ON

THE CONSTRUCTION OF THE

PERMANENT WAY OF RAILWAYS;

WITH

AN ACCOUNT OF THE WROUGHT-IRON PERMANENT WAY LAID DOWN ON THE MAIN LINE OF THE MIDLAND RAILWAY.

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No. 839.—" On the construction of the Permanent Way of Railways; with an account of the Wrought-Iron Permanent Way, laid down on the Main Line of the Midland Railway."* By William Henry Barlow, M. Inst. C.E.

The subject of the " Permanent Way " of Railways has latterly occupied much public attention, in consequence of its important influence on the value of railway property, and great efforts are being made to improve the construction, in order to reduce the expenses of maintenance and renewal. It has, however, been difficult hitherto to obtain data from which the actual cost of permanent way, as at present constructed, can be determined, or estimated. In the earlier stages of railway management, contracts were entered into at prices which subsequent experience has shown to have been much too high; whilst the introduction of express trains and heavy engines, rendered necessary certain alterations in the strength and construction of the road, the cost of which should form no part of the current expense of its maintenance.

Thus the payments made by Railway Companies, on account of the permanent way, have not hitherto afforded a fair criterion, from which the real cost of maintenance can be determined, while in endeavouring to compare the expenses of one line with another, differences are found to exist in the management and mode of keeping the accounts, which prevent any accurate conclusions being deduced.

The Midland Railway, however, offers at the present time, a good field for inquiry into the nature and origin of this expenditure. The expensive contracts entered into in past times have gradually expired; the greater part of the line is now maintained by the Company, and those portions which are still under contract, are let

* The discussion on this Paper was extended over a portion of two meetings, but an abstract of the whole is given consecutively.

at prices which only yield a fair and reasonable profit to the contractors. This railway occupies an extensive district of country, consisting of various geological formations, and the several divisions of the line present a great variety of circumstances, both in the nature and extent of the works upon them, and the amount of traffic.

It is unnecessary to enter into the question of the separation of 'renewal' from 'maintenance,' more than to remark that the item of maintenance of way was undoubtedly intended, in the first instance, to include every expense attendant on the upholding of the line and works, including the renewal of decayed, or worn out, permanent way materials. It is now the general custom, and this practice has been adopted on the Midland Railway, to include in the item of 'maintenance' all labour and materials, except the rails, chairs, and sleepers; the 'renewal' comprise the rails, chairs, and sleepers, delivered on the line.

It appears to be considered by the public, that the maintenance of way is dependent on certain characteristics of the line, and may be calculated at so much per mile, without reference to the traffic, or the construction of the road. It has, however, been demonstrated, that the expense of maintenance of way is occasioned, first, from the effects of the weather; and secondly, from the disturbance produced in the road, by the transit of the trains. The former of these, which includes the keeping up of the fences, drains, slips, bridges, and works, may be readily estimated, at so much per mile, but the latter, which includes the packing of the sleepers, making good the fastenings, repairs of points, crossings, &c., is dependent directly on the nature and amount of the traffic, and incidentally upon the length of time which the line has been opened for traffic. After a line has been executed a sufficient length of time for the subsidence of the embankments to have ceased, and the works to have become consolidated, the effect of the disturbance produced on the road, by the passing of the trains, forms by far the most important item in the expenditure.

It has been stated, that the expensive contracts on the Midland line have gradually expired: the result of this and other changes, has been a gradual reduction in the average cost of maintenance of way from £240 per mile, which was the amount in 1846, to £131. 2*s*. per mile, which has been the average cost, during the last half year of 1849. The latter sum represents, as nearly as it can be ascertained, the actual cost of the work performed; but if the cost of the repairs to the Derby workshops and the yard, the weighing machines, the stations, the office expenses, and the salaries, which amount to £17. 12*s*. per mile, be deducted, the average cost is reduced to £113. 10*s*. per mile; this, however, varies on the different portions of the line, as is shown in the following statement.

Name of District.	Average Length Maintained during the Half Year.						Cost of Maintenance per Mile per Annum.	Number of Trains per Mile per Week.
	Double Line.			Single Line.				
	M.	C.	F.	M.	C.	F.	£.	
North Midland	73	4	5	1	2	0	158·9	303
Sheffield and Rotherham . .	6	0	0	1	0	0	147·9	306
Midland Counties . . .	58	4	0		..		146·8	267
Syston and Peterbro' . . .	38	2	3½		..		92·9	109
Leicester and Swannington .	16	4	1¾	9	4	6¾	57·2	83
Erewash Valley	13	3	1	9	0	9	52·7	65
Nottingham and Mansfield .	4	6	0		..		50·3	65
Nottingham and Lincoln .	35	5	4½		..		63·0	92
Derby and Birmingham . .	48	4	0		..		117·1	176
Bristol and Birmingham . .	81	4	0	4	2	7	115·2	152
Leeds and Bradford . . .	36	0	1½		..		130·9	198

From this statement, it is evident, that the cost of 'maintenance' is materially affected by the traffic. By an analysis of the different items in each case, it appears, that the expenses arising from the effects of the weather, and other causes, independent of traffic, vary from £20 per mile to £30 per mile, the average for the whole line being £28 per mile; whilst those due to traffic, vary from 2 pence to 2·7 pence per train per mile, the average in this case being 2⅛ pence per train per mile, of which about 2 pence per train per mile, or more than £30,000, arises from the derangement occasioned by the passing of trains. It is not possible to trace to what extent this 2 pence per train per mile, is affected by different constructions of road. It appears, however, that the broad gauge road, on longitudinal timbers, costs about as much in labour as a narrow gauge road on transverse sleepers; that on the Midland Counties Railway, where the rails, which weigh 78 lbs. per yard, are laid on stone blocks 2 feet 2 inches square, and the ballast is good, one man per mile, and in some cases, one man for two miles, is required more than on the sleeper road; and on that part of the North Midland Railway, with rails weighing 65 lbs. per yard, laid on smaller blocks, many of which are of a soft quality of stone, the cost of the labour is much greater, and with bad ballast it is excessive.

