April 4, 1871.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

THE following Candidates were balloted for and duly elected:—ROBERT LUNN, JOSEPH WILLIAM TRUTCH, and HENRY WOOD, as Members; HENRY BRADY, EDWARD BUCKHAM, ARCHIBALD DAVIS DAWNAY, SYDNEY GEDGE, M.A., GEORGE WILLIAM GOODISON, JOHN JACKSON, CHRISTIAN HENDRIKS MEYER, EDWIN MUIR, HOWARD DEVENISH PEAR-SALL, Stud. Inst. C.E., THOMAS MELLARD READE, CAMPBELL THOMSON, JOHN THOMSON, ROBERT VAWSER, JAMES HENRY WHITTLE, and WILLIAM YUILL, as Associates.

It was announced that the Council, acting under the provisions of Section III. Cl. VII. of the Bye-Laws, had transferred BENJAMIN CHAPMAN BROWNE, GEORGE EEDS EACHUS, and ALGERNON JOY, from the class of Associate to that of Member.

Also that under the provisions of Sect. IV. of the Bye-Laws, ALFRED HENRY HOLLIS had been admitted a Student of the Institution.

No. 1,281.—“On the Testing of Rails; with a description of a machine for the purpose.” By JAMES PRICE, M. Inst. C.E.

THE best mode of determining beforehand the fitness of rails for their work is a question of the greatest interest, especially to those engineers who have been in practice long enough to see the end of both good rails and bad rails. The disadvantages of the latter may be stated under three heads:—The danger arising from sudden breakages, and from worn rails before they can be replaced. The danger in replacement, for where so much depends on human skill and care, failure must sometimes take place; besides, the mere laying down of the new rails, and the removal of the old, are attended with risk and inconvenience to the traffic. Lastly, the economic question, involving great expense in labour and materials, including not only rails, but sleepers and fastenings, which, if left alone, might have lasted many years longer. Such remarks would be hardly necessary, except that engineers in constructing railways often disregard these considera-

tions, and, to effect a trifling saving in first cost, admit elements of future weakness.

In addition to the ordinary and unavoidable causes whereby rails are worn out, there are other causes of wear which are avoidable. Of these, two are often overlooked, but they are, nevertheless, of consequence.

First, where on the same system there are different sections of rail, it frequently happens that the forms of the rail-tops vary very much in width and roundness; the consequence is that the tires of those engines which are worked mostly on one branch become worn to suit that particular rail-top; and when it is necessary to run such engines over the other parts of the railway, the tires do not fit the rails, but roll along edges, not surfaces (Plate 13, Fig. 1). In this manner the rails are gradually broken down, and much injured. Care should therefore be taken that, on all extensions and branch lines, the rail-tops at least should conform to those on the parent line. On the whole, a moderately flat-topped rail is to be preferred to one much rounded.

Secondly, where a railway abounds in curves, there is considerable increase of wear if the super-elevation of the outer rail is not properly attended to; it is often too great, and the inner rail suffers accordingly. The difficulty in instructing platelayers and inspectors on this point arises from the fact, that the super-elevation is given in terms of the radius, which is not generally known, and which must be ascertained by the use of another formula. The Author has prepared a simple rule, which is theoretically true, and requires no calculation. The term 'radius' is eliminated, and a chord is found, the versed sine of which is equal to the proper super-elevation. The length of this chord is the same for curves of any radii, and depends solely on the assumed speed and the gauge, which are practically invariable. For a speed of 40 miles per hour, this chord will be 64 feet in length for the English gauge, and 67 feet for the Irish gauge (5 feet 3 inches); so that a chain length (66 feet) is sufficiently near for both.

The rule is as follows:—Stretch a line between two points one chain apart on the hollow side of a single series of rails; the distance from the middle point of this line to the edge of the rail is the correct super-elevation (Fig. 2). For any gauge and any velocity the formula becomes

Length of chord = $\frac{1}{2}$ velocity in feet per second $\sqrt{\text{gauge}}$.

