 gallons of water. These engines are similar to those in use both in Norway and in India, and are found to run smoothly and well up to 40 miles per hour, though their working speed does not exceed 20 miles per hour, at which speed they are capable of taking 90 tons of gross load, including engine, upon a line having ruling gradients of 1 in 100. The cost of one of these engines with tender complete, free on board in England, is £1,400. Tender-engines are also used upon that section of the line which includes the Little Liverpool incline, 3 miles in length; but they are of a more powerful class than the former, weighing 20 tons when in working order, and upon eight wheels. The driving-wheels, six in number, are 3 feet 3 inches in diameter, placed as closely together as possible, having a wheel base of 7 feet 2 inches only, and the centre pair of wheels being without flanges. The leading-wheels are 2 feet in diameter, and are fitted with a Bissel's bogie. The diameter of the cylinders is 11 inches, the length of stroke 18 inches, the heating surface 600 superficial feet, length 21 feet, and extreme width 7 feet. The tenders are 12 feet long, on four wheels, weigh 9 tons, and have 100 cubic feet of fuel space, and tank capacity for 600 gallons of water. The motion and axles of these engines are of Bessemer steel. These engines are designed for the same gross load as those of the first-class, but for gradients of 1 in 50, though of comparatively short lengths. The cost of one of these engines with tender, free on board in England, is £1,800. The engines for use on the Main Range incline are upon Mr. Fairlie's system (Plate 5). They consist of two bogie frames, carrying a boiler, with a smoke-box at each end, and a central fire-box, having a fire surface of 71 square feet. The boiler has two hundred and seventy tubes, is 9 feet 10 inches long, with a total heating surface

of 1,000 superficial feet. The frames also form the water-tank, thus keeping the centre of gravity as low as possible. Each engine has two bogies, connected with the boiler by central bogie-pins 3 inches in diameter, and by slotted quadrants having studs working in them at each end of the fire-box. These quadrants form the chief means of transmitting the power of the engine, the bogie-pins being used only as centres upon which the bogies move. Each bogie-truck is carried upon six wheels, each 3 feet in diameter, having a wheel base of 6 feet 6 inches, the centre pair of wheels being without flanges; these six wheels are driven by two cylinders, each 11 inches in diameter, with a length of stroke of 18 inches; making twelve wheels and four cylinders to each engine. The engine is provided with a fire-door on each side, and the driving platform, which is at the side, is arranged to give the driver a good view when running either way. All the gauges, working handles, reversing gear, and breaks are placed in convenient positions. The weight of the engine, including 150 cubic feet of fuel and 800 gallons of water, is about 30 tons, upon twelve wheels; and the engine is calculated to take 120 tons of gross load, at a speed of 15 miles per hour, up an incline 16 miles in length, having ruling gradients of 1 in 50, and frequent curves of 5 chains radius. The bogie-pins, quadrants, motion, valve-rods, and axles, are of Bessemer steel. The cost of each engine complete, free on board in England, is £2,500, or considerably less than if two tank-engines of half the power had been substituted. The Author has tried several experiments, on the Anglesea Central Railway, with an engine similar in construction, which weighs 24 tons, has eight driving-wheels, and takes a load of 160 tons up 1 in 70, for a distance of $1\frac{1}{2}$ mile, at 20 miles per hour. This engine ran with perfect steadiness at upwards of 40 miles an hour, and the smoothness with which it passed round curves of even 170 feet radius was remarkable.

In designing these several classes of locomotives great care has been taken to keep down the weights, and it will be found that in no case does the weight on any wheel exceed 3 tons. The fire-boxes are made for burning fuel composed of two-thirds of wood and one-third of coal; ample heating surface, and fuel and water spaces, being also provided. Break power is applied to nearly all the wheels, and there is an arrangement for sanding the rails under each of the driving-wheels. The drivers are well sheltered from the heat. With a view to facilitate passing round curves of sharp radii, and for obtaining elasticity between the rail and the wheel, in none of the engines does the rigid wheel base exceed 7 feet 2 inches; all the wheels are fitted with the best springs, and with Adams' spring tires, the latter in all cases being cylindrical and not coned.

The permanent way consists of flat-bottomed rails, weighing 40 lbs. to the lineal yard, generally in lengths of 20 feet, laid vertically, fished with Adams' bracket plates, secured at the joints by fang bolts, and elsewhere by dog spikes, to transverse rectangular sleepers, laid 2 feet 6 inches apart from centre to centre. (Figs. 3, 4, and 5.)

Fig. 3.

Queensland Railways. Section at Joint; Fishes 8½ lbs. and 10½ lbs.

Fig. 4.

Queensland Railways. Chair for Ordinary Curves: mode of fastening. Rail 40 lbs. per yard.

Fig. 5.

Queensland Railways. Chair and Guard Rail for Curves of smallest Radius.

The ballast, which is very expensive in Queensland, consists of broken rock. During the manufacture of the rails, a sample was picked out at random from each day's make, and tested upon bearings 3 feet 6 inches apart, with a dead weight of first 15 tons, and secondly 18 tons. The average deflection with the former was $\frac{3}{8}$ ths of an inch, with a permanent set of $\frac{3}{16}$ ths of an inch; with the latter the deflection was $1\frac{1}{4}$ inch, and the permanent set was $\frac{7}{8}$ ths of an inch. The rails were also tested with a weight of 661 lbs. falling through 6 feet twice, to show a permanent set of not more than $1\frac{1}{4}$ inch at the second blow, and with the same weight falling through 9 feet once without breaking the rail. The sleepers are cut out in the forest, and at once adzed, to give accurate bearings for the rails, by a machine sent from England, which, accompanied by a portable engine, can run on the railway to the nearest point, and then, having moveable flanges on its wheels, is drawn by horses to the site where the trees are felled. In this way a great saving in haulage and in labour is effected. The cost of the permanent way, including ballast of broken stone, is £2,162 per mile, as compared with £2,996 per mile, the cost of the permanent way on the railways of a sister colony.