If the progress of derangement of the ordinary road be watched, it will be found to commence at the joint chair, which with its sleeper becomes inclined in the direction of the traffic, producing an irregularity, or unevenness in the level of the rails. This causes a blow to be given by every wheel, which loosens the joint key and disturbs the sleeper in the ballast. This disturbance is at length communicated to the intermediate sleepers, inducing constant labour in readjustment, which is rendered greater, by the number of small parts of which the road is composed.

The expenses attendant on the renewal of the permanent way cannot be ascertained, with so much certainty, as those of the maintenance, because the question of duration is involved in it, and this is still, to a great extent, a matter of opinion.

After an elaborate inquiry into the duration of 'permanent way materials' the officers of the London and North Western Railway state, that on their line, the rails should last twenty years, and the timber sleepers (if creosoted) also twenty years, if not creosoted only twelve years.

Now the wear of the rails is a direct effect of the traffic, and if the duration of rails is twenty years, on the London and North Western line, where the average traffic exceeds three hundred trains per week, the duration of the rails on the Midland line, which has only about one half that traffic, ought to be nearly forty years. There is no doubt, that the wear of the rails is much greater where inferior iron is used, and that it is accelerated by uneven joints and a badly-maintained road, but all these circumstances being similar, it is clearly a cost dependent on the traffic, and is an expense per train per mile.

Assuming the estimate of twenty years to be correct, with a traffic of three hundred trains per mile per week, the weight of the rails to be 258 tons per mile, and the cost of re-rolling, or reproduction to be £2 per ton, then the cost of renewing rails will be ·396ths of a penny, per train per mile; but if a renewal fund be established from the commencement, that is, if a limited portion of the revenue be allowed to accumulate, at 4 per cent. interest, until the period of renewal arrives, the cost would be about ⅔rds of ·396ths of a penny, or a little more than one farthing per train per mile.

On the other hand, the decay of the wooden sleepers proceeds irrespective of traffic, and thus bears with greater severity on those lines and branch lines which have but small traffic.

Referring again to the published report of the London and North Western Railway, it appears, that on the main line the annual cost of renewing one mile of rails is only £516, whilst the cost of renewing one mile of sleepers, is estimated at £1,027; so that with the traffic on that line the cost of renewing sleepers (if creosoted) is estimated at double that of renewing rails; it follows, therefore, that as the traffic of the Midland line is only one-half that of the main line of the London and North Western, the cost of renewing the sleepers will be four times that of the cost of renewing the rails, and on branch lines, with a small traffic, it will be in a much higher ratio. This view is confirmed by the report of Mr. Cabrey, published by the Committee of Inquiry on the York and North Midland Railway, in which the renewal of the rails and chairs, for the next nine years, is estimated at £51,569, and that of the sleepers for the same time at £178,816, or in the ratio of one to three and a half nearly.

It is also a question, on which there is not any positive experience, whether creosoted sleepers will last twenty years; but even supposing these expectations to be realized, the expense of renewing the sleepers will be equal to their first cost, whereas the cost of renewing the rails has been estimated by the officers of the London and North Western Railway at £2 per ton, or £325 for every £1,000 originally expended; this estimate has been confirmed by contracts subsequently entered into, both by that Company, and by the Midland Company.

In endeavouring to seek a remedy for the imperfections of the permanent way, as at present constructed, and observing that other engineers in their more recent works, were using a bridge rail of very large dimensions, it appeared that by an additional weight of from 20 lbs. to 30 lbs. per yard, a sufficient width of base might be obtained, to enable the rail to form its own bearing surface on the ballast, without the use either of sleepers, or of other supports, and that this arrangement would combine the advantages of great strength and simplicity of construction, be very durable, and be capable of being renewed at a moderate cost, by which means the chief source of expense, in the maintenance and renewal of the ordinary permanent way, would be avoided.

It is on this principle that the wrought iron permanent way, Plate 19, which it is the object of this paper to describe, has been constructed.

Fig. 1 represents a section of the rail, which is 13 inches wide, and 5¾ inches deep, and weighs 126 lbs. per yard. Figs. 2 and 3 are modifications of the same kind of rail.

Figs. 4, 5, and 6 show the plan, elevation, and section of the permanent way complete.

The joint is made by a cast-iron chair, or saddle (Figs. 7 and 8) for receiving the ends of the rails, into which they are keyed with six wooden keys. The gauge is preserved by a tie bar, 2½ inches deep by ¾ inch thick, fitted and keyed into sockets cast on the chairs (as shown in Fig. 6), the depth of the bar, so employed, being sufficient to preserve the proper bevil of the rails.

At first some difficulty was encountered, in getting the rails manufactured; but the invention was taken up in a very spirited manner by Messrs. Bolckow and Vaughan, of Middlesbro' on Tees, and the talent and practical experience of Mr. Vaughan enabled him to overcome all difficulty in their manufacture.

The price at which these rails are now made is £6. 10*s*. per ton, delivered at Middlesbro'; this is somewhat more than the cost of the ordinary rails, which arises chiefly from the necessity of employing a superior quality of iron.

The rail, as now manufactured, has hard metal placed in the upper portion, and a tough metal in the lower part, by which its strength is increased, and its durability rendered equal, in all probability, to the ordinary rail with two surfaces. By experiments made with the hydraulic press (*see* Appendix, page 16) this rail, with bearings 4 feet 4 inches apart, bore 27 tons, applied in the centre, before the elasticity was injured, being nearly three times the strength of the ordinary double-headed rail weighing 80 lbs. per yard.

In order to test the resistance to spreading, an experiment was made, by fixing two pieces of cast-iron, each 9 inches wide, one above and the other below the rail, and then applying the force of the hydraulic press; the rail then bore a weight of 40 tons, with no other injury to it, than an indentation, amounting to about 4-10ths of an inch, in that part of the lower flange, where the cast-iron beam pressed upon it, the upper surface remaining perfect; the spreading with this weight was very slight. There can therefore exist no doubt, that the strength is considerably more than is required, and in future a modified section, with a reduced weight, will be employed.