The proof of which is as follows:

Let y = gauge.

g = force of gravity = 32.

v = velocity in feet per second.

r = radius of curve.

l = length of chord required.

d = versed sine.

And x = super-elevation.

Problem: find l , so that $x = d$. That equilibrium may exist, the centrifugal force must equal the resistance of the inclined plane, or

$$\frac{v^2}{g r} = \frac{x}{y}, \text{ therefore } x = \frac{y v^2}{g r},$$

but
$$r = \frac{l^2}{8 d}, \text{ therefore } x = \frac{8 y v^2}{g l^2} \times d;$$

in order that (x) may equal (d) ,

put
$$\frac{8 y v^2}{g l^2} = 1;$$

inserting the value of (g) ,

$$l^2 = \frac{8 y v^2}{32}, \text{ therefore } l = \frac{1}{2} v \sqrt{y}.$$

The Author has used a simple level for ascertaining the heights of the rails; it consists of a thin iron gauge, with a hole near each end, and a piece of string about 7 feet long; the ends of the string are looped through the holes, and a knot adjusted in the middle, so that the bar will hang level over still water if suspended from the knot held freely between the finger and the thumb (Fig. 3).

The qualities sought in a rail are fourfold:—First, strength, as a girder, to sustain a moving load; secondly, toughness, to resist sudden strain or impact; thirdly, solidity, to resist separation under pressure; fourthly, hardness, to resist wear of the surface. The first and second affect the safety of a road, and are therefore more important than the third and fourth, which are economic properties regulating the cost of renewals and the amount of available profits.

1st. Strength.—This quality depends both on the form of the rail, and on the nature of the iron. The double-headed, and the flange, or Vignoles rails, are all that can be desired as to form for strength, though the latter has somewhat the advantage, the iron in the bottom flange being disposed at a greater distance from the neutral axis, besides being a better form to resist side strains and torsion.

Rails of the bridge type are bad girders; iron is wasted in the double vertical web at the expense of the bottom flange; such rails possess hardly two-thirds the strength of rails equal in weight, but of girder forms. In the Author's experience of bridge-rails, whether on longitudinal or on cross sleepers, about 30 per cent. break through the flange holes long before the tops are worn out. Being at the same time stiff and weak, they are unsuited to the elasticity of longitudinal sleepers, and are unfit for a cross-sleeper road.

The consideration of the strain which a rail has to bear as a girder naturally suggests an inquiry into the proper interval between the sleepers. This is a question of importance, and capable of easy solution. Experience will show the amount of base area of sleepers required to sustain a given weight of traffic over a known substratum; but experience will not necessarily indicate the best arrangement of this bearing surface,—that is, the correct spacing of the sleepers. When the driving-wheel of an engine is placed exactly over a sleeper, the surface of the rail is depressed, owing to the compression of the timber and the yielding of the ballast. Let this depression = a . When the wheel stands over the centre of an interval, the weight being borne equally by two sleepers, the depression over each becomes less. Let its amount = b . Then, in order that the line of motion may be straight, and not undulating, the deflection of the rail must = $a - b$ (Fig. 4): if it is greater, there will be hollows between the sleepers; if less, hollows over the sleepers.

To carry this idea into practice, the Author fixed indices in different positions on the sides of rails within view of a level, and, placing the driving-wheel of an engine on the above-mentioned parts, found that with the sleepers 3 feet apart, from centre to centre, a flange rail, weighing 80 lbs. to the yard (Fig. 5), did not deflect enough, so that the centre rose 0.03 inch; but that with a bridge-rail of the same weight (Fig. 6) the deflection was too great, as the rail sunk in the centre 0.1 inch. Though the amount of deviation from a straight line is minute, still from its rapidity the effect is sensible. Assuming a speed of 40 miles an hour, there would be thirty-eight vibrations per second, which must have an injurious effect both on rails and wheels. The spacing of the sleepers should therefore be increased or diminished as may be necessary; the rule being to vary the spacing when rails of different degrees of stiffness are used, so that the cubes of the clear intervals may be proportional to the stiffness.