The cost of these railways taken from Mr. FitzGibbon's estimates is as follows :—

	Total, including Surveys, Land, Superintendence, Stations, Sidings, and Rolling Stock. Per mile.	Works only. Per mile.
Ipswich to foot of Main Range, omitting Little Liverpool Range	£ 7,732	£ 6,660
Little Liverpool Range	12,532	11,400
Main Range	11,132	10,000
Toowoomba to Dalby	5,589	4,567
Toowoomba to Warwick	5,990	5,445
Actual average cost	8,600	..

From this it will be seen, that these lines may be constructed, under the most difficult circumstances, for between £11,000 and £12,000 per mile, and under ordinary circumstances for £6,000 per mile, including everything, and this notwithstanding the rates of labour ruling in the colony; being from six to seven shillings per day for an unskilled labourer, and from ten to twelve shillings per day for a skilled workman. It must also be remembered, as remarked by Mr. FitzGibbon, that "the construction of the road and the various appliances employed are in all respects equal to any railway in the world, excepting only that they are limited in power to the wants of the case."¹

The Great Northern Railway of Queensland, which will run from Rockhampton in the north several hundred miles into the interior, and which is being carried out under the superintendence of Mr. Henry J. Plews, the Government Engineer for that part of the colony, does not at present call for any special remark. It resembles, so far as regards the first section now in course of construction, the lighter portions of the Southern and Western Railway, and is supplied with bridges, permanent way, rolling stock, engine and carriage sheds, and workshops and stations of a similar character. Its locomotives are precisely the same as those of the first-class on the Southern and Western Railway. The passenger carriages, however, which were designed by Mr. Plews, are somewhat different; being 45 feet in length, upon six wheels, fitted with Clark's radial axle-boxes, each holding twenty first-class and forty second-class passengers, the seats being placed longitudinally, on either side of the carriage, with a passage down the middle, and open platforms at the end, from which the breaks are applied. The cost of these carriages is about £10 per passenger.

¹ Mr. FitzGibbon states, in a note to the Secretary of the Inst. C.E., dated Ipswich, 20th May, 1867, that the line to Toowoomba had then been opened, and that the 16-ton engine, four wheels coupled, took a net load of 40 tons up the Main Range incline at a speed of 12 miles an hour. The cost of the 78 miles, including everything, averaged £13,700 per mile; while the cost west of the Main Range varied from £6,000 to £7,000 per mile.—Sec. Instr. C.E.

It so happens that, in the three cases referred to in this Paper, the gauge is 3 feet 6 inches. But the Author considers that the gauge is after all a matter which must be entirely dependent upon surrounding circumstances, and which, if kept within certain limits, will not affect the cost in ordinary countries to nearly so great an extent as that which, the Author would repeat, is in his opinion the basis of the light railway system—the reducing of the weight upon every wheel in the train (including the engine wheels) to 3 tons, the limitation of the speed to 25 miles per hour, and the adaptation of every detail to these conditions. In Queensland, the gauge of 3 feet 6 inches was determined on for the following reasons:—first, there were already two gauges in Australia, so that uniformity was out of the question; secondly, a curve of 5 chains radius on this gauge is nearly equal to a curve of 8 chains radius on the 4 feet 8½ inches gauge, and the country, on the Main and Little Liverpool ranges, is of so peculiar a character, with frequent ravines and spurs running out from the Main Range, that it was found, by a careful survey and estimate, if curves of 8 chains radius were adopted, as upon the Blue Mountains, New South Wales, the cost would be increased more than threefold. In the item of viaducts alone, the cost would have been £35,040 per mile, as against £6,100, an amount quite beyond the means of the colony. The gauge was therefore fixed at 3 feet 6 inches, and the minimum radius of the curves was reduced to 5 chains.

In a country, however, where the trunk lines already exist, of either the 4 feet 8½ inches, or some other gauge, and where the country through which the branch line has to pass is not of a peculiarly difficult character, requiring very sharp curves, it would, in the Author's opinion, be generally found advisable to avoid break of gauge, constructing the branch upon the light system, so that it may take all the rolling stock which the parent line may bring to it, with the one exception of the locomotives.

In conclusion, the Author trusts that this Paper may elicit a discussion which shall bring forward, more forcibly than he has been able to do, the importance of a system which he believes will be found before long to have much influence upon railway construction for branch lines, both in this and other countries, especially where the amount of traffic is somewhat limited, and where high speeds are not required.

The communication is illustrated by numerous diagrams, from which Plates 4, 5, and 6, and woodcuts Figs. 1 to 5, have been compiled. The Appendix contains a copy of the Report, dated Brisbane, Queensland, 9th July, 1863, from Mr. FitzGibbon, upon a proposed line of railway from Ipswich to Dalby and Warwick, *via* Toowoomba.

12-WHEELED DOUBLE BOGIE LOCOMOTIVE, FAIRLIE'S SYSTEM, FOR THE QUEENSLAND RAILWAYS.

LIGHT RAILWAYS.
BRIDGE OVER THE RIVER BREMER, QUEENSLAND.

PLATE 6.

HALF ELEVATION.

Scale for Half Elevation
10 20 30 40 50 100 150 200 Feet.

Scale for Cross Section.
9 12 15 18 21 24 27 30 33 Feet.

CROSS SECTION.