The form of section adopted in this case, was selected in order to facilitate, as much as possible, the process of rolling; but the experience since acquired in the manufacture is such, that any variation of form which may be thought advisable, can now be introduced.

It is not necessary here to discuss, in detail, the question of the best form for maximum strength, because both its longitudinal strength, and its resistance to spreading, must in that case be considered. It may, however, be stated generally, that the rail appears to be too thick at the points, *a*, *a*, Fig. 1, and the sections shown in Figs. 2 and 3 would probably be found preferable.

The experiments would seem to prove, that the strength of this rail is greater in proportion to its weight, than the ordinary double-headed rail; this may be accounted for, first, from the different qualities of metal in the upper and lower portions of the rail, and, secondly, from the wide flange causing the centre of extension to be lower down, and at a greater distance from the centre of compression, than in the common rail.

The simplicity of construction of this road, the firmness of the joint, and the few parts of which it is composed, must necessarily reduce the labour of maintenance, and diminish to a great extent, that portion of the expenditure arising from the disturbance produced by the passing of trains, the consequent beating up of the sleepers, and the tightening and making good the various fastenings; and the expense of renewal will be reduced to that arising simply from the abrasion of the rail, as there are no sleepers to decay.

In point of safety, it possesses important advantages from its great strength; the employment also, almost exclusively, of wrought iron will prevent the extensive breakage of chairs which occasionally happens, when waggons are thrown off the line by any jerking of the engine.

An experiment was made with a pile engine, having a ram of 12 cwt., for testing the strength of the joint (*see* Appendix, page 17); from this experiment it appeared that the strength of the joint was greater than that of many rails weighing 80 lbs. per yard of the ordinary construction, with a bearing of 3 feet 6 inches.

The length of road, constructed on this principle, is laid down on the main line of the North Midland Railway; it therefore has to carry the express trains, and the heaviest traffic of the line. It is perfectly quiescent under the greatest loads, and the highest speeds; no motion is perceptible, either at the joints, or in the other parts of the rail, which may be attributed to the simplicity of the construction, and to the great stiffness of the rail, which virtually increases its bearing surface; for if a weight be placed over the centre sleeper of a length, and the rail be flexible, the whole of that weight will be borne by the sleeper, whereas if the rail be rigid, the weight will be equally distributed over all the adjoining sleepers. It is therefore evident, that though the area of surface may be equal in both cases, the bearing surface positively brought into action, will depend on the stiffness of the rail, and this reasoning equally applies, whether longitudinal, or transverse sleepers be employed.

The weight of the rail employed in the length laid down, is 126 lbs. per yard, and the actual cost of the road, per mile of double line is—

			£.	s.	d.		£.	s.	d.
Rails	395 tons,	at	7	0	0	(contract price)	2,760	0	0
Castings	108 ,,	.	4	4	0	. . . .	453	0	0
Tie-bars	10 ,,	.	7	0	0	. . . .	70	0	0
Keys	. . .					. . . .	40	0	0
							£3,323	0	0

The road, as now laid down, is however of unnecessary weight and strength, and though it is impossible, at present, to say to what extent it may be reduced, it is more than probable, that a rail 12 inches wide and 5 inches deep (Figs. 2 and 3), weighing 100 lbs. per yard, will be found sufficient for all purposes; the chief consideration being, whether such a rail would be heavy enough to remain steady and quiescent on the ballast, during the passing of heavy trains at high velocities.

Messrs. Bolckow and Vaughan now undertake to make these rails in lengths of 18 feet for £6. 10*s*. per ton, so that the cost of one mile of double line would be—

			£.	s.	d.		£.	s.	d.
Rails	314 tons	at	6	10	0	. . . .	2,041	0	0
Chairs	80 ,,	.	4	4	0	. . . .	336	0	0
Tie-bars	10 ,,	.	7	0	0	. . . .	70	0	0
Keys	. . .					. . . .	40	0	0
							£2,487	0	0

which is considerably less than the cost of the ordinary sleeper road.

By the order of the "Committee of Way and Works" of the Midland Railway, a mile of road has been laid down, at the same part of the line as the wrought-iron rail and sleeper, with the cast-iron sleepers, introduced by Mr. P. W. Barlow, for adaptation to the ordinary rail; as it was at first supposed, that the difficulties in the manufacture of the wrought-iron rail, above described, would prevent its being used. In another part of the line a mile of road has been laid with cast-iron sleepers at the joints only, wooden sleepers and chairs being used for the intermediate supports: this construction is found to be cheaper, than when wooden sleepers are used throughout.

The motion of the trains is particularly firm and steady both upon the common rails laid with cast-iron sleepers, and upon those where cast-iron sleepers are employed at the joints, with intermediate sleepers of wood; in fact there is no noticeable difference between the two, and both are superior to the ordinary road, from the absence of any jerk at the joint. Upon the wrought-iron rail there is the same firm steady motion, but with a greater sensation of hardness, which appears to result from the rails having been down a shorter time, and not having been yet worn to the same degree of evenness on the upper surface.

In conclusion it may be stated, that tenders have been made by contractors of the highest respectability, for the maintenance and renewal of the wrought-iron road, at prices very much below those now paid, and similar tenders have been made for the maintenance and renewal of the road laid with cast-iron sleepers. In both systems the object is the same, to exclude entirely the use of timber in the construction of the permanent way, and it is believed, that if this can be satisfactorily accomplished, great economy will be produced, both in its maintenance and renewal, and thus one great source of expenditure of Railway Companies will be much reduced.

The paper is illustrated by a series of diagrams from which Plate 19 has been compiled.

APPENDIX.

Table of Experiments on the Strength and Deflection of Railway Bars, made at the Station Yard, Derby, in February 1850.