The Author has adopted an interval of 3 feet 6 inches, from

centre to centre, in preference to one of 3 feet for a high flange rail (Fig. 7); and by employing larger sleepers, so as to have the required bearing, more massive and better grown timber is obtained without any increase of cost.

The interval between the sleepers being fixed upon, the testing span can be arrived at in this manner. A rail to be thoroughly safe should not break, or take a permanent set under the weight of an engine, even if every alternate sleeper were left out of the road; for in practice any one sleeper may be so badly packed, or decayed, as to offer no resistance to a deflection of $\frac{3}{8}$ ths of an inch, which is about the extent to which a good rail will bend under an engine when spanning an interval of 6 feet. The reason for not taking a case of two bad sleepers together is, that the rail under such circumstances would deflect so much that it must find some support before it could break. It would be disastrous if a single case of bad packing should lead to the breakage of a rail; therefore, it may be assumed that all rails should be tested for strength at such a clear interval as would be obtained in practice, by leaving out every alternate sleeper. The Author has adopted for this purpose a span of 6 feet between the supports.

2nd. Toughness.—This quality is as necessary as strength. It is possible for a rail to bear a great dead weight, and yet to break easily under a suddenly applied strain. The latter being the condition of strain to which rails are subjected, toughness becomes essential. It is best measured by the extent to which the iron composing the rail will stretch before fracture is produced by direct tension. The Author obtained from 8 to 9 per cent. of elongation in tearing asunder strips cut from the base of flange-rails, which strips broke under a direct tensile strain of 21 tons per square inch of original section. One of the many advantages possessed by flange-rails is the opportunity this form affords of having a tough fibrous iron in the bottom, and material of a hard compact quality in the head. As a matter of practice, none but ductile tough iron can be rolled into a wide flange; consequently, it is found that flange rails never break in the road.

3rd. Solidity.—Of the economic qualities this is the most important; by which is meant freedom from particles of foreign matter, and perfect welding. The rapid lamination, breaking down, and destruction of rails, is mainly due to the absence of this property.

4th. Hardness, though desirable, is not so essential as the other qualities. A rail that is of solid texture will rarely be so soft as to lose its form from bulging; the top will even harden under the

cold rolling to which it is subjected. At shunting stations, however, and on inclines, under the influence of sand and breaks, the surface of a soft rail is rapidly worn away.

Existing modes of testing rails may be divided into dead-weight tests, falling-weight tests, and examination of fracture.

The dead-weight tests determine the strength of a rail as a girder; but in practice, rails are subjected to strains of a different character, namely, that produced by rolling weights; the results are, therefore, not reliable.

The endeavour to ascertain whether a rail has sufficient toughness, by submitting it to the action of a falling weight, is most fallacious. This test goes as far beyond the mark as that by dead weight falls short of it; because it requires an amount of toughness which is quite unnecessary, and incompatible with a proper degree of hardness. By its use rails of a very serviceable quality may be rejected, while bad rails escape. The unfairness of this mode can be shown by considering the effect of a weight falling, say 4 feet, which is considered a low fall, with the action of a rolling weight advancing at the rate of 40 miles per hour. The falling weight strikes and bends the rail with a velocity of 16 feet per second, whereas the rolling weight, the interval being 6 feet and the deflection $\frac{3}{8}$ ths of an inch, bends the rail with a velocity of $7\frac{1}{4}$ inches per second, or $\frac{1}{8}$ th part of the former velocity.

The determination of the solidity of a rail is hardly attempted. Appearance of fracture, or a planed section treated with acid, may to a practised eye be a criterion, but it is not sufficiently tangible to embody in a specification.