The ram used in the following experiments weighed 12 cwt.
The deflections were taken with a straight-edge, 7 feet 4 inches long.

Description of Rail.	Number of Blow.	Fall of Ram.	Distance between Bearings.	Deflection of Rail.	Difference.	Remarks.
		Ft. In.	Ft. In.	Inches.	Inches.	
Experiment No. 1.						
Old Midland Counties	1	3 0	4 0	·06	·19	Broke at 5th blow; fracture perfectly crystalline.
Rail, double table,	2	3 6	4 0	·25	·31	
5¼ inches deep, 78 lbs.	3	4 0	4 0	·56	·44	
per yard.	4	4 6	4 0	1·00		
	5	5 0	4 0	..		
Experiment No. 2.						
Ditto	1	5 0	4 0	·75	·63	Broke at 4th blow; fracture perfectly crystalline.
	2	5 0	4 0	1·38	·50	
	3	5 0	4 0	1·88		
	4	5 0	4 0	..		

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 3.								
Old Midland Counties	1	3	0	4	0	·20	·25	Broke at 3rd blow; frac-
Rail, double table,	2	3	0	4	0	·45		ture perfectly crystal-
$5\frac{1}{2}$ inches deep, 78lbs.	3	3	0	4	0	..		line.
per yard.								
Experiment No. 4.								
Ditto, turned over .	1	3	0	4	0	·16	·18	Broke at 3rd blow; frac-
	2	3	0	4	0	·34		ture perfectly crystal-
	3	3	0	4	0	..		line.
Experiment No. 5.								
Derby and Birming-	1	1	6	3	0	·25	·50	Broke at 3rd blow.
ham Rail, single	2	2	0	3	0	·75		
table, 5 inches deep,	3	2	6	3	0	..		
56 lbs. per yard.								
Experiment No. 6.								
Ditto	1	2	6	3	0	·75	·81	Broke at 6th blow; frac-
	2	2	6	3	0	1·56	·38	ture fibrous.
	3	2	6	3	0	1·94	·68	
	4	2	6	3	0	2·62	·76	
	5	2	6	3	0	3·38		
	6	2	6	3	0	..		
Experiment No. 7.								
Ditto	1	3	0	3	0	1·00	1·25	This experiment was dis-
	2	3	0	3	0	2·25		continued, in conse-
								quence of a crack
								having appeared.
Experiment No. 8.								
Ditto	1	3	0	3	0	1·38	1·50	Broke at 4th blow; frac-
	2	3	6	3	0	2·88	1·74	ture fibrous.
	3	4	0	3	0	4·62		
	4	4	6	3	0	..		
Experiment No. 9.								
Ditto	1	6	0	3	0	1·05		Broke at 2nd blow; exhi-
	2	6	6	3	0	..		bited a slight crack at
								the first blow.
Experiment No. 10.								
Ditto	1	4	6	3	0	·80	·62	This experiment was dis-
	2	5	0	3	0	1·42		continued, in conse-
								quence of a number of
								cracks having appeared.
Experiment No. 11.								
Ditto	1	8	0	3	0	..		Broke at the 1st blow.
Experiment No. 12.								
Ditto	1	1	0	3	0	·06	·19	Broke at 7th blow; frac-
	2	1	6	3	0	·25	·22	ture perfectly fibrous.
	3	2	0	3	0	·47	·28	This rail was taken
	4	2	6	3	0	·75	·25	up from the perma-
	5	3	0	3	0	1·00	·58	nent way, two miles
	6	3	6	3	0	1·58		west of Derby.
	7	4	0	3	0	..		

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 26.								
A 68 lb. Rail, double table, $4\frac{3}{4}$ inches deep	1 to 5	1	0	3	4	·00	·02	Not broken. This rail was a little worn.
	5 to 10	1	0	3	4	·02	·03	
	10 to 20	1	6	3	4	·05	·03	
	20 to 30	2	0	3	4	·08	·07	
	30 to 40	2	6	3	4	·15	·09	
	40 to 43	3	0	3	4	·24	·04	
	44	3	0	3	4	·28	·02	
	45	3	0	3	4	·30	·02	
	46	3	0	3	4	·32	·02	
	47	3	0	3	4	·34	·02	
	48	3	0	3	4	·36	·02	
	49	3	0	3	4	·38	·02	
	50	3	0	3	4	·40		
Experiment No. 27.	1 to 5	1	0	3	4	·00	·05	Not broken. This rail was a little worn. At the 52nd blow a small crack was perceptible in the middle of the rail, but it did not appear to increase. At the 56th blow the bed-plate of one of the chains broke.
Ditto	5 to 10	1	0	3	4	·05	·10	
	10 to 20	1	6	3	4	·15	·07	
	20 to 25	2	0	3	4	·22	·06	
	25 to 30	2	0	3	4	·28	·18	
	30 to 35	2	6	3	4	·46	·16	
	35 to 40	2	6	3	4	·62	·28	
	40 to 46	3	0	3	4	·90	·12	
	46 to 50	3	0	3	4	1·02	·18	
	51	4	0	3	4	1·20	·30	
	52	5	0	3	4	1·50	·35	
	53	6	0	3	4	1·85	·35	
	54	7	0	3	4	2·20	·55	
	55	8	0	3	4	2·75	1·15	
	56	9	0	3	4	3·90	1·10	
	57	10	0	3	4	5·00		

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference Inches.	Remarks.
Experiment No. 19.								
An 80 lb. Rail, double	1	3	0	4	0	·25		Broke at 2nd blow.
table, 5¼ inches deep	2	3	0	4	0	· ·		
Experiment No. 20.								
Ditto	1	3	0	3	0	·02	·10	Broke at 6th blow; fracture exhibited coarse crystals.
	2	3	0	3	0	·12	·04	
	3	3	0	3	0	·16	·09	
	4	3	0	3	0	·25	·07	
	5	3	0	3	0	·32		
	6	3	0	3	0	· ·		
Experiment No. 21.								
Ditto	1 to 40	1	0	3	6	·00	·01	Not broken.
	40 to 60	1	6	3	6	·01	·09	
	60 to 70	2	0	3	6	·10		
Experiment No. 22.								
An 83 lb. Rail, double table, 5¼ inches deep	1	3	0	4	0	· ·		Broke at 1st blow; fracture perfectly crystalline.
Experiment No. 23.								
Ditto	1	3	0	3	0	· ·		Broke at 1st blow.
Experiment No. 24.								
Ditto	1	2	0	3	0	·00		Broke at 8th blow; fracture exhibited coarse crystals.
	2	2	0	3	0	·00		
	3	2	0	3	0	·00	·05	
	4	2	6	3	0	·05	·02	
	5	2	6	3	0	·07	·01	
	6	2	6	3	0	·08	·02	
	7	2	6	3	0	·10		
	8	2	6	3	0	· ·		
Experiment No. 25.								
Ditto	1 to 40	1	0	3	0	·00	0·3	Not broken.
	40 to 45	1	6	3	0	·03	·02	
	45 to 50	1	6	3	0	·05	·03	
	50 to 60	1	6	3	0	·08	·03	
	60 to 70	1	6	3	0	·11	·03	
	70 to 80	1	6	3	0	·14	·04	
	80 to 90	2	0	3	0	·18	·03	
	90 to 100	2	0	3	0	·21	·09	
	100to105	2	6	3	0	·30	·06	
	105to110	2	6	3	0	·36	·16	
	110to115	3	0	3	0	·52	·10	
	115to120	3	0	3	0	·62	·08	
	121	4	0	3	0	·70	·10	
	122	5	0	3	0	·80	·20	
	123	6	0	3	0	1·00	·20	
	124	7	0	3	0	1·20	·20	
	125	8	0	3	0	1·40	·30	
	126	9	0	3	0	1·70	·30	
	127	10	0	3	0	2·00	·30	
	128	13	0	3	0	2·30		

Table of Experiments on the Strength and Deflection of Railway Bars—*continued.*

Description of Rail.	Number of Blow.	Fall of Ram. Ft.	Fall of Ram. In.	Distance between Bearings. Ft.	Distance between Bearings. In.	Deflection of Rail. Inches.	Difference. Inches.	Remarks.
Experiment No. 26.								
A 68 lb. Rail, double table, 4½ inches deep	1 to 5	1	0	3	4	·00	·02	Not broken. This rail was a little worn.
	5 to 10	1	0	3	4	·02	·03	
	10 to 20	1	6	3	4	·05	·03	
	20 to 30	2	0	3	4	·08	·07	
	30 to 40	2	6	3	4	·15	·09	
	40 to 43	3	0	3	4	·24	·04	
	44	3	0	3	4	·28	·02	
	45	3	0	3	4	·30	·02	
	46	3	0	3	4	·32	·02	
	47	3	0	3	4	·34	·02	
	48	3	0	3	4	·36	·02	
	49	3	0	3	4	·38	·02	
	50	3	0	3	4	·40		
Experiment No. 27.								
Ditto	1 to 5	1	0	3	4	·00	·05	Not broken. This rail was a little worn. At the 52nd blow a small crack was perceptible in the middle of the rail, but it did not appear to increase. At the 56th blow the bed-plate of one of the chains broke.
	5 to 10	1	0	3	4	·05	·10	
	10 to 20	1	6	3	4	·15	·07	
	20 to 25	2	0	3	4	·22	·06	
	25 to 30	2	0	3	4	·28	·18	
	30 to 35	2	6	3	4	·46	·16	
	35 to 40	2	6	3	4	·62	·28	
	40 to 46	3	0	3	4	·90	·12	
	46 to 50	3	0	3	4	1·02	·18	
	51	4	0	3	4	1·20	·30	
	52	5	0	3	4	1·50	·35	
	53	6	0	3	4	1·85	·35	
	54	7	0	3	4	2·20	·55	
	55	8	0	3	4	2·75	1·15	
	56	9	0	3	4	3·90	1·10	
	57	10	0	3	4	5·00		

Table of Experiments on the Strength of Mr. W. H. Barlow's Rail.

The weight was applied midway between the points of support, by means of an hydraulic press, in which the diameter of the plunger was 1½ inches, the diameter of the ram 7½ inches, and the lever as 20 to 1, or 2 lbs. equal to 1 ton.

Experiment No. 1.

Distance between the supports 4 feet 4 inches.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·00	0·02	14	0·14	0·01	0	0·09	0·03
2	0·02	0·01	15	0·15	0·01	5	0·12	0·04
3	0·03	0·00	16	0·17	0·02	10	0·16	0·04
4	0·03	0·01	17	0·17	0·00	15	0·20	0·04
5	0·04	0·00	18	0·19	0·02	20	0·24	0·01
6	0·04	0·03	19	0·20	0·01	21	0·25	0·01
7	0·07	0·01	20	0·21	0·01	22	0·26	0·01
8	0·08	0·01	21	0·22	0·01	23	0·27	0·01
9	0·09	0·01	22	0·22	0·00	24	0·28	0·01
10	0·10	0·02	23	0·24	0·02	25*	0·29	0·01
11	0·12	0·01	24	0·24	0·00	26	0·30	0·02
12	0·13	0·00	25	0·26	0·02	27†	0·32	0·02
13	0·13	0·01				28	0·34	0·05
						29	0·39	
						30‡		

* Width across the bottom diminished 0·05 of an inch..
† Elasticity injured.
‡ Casting broke with 30 tons pressure.

Experiment No. 2.