The deflection of a rail under a given load is generally assumed to be inversely as its hardness, and is therefore considered a measure of the absence of this quality. However this may be, it is not applicable to flange-rails, which, if properly made, with hard tops and tough flanges, will deflect considerably; and in a double-headed rail it is difficult to conceive how hardness, as shown by a small deflection, can co-exist with extreme toughness to resist the impact of a falling weight; such iron may be procured, but not among those qualities used for rails.

From the foregoing and other reasons, the Author, having arrived at the conclusion that existing tests bear no analogy to actual work, designed a machine for the purpose of subjecting rails to the test of rolling weights, whereby both their strength and their wearing properties could be determined with accuracy.

The machine consists of a simple arrangement of two or more

metal or steel rollers, supporting a circular frame which confines them. The frame is connected by radii with a centre boss, through which passes a vertical axle (Fig. 8); or the frame may be cruciform for four rollers (Fig. 9), or a simple beam passing across the centre for two rollers (Fig. 10): in every case sufficient strength being given to the radii, or arms, to resist the centrifugal force generated when revolving. The rails to be tested are formed into a circle or polygon, and are supported on sleepers, packed up with ballast in the usual manner. This arrangement forms the road under the rollers, upon which they are caused to travel at any required speed, by means of motion communicated to the centre axle from shafting underneath, or by direct action of a pair of cylinders. The frame is sufficiently stiff to bear entirely on the rollers; and the boss should be free to move up and down on the vertical axle, so that the machine may conform itself freely to the inequalities of the road.

The weight with which each roller bears upon the rails should be equal to the weight of the driving-wheel of the heaviest engine likely to be worked over the same rails when in actual use. The rollers should have treads sufficiently wide to work over the rails arranged as a polygon (Fig. 11), and being portions of cones radiating to the centre at the level of the top of the rails (Fig. 12), they will traverse over a polygon as easily as along a curve.

In using the machine to test the strength of rails, some of the sleepers are left out at several parts of the circle, so that the rails at those places may span double intervals. If a rail takes a set or breaks under the action of the revolving rollers it is unfit for use, for the reasons before mentioned. To carry the experiment farther, so as to arrive at the proper margin of strength, the lower member is weakened, by cutting or drilling, until it breaks. By treating rails of known good quality in a similar way, a standard of strength can be obtained.

The determination of the wearing properties of rails is manifestly accomplished by keeping the machine revolving until the rails are worn out.

Before commencing the series of experiments detailed hereafter, the Author assumed the substantial truth of that law according to which rails are worn out by the action of a certain number of 'speed-tons,' which was first demonstrated by Mr. Price Williams, M. Inst. C.E., from a collection of facts obtained on the principal railways.¹ This law, however, did not separate the action of the lighter

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 353.

traffic of wagons and carriages from the wear produced by engines; so that it could not be determined *a priori* how many 'speed-tons' rails would bear if subjected to the action of this machine, which is analogous to the continuous passage of trains of engines. It was, however, hoped, and partly expected, that the results would be much more rapid under the machine, so that the test might be easily carried out. This has proved to be the case, which demonstrates, what might have been anticipated, that the number of 'speed-tons,' borne by any rail during its life under ordinary traffic, must be reduced by some function of the intensity of the weights at their applied points. It is almost self-evident that weights applied in small parcels, say of a few pounds, would never cause rails to laminate or crush; whereas, so great a weight might be applied at a single point that the rail would be utterly destroyed at once.

The absence of springs will no doubt add to the severity of the test; but if this is made an objection, there is no difficulty in using springs by lightening the rollers, and throwing the greater part of the weight into the frame. Such, however, might not be desirable, as the prolongation of the test is unnecessary, a ratio of comparison with a standard rail of known good quality being all that is sought for. It will be admitted if ten rails are placed under the machine together, one being a standard, that those that wear out before the standard are inferior to it; that those which wear out first are the worst; and that the number of 'speed-tons' borne by each is the measure of its value.