Distance between the supports 4 feet.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·06	0·02	12	0·20	0·01	23†	0·33	0·02
2	0·08	0·02	13	0·21	0·01	24	0·34	0·01
3	0·10	0 02	14	0·21	0·00	25	0·36	0·02
4	0·12	0·02	15	0·22	0·01	26	0·37	0·01
5	0·14	· ·	16	0·23	0·01	27	0·40	0·03
1	0·12	0·00	17	0·24	0·01	28‡	0·41	0·01
3	0·12	0·02	18	0·25	0·01	29§	0·45	0·04
5	0·14	0·01	19	0·26	0·01	30	0·48	0·03
6	0·15	0·01	20*	0·27	0·01	31	0·53	0·05
7	0·16	0·00	0	0·09	· ·	32	0·59	0·06
8	0·16	0·01	1	0·12	0·03	33‖	0·63	0·04
9	0·17	0·01	20	0·28	0·16	34	0·73	0·10
10	0·18	0·01	21	0·30	0·02	1	0·50	
11	0·19	0·01	22	0·31	0·01	0	0·45	
					0·02			

* Width across the bottom diminished 0·02 of an inch.
† Ditto ditto 0·03 of an inch.
‡ Ditto ditto 0·05 of an inch.
§ Elasticity destroyed.
‖ Width across the bottom diminished 0·07 of an inch.

Experiment No. 3.

Distance between the supports 8 feet.

Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.	Weight applied.	Deflection.	Difference.
Tons.	Inches.	Inches.	Tons.	Inches.	Inches.	Tons.	Inches.	Inches.
1	0·00	0·06	3	0·12	0·02	10	0·42	0·06
2	0·06	0·04	4	0·14	0·02	11	0·48	0·06
3	0·10	0·04	5	0·18	0·04	12	0·54	0·06
4	0·14	0·04	6	0·22	0·04	13	0·59	0·05
5	0·18	..	7	0·26	0·04	14*	0·72	0·13
1	0·08	0·02	8	0·30	0·04	15†	0·88	0·16
2	0·10	0·02	9	0·36	0·06	1‡	0·44	..
					0·06			..

* Elasticity injured.
† Width across the bottom diminished 0·02 of an inch.
‡ Permanent set.

Experiments on the Strength of Mr. W. H. Barlow's Joint Casting.

In these experiments the rails were laid as described in the paper; and at the joints a piece of iron 2 inches wide and 1 inch deep was laid, and was subjected to blows from a ram weighing 12 cwt. Five blows, each with a fall of 1 foot, were, in the first instance, given, in all cases, to consolidate the ballast.

In the first experiment the fall of the ram was 4 feet, when the third blow broke the sleeper, which exhibited a fracture on each side, close to, but on one side only of the rib of the joint. On removing the broken sleeper, it was found that the sleeper had not been well beaten up.

In the second experiment the fall of the ram was also 4 feet. At the eleventh blow a slight deflection was observable. At the twelfth blow the sleeper was broken at a distance of 4 inches from the joint chair, the fracture curving away from the joint. The thirteenth blow produced a fracture on the opposite side, close to the joint chair, and extending across the sleeper.

In the third experiment the fall of the ram was 1 foot for the first ten blows, 1 foot 6 inches from ten to twenty blows, 2 feet from twenty to thirty blows, 2 feet 6 inches from thirty to forty blows, 3 feet from forty to fifty blows, and 4 feet afterwards, when the fifty-second blow broke the joint chair.

Experiments on the Strength of Mr. P. W. Barlow's Cast-Iron Sleepers.

In making the following experiments two rails were fixed on the iron sleepers in the ordinary manner, and the ram, which weighed 12 cwt., was made to take effect upon the joint. In all the experiments the fracture occurred just where the tie-rod was introduced, which part would appear to require a little additional metal; but in the first and second experiments the parts of the sleepers did not separate on being taken up; in fact the fractures did not extend completely through them.

In the first experiment the fall of the ram was 3 feet. At the third blow a slight crack was observed, which was a little increased by the fourth blow, and at the tenth blow the experiment was discontinued, in consequence of the crack having further increased.

In the second experiment the fall of the ram was 2 feet 6 inches. At the second blow a slight crack was observed, and at the fourth blow the experiment was discontinued, though the sleeper was not completely broken.

In the third experiment the fall of the ram was 1 foot for the first ten blows, 1 foot 6 inches from ten to twenty-two blows, and 2 feet from twenty-two to thirty blows. At the nineteenth blow a slight crack was observed, which was gradually increased from the twenty-fifth blow, until the thirtieth blow broke the sleeper.

Mr. W. H. Barlow observed, that at present very different opinions were entertained, as to whether a line was in good, or bad order. He had therefore contrived a self-recording apparatus for registering the inequalities of the road. It consisted of a barrel, around which was coiled a sheet of paper, attached to one of the wheels of a carriage, and revolving with it; the axle-box carried a pencil, and, by means of levers, registered on the paper every motion of the axle-box in the horn plates, to the scale of 1 *inch* to every 80 feet of rail, so that every bad joint was registered. He thought the machine produced a fair representation of the road, and the diagrams drawn by it, at a velocity of from 18 miles to 20 miles an hour, indicated with sufficient accuracy, the spots to which attention should be directed. Of course the character of the figure traced by the pencil varied most at high velocities.

Mr. Peter W. Barlow said, his experience had been chiefly confined to the application of cast iron to railways; he should therefore only allude to the omission in the paper, of the advantage experienced in the laying of new lines, from the position of the sleepers in the ballast. Wooden sleepers required a much greater quantity of ballast, on account of their lying deeper in it; in this item alone he had been enabled to effect a saving of £300 a-mile by the use of the iron road. The facility for drainage which affected very materially the cost of maintenance was also much increased by the use of the iron road; the drainage did not require to be carried to so great a depth, and was therefore more likely to be effectual, and to be less disturbed by the passing of the trains. He had constructed five miles of road on that principle, some of which had been down above a year, and he had observed a decided advantage in its construction.

Mr. W. H. Barlow stated, in answer to questions from the President, that at present he had not attempted to apply his rail to points and crossings, or in stations; he however saw no practical difficulty in doing so, but as yet he had not had an opportunity of exemplifying the facility of such an application.