Objections on the score of the texture of the iron having been injured by bending have, in the Author's experience, been found of no moment, provided the rails are bent at a dull red heat. But, as before remarked, the rails can be used straight, arranged as a polygon, which plan possesses the collateral advantage that the rollers wear more evenly over their entire surface.

The wearing effect produced by a machine having four rollers bearing with a pressure of 7 tons each, upon a ring of rails 40 feet in diameter, and worked at a speed of 40 miles per hour, may be stated thus: 42 revolutions per mile $\times$ 40 miles per hour $\times$ 22 hours $\times$ 28 tons = 1,034,880 tons per day of 22 hours, allowing 2 hours out of every 24 hours for oiling, packing, &c.; this would give 41,395,200 speed-tons per day. Two such days' work would discover any defective rails, if not destroy the best.

The machine constructed by the Author, from which the results hereafter detailed have been obtained, consists of a horizontal beam supported on a pair of metal rollers, 5 feet in mean diameter and

16 inches wide. The circle traversed is 40 feet in diameter. The rollers weigh $2\frac{1}{4}$ tons each, and with the beam weighing $6\frac{1}{2}$ tons, the pair of rollers press on the rails with a total weight of 11 tons. One roller bears with 5 tons' pressure, and the other with 6 tons. Motion is imparted to the centre vertical axle by means of shafting underneath, and bevelled wheel and pinion, driven by a steam-engine. The power is sufficient to get up a speed of 20 miles per hour. As the engine works a sawmill during the daytime, it has been necessary to use the machine mostly by night. A counter is employed to register the revolutions. The experiments first tried by the Author had reference to the strength of rails, when it was ascertained that if the rails were curved while hot no diminution of strength took place. In the next place, a flange rail, of the section shown in Fig. 13, weighing 76 lbs. to the yard, after having been in use on a railway for seven years without showing any flaw, during which time traffic amounting to about 3,500,000 tons passed over it, when placed in the circle and left unsupported for a clear interval of 6 feet did not break or take a set. The flange was then drilled in the centre of the span with two $\frac{3}{4}$ -inch holes; in this instance it did not break or take a set under the rollers travelling at the rate of 16 miles per hour. Again the flanges were cut away from the holes to the outer edges (Fig. 14); when traversed by the rollers it took a set but did not break, though no doubt it would have done so under long-continued rolling. Finally, the flange was weakened by cutting it away, as shown shaded on Fig. 15, when it at last broke. This rail possessed a wide margin of strength, and having a hard compact top, as subsequently proved under the wearing process, must be reckoned as one of first-class quality. Other rails of like section were broken, and the results obtained were not very different.

The next experiments had reference to the wearing properties of rails. Eight samples of foot rails were tested, and six of these have been worn out. The rails were manufactured at different times by five different firms. The results are given in the Appendix.

The third set of experiments referred to the strength and toughness of Bessemer steel rails. As their wearing properties were undeniable, attention was only directed to their bearing qualities. No doubt some few out of almost any large number of Bessemer steel rails will be found too brittle for use; and any one of these breaking in the road and causing an accident would bring discredit on the whole. It is therefore desirable that a very large number, if not every rail, should be placed under the machine for a few

revolutions, with a clear interval of 6 feet between the bearings. This can be effected in a simple manner, as shown in Fig. 16. Each rail across the gap is subjected to fifty revolutions, and then withdrawn endways and another pushed into its place, without stopping the machine; at a single opening 4 or 5 tons of rails per hour can be thus tested. In this manner the Author tested four hundred and twenty-seven rails of Bessemer steel, of the section shown in Fig. 7, out of which only four broke; any one of these, however, would have broken under ordinary traffic.