Mr. HAWKSHAW said, the subject treated of in the paper, if viewed comprehensively, was extremely difficult and complicated, as it embraced so many considerations. It must be remembered, that the cost of the maintenance of way diminished as the line became consolidated, provided always that adequate attention was given to the repairs; therefore, when it was stated, that the maintenance of railways now cost a less sum than formerly, it should also be stated, that when railways were new, the earthwork was not consolidated, and the rails were not settled; so that a contractor who undertook to maintain a railway when first opened, required a larger sum per mile than was necessary, when a line had been in existence for ten, or twelve years.

He was rather disposed to approve of the particular shape of rail suggested by Mr. Barlow; but if timber sleepers were as durable as the iron rails, and if together they would last as long, and remain in as good travelling condition as the iron road, nothing would be gained by the change, except that when the iron road was taken up, the old iron would realize a greater amount than the old timber. He had, at present, longitudinal sleepers in use, which were carrying a second set of rails; this showed that the wood had worn out the iron. Supposing then, that the wooden sleeper lasted as long as the iron rail, it became a question, whether it would not be more expedient, and more economical, to use a light rail of the best material, in combination with perfectly creosoted longitudinal timbers, than to adopt the large mass of iron necessitated by the system proposed by Mr. Barlow.

After trying almost every system of laying the permanent way, with every variety of longitudinal and transverse sleepers, both of timber, and cast-iron, Mr. Hawkshaw had arrived at the conviction, that well-creosoted longitudinal timber sleepers, with heavy malleable iron rails, formed the best and most durable line; it was the cheapest in first cost, and in the subsequent maintenance, and was least injurious to the rolling stock, the wear and tear of which formed so important an item in railway accounts.

Some years ago, the late Mr. Reynolds proposed a continuous trough-shaped bearing of cast iron, on which was placed a malleable iron rail:* that plan had been tried on several lines, but it was found

* *Vide* Trans. Inst. C. E., vol. ii., page 73.

to be too rigid, and under the passage of heavy trains, at great speeds, it was found to shake out of its position, and could not be easily adjusted.

The chief practical difficulty connected with Mr. Barlow's proposed system, would be in getting the joints to remain permanent; and it was a question, whether that end would not be more likely to be attained, by the introduction of pieces of malleable iron on each side of the joint, than by the cast-iron chair.

Mr. Brunel said, it was well known, that he had generally adopted the system of laying rails on longitudinal timbers, and he had arrived at the same conclusions as Mr. Hawkshaw. He believed, that longitudinal timbers thoroughly creosoted, and properly put together, were at least as durable as the iron rails, and he might even say that, under certain circumstances, the timber would last the longest. It might be said, that a rail which was destroyed in five years, by abrasion, was either originally composed of bad materials, or had been subject to unfair usage, consequently, that to institute any comparison, as to the relative durability of the iron rails and the timber sleepers, from such an example, would be incorrect. He, however, believed, that, with fair usage, the timber would be more durable than the iron; so that he did not agree in the desirability of abandoning timber, and adopting iron for sleepers. He disagreed entirely with Mr. Barlow in his financial calculation, both as to the first cost of the permanent way, and the saving to be anticipated, from such an improvement as that treated of in the paper. He did not think there was such room for saving in the cost of the maintenance of way, as could ever materially affect the value of railway property; the great bulk of the cost of maintenance in railways did not, unfortunately, depend on circumstances capable of being materially affected by any improvements in the construction of rails.

The result of his own experience, in the use of longitudinal timbers, led him, however, to hope that some advantages might be derived from such a modification, as that suggested in the paper. At the present relative prices of iron and timber, it was certainly possible to use the former material, and if rails of this width of base could be cheaply rolled, it would probably be less costly to adopt that form, than to lay the ordinary rails on longitudinal timbers; the subject however required careful experiments, and practical experience, before it was possible to decide on making so great a change. He strongly objected to the use of cast-iron joint chairs, on account of their liability to fracture, particularly in case of the carriages, or the engines getting off the line, and he advised experiments being made on a length of line, with the joints riveted together with wrought-iron side-plates, as had been successfully practised by Mr. Hawkshaw, and by himself as an experiment; the travelling surface was excellent, and no annoyance had been found to arise, from the effects of contraction and expansion under changes of temperature. He intended to try Mr. Barlow's form of rail, in such a situation as would enable him to compare it with the ordinary kind, and he entertained hopes that the plan suggested might prove valuable.

Mr. Peter W. Barlow said, he found that rails laid on longitudinal bearings had worn out quicker than the timber, and he was satisfied this arose from the defective mode of construction, in placing the rails on wood, and thus giving them a partially flexible foundation which allowed them to yield under the weight of the engine. He had tried a more rigid foundation, or bearing, for the rails on a portion of the Greenwich Railway, where longitudinal timbers were also in use, and he was satisfied that the destruction of the rails arose from their being laid on timber.

He could not perceive any difference in the use of cast and wrought iron, provided the former was sufficiently strong to resist any shock that could be brought to bear on it. As cast iron answered well for common chairs, there could be no reason why it should not be used for chairs which were extended so as to take their bearing on the ballast, instead of on the sleepers.

Mr. Brunel replied, that any rails which Mr. P. W. Barlow had under his direction must have worn out in less than the ordinary term of the duration of rails, for they could not have been laid down ten years; their rapid destruction must therefore have arisen from other causes, than the alleged yielding of the bearing. He must expressly state his conviction, that at the expiration of forty years, well-creosoted longitudinal timbers, would be found in a sound and serviceable condition.

Mr. C. H. Gregory said, the paper alluded to the difficulty of securing the rails at the joints, and as this was a most important consideration in all kinds of permanent way, he would direct attention to a method of remedying the difficulty, which had been proposed by Mr. Samuel and Mr. Adams (of Bow). It consisted in "fishing" the joints of the rails with two pieces of cast, or wrought iron, secured by bolts, or rivets, to the body of the rail; chairs of the ordinary construction were placed at short distances from the ends of the rails, and the surface was preserved perfectly continuous and level.

Mr. Glynn observed, that the plan just alluded to by Mr. Gregory had been tried on the Eastern Counties Railway, and up to the present time had been successful, but it had not been laid down a sufficient length of time to enable a decided opinion, as to its merits, to be given.

Every person of experience in railways was aware, that the destruction of the rails commenced at the joint, and many plans had been proposed for preventing the deflection at that point. Mr. J. Fowler had tried rails 30 feet long, in order to diminish the number of joints, and had proposed a very ingenious chair for securing the rail, still however retaining the wooden sleepers. It would be desirable that some plan should be devised, by which both the timber sleepers and the cast-iron chairs might be got rid of, and at the same time the joints of the rails could be secured, and he thought the Institution was much indebted to Mr. Barlow, for directing attention to the subject.

Mr. Locke, M.P., thought, that the contrariety of opinions on this important subject might be accounted for, by the difference in the quality, and form, of the various rails, from which the experience had been obtained. He had been much struck with the statement of Mr. P. W. Barlow, that on the Greenwich Railway the rails had worn out very quickly on longitudinal timber bearings; he had himself observed the same rapid destruction on transverse sleepers. He believed, that if the quality of the rails manufactured at the present time, was compared with that of the rails manufactured ten or twelve years since, the latter would be found to be much superior, so that it would be wrong to assume that the defects referred to, resulted entirely from the different modes of laying the line. The Grand Junction Railway was opened in 1837, and up to within the last two years none of the rails on that line had been displaced. Latterly a length of two, or three miles of rails had been relaid; and it was a positive fact, that some of those new rails, although they weighed 80 lbs. per yard, were now in a worse condition than some of the original rails, which only weighed 65 lbs. per yard. He therefore felt justified in stating, that the rapid destruction of the rails was more to be attributed to defects in the quality, or the mode of manufacture of the iron, than to the system of laying the permanent way.

He agreed, that, in many instances, the duration of the timber had varied almost as much as that of the rails. Since the opening of the South Western Railway, nearly twelve years ago, although the rails had not been taken up, a great many of the sleepers had been replaced. He was anxious to caution the profession, against drawing conclusions, not borne out by facts, when all the circumstances of the case became known.

Although stone blocks were now almost universally discarded, he could not join in their condemnation, as he had found them, in many instances, perfectly sound, after very hard service. During the last six months a length of line on the Grand Junction Railway, at Stafford, had been taken up, in order to lay down a line with a bridge rail, on longitudinal timbers, and out of 2,500 blocks which were removed, 2,360 were so little the worse for wear, as to be actually re-sold to the contractor, to lay down on other parts of the line. All these facts coupled together, tended to show how necessary it was to be careful in drawing conclusions as to the formation of the permanent way.

The cost of maintaining the permanent way, of a newly-constructed line, could bear no analogy to, and ought never to be brought into comparison with, the cost of maintenance after the line had been open for a number of years, when every work had become perfectly consolidated. No one was more anxious than himself to try useful experiments, but it behoved the profession, before adopting a change which involved a certain cost, to be careful not to incur it, without, as far as possible, securing that the cost of the innovation should not be greater than any benefit that could ultimately arise from it. He agreed with Mr. Brunel as to some of the advantages of using longitudinal timber bearings, and though the deflection of the timber might have some influence on the rail, the fastenings were fewer in number, and less liable to work loose, than in a road of the ordinary construction; this was especially the case at the joint, where the number of detached pieces seriously affected both its safety and firmness. The mode of riveting the rails to a wrought-iron chair was much preferable.

One of the advantages of the ordinary double-headed rail, was its capability of being reversed in the chair; whereas if the surface of the single-headed rail became abraded, it must necessarily be replaced by another length; even the badly-manufactured rails, which he had referred to on the Grand Junction line, might be turned, whilst their strength would be very slightly impaired; that was an advantage which would still induce him to adhere to the use of the double-headed rail, in spite of the inherent defects in the fastening.

The Institution was much indebted to Mr. Barlow, and to the various speakers on this subject, which was one of great interest to all parties, for in the present state of railway property, anything that could be done to save expense, would be a boon conferred on the public.

Mr. W. H. BARLOW explained, that he took as the basis for his calculation the Report of the officers of the London and North Western Railway, in which it was stated, that, with the traffic on their line, they considered the duration of the rails, and also of the creosoted sleepers, would be about twenty years. Now he had shown, and no one has disputed the point, that the duration of the rails depended on the traffic, but not so the sleepers; therefore on a line with half the traffic the duration of the sleepers would be the same, though the duration of the rails would be doubled.

With regard to the use of stone blocks, which had been referred to, the number required to be replaced on the North Midland Railway, where they had unfortunately used soft stone, far exceeded that which had been stated to have been required on the Grand Junction line. The great expense on the North Midland Railway had been in the renewal of sleepers, and had it not been for the rails being originally too light, they would not have had cause to replace them. The permanent way, he advocated, could be laid down at the same cost as a common line, and the best proof of the economy in its maintenance and renewal of the form, was the fact of a tender being made by contractors of the highest respectability, offering to maintain and renew, for a period of fifteen, or twenty years, any part of the Midland line, at a rate of £70 per mile per annum, less than the sum now paid by that Company.

Mr. ERRINGTON apprehended, that the chief objection to the form of Mr. Barlow's rail, was the cost of removing and renewing so heavy a mass of iron, in case of its surface laminating and its edge being destroyed, which would occur long before the lower part of the rail was in the least degree injured. It would be very advantageous to ascertain the actual duration of rails and sleepers, under various circumstances; the officers of the London and North-Western Railway assigned twenty years as the limit; now he had recently examined a railway which had been constructed twelve years ago, under the direction of Mr. Jee, and he had found a very small proportion of the rails injured; they were double-headed