The Author has not, as yet, made a sufficient number of experiments on the breaking of steel rails to arrive at the true characteristics of that material. However, the following experiment seems to show, that steel and iron are very differently acted on by rolling weights. A steel rail of the section shown in Fig. 17, weighing 80 lbs. to the yard, having been put under the rollers, broke when weakened in the flange to the extent shown shaded; whereas the iron rail before mentioned, and weighing only 76 lbs. per yard, required a greater amount of weakening. Strips having been cut from the flanges of both of these rails and subjected to direct tensile strain, the steel bore 30 tons per square inch before fracture, and stretched 20 per cent. of its length, and was then so tough as to bend double cold; but the iron bore only 21 tons per square inch, and stretched only 9 per cent. This indicates that steel, though stronger and apparently tougher under slowly applied strain, is really more brittle than iron under sudden strain, as if the molecules of steel required time to arrange themselves to resist separation.

The effect on the surface of the metal rollers from long-continued work over a circular ring is very considerable after the outer skin has worn off. The Author is preparing to have the rollers turned down and fitted with steel tires, which was always contemplated. When worked over polygons, to bring the wear evenly over the whole surface, each set of tires will last a long time.

It may be remarked, in conclusion, that this machine will also test the strength of all fastenings, sleepers, and ballast. Almost all the ordinary type of fish-plates break. Those with a small flange below, as shown in Fig. 18, alone stand under the machine. The rails also show a weakness at the fish-holes, which should be abolished, if practicable.

The effect produced on rails by breaks, sand, or water, can also be ascertained.

As to the probability of rails heating under a more destructive machine than the Author's, it may be remarked that all the heat

generated will be as rapidly conducted and radiated away by the large mass of iron in the rails and rollers, so that an accumulation will be impossible. In planing down a rail more rapid destruction takes place, more heat is therefore generated, but the rail does not heat.

Such machines established in proximity to the centres of iron and steel manufactures would be beneficial in satisfying Engineers and railway companies as to the quality of the materials they were procuring, without the present slow and unpleasant process of paying for their experience.

The communication is accompanied by a series of diagrams, from which Plate 13 has been compiled.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

without load
Load between Sleepers
Load over Sleeper
LINES OF VERTICAL MOTION.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Scale: 6' to $\frac{1}{4}$ "

a. Rollers
b. Beams
c. Castings to receive Journals
d. Tie-rods
e. Bevel driving wheel
f. Driving arms.

Fig. 9.

Scale: 6' to $\frac{1}{4}$ "

a. Rollers
b. Beams
c. Castings to receive Journals
d. Bevel driving wheel
e. Driving spuds.

Fig. 10.

Scale: 6' to $\frac{1}{4}$ "

Fig. 11.

Scale: 6' to $\frac{1}{4}$ "

Fig. 16.

Fig. 12.

Fig. 13.

Fig. 14.

Fig. 15.

Fig. 17.

Fig. 18.

APPENDIX.

TABLE of the RESULTS of EXPERIMENTS with FOOT RAILS.

Mark.	Weight per Yard.	Number of Tons passed over.	Speed per Hour.	Speed-Tons.	Remarks.
	lbs.		miles.		
A	76	3,355,482	14	46,976,748	{ This rail was in the rail- way under ordinary traffic for 7 years pre- viously, and must have borne $3\frac{1}{2}$ million tons at 20 miles per hour; it is not yet worn out, but broken at the fish-holes.
B	76	3,964,511	13	51,538,643	{ Two new rails, not yet worn out.
C	76	1,861,277	14	26,057,878	This rail worn out.
D	76	1,861,277	14	26,057,878	{ This rail was bent cold; worn out.
E	80	3,510,540	13	45,637,020	{ This rail worn out in one part.
F	68	1,098,361	14	15,377,054	This rail worn out.
G	68	834,548	14	11,683,672	This rail worn out.
H	60	416,240	10	4,162,400	{ Worn out. Two rails, one straight and other curved.

[Mr. J. PRICE