The President. place on the Princetown railway, where the problem to be solved was, whether a truck blown away by the wind would go down an incline, mount another, and get over a summit. The result was that a 12-ton wagon, loaded with 10 tons of granite, moved beautifully across at 84 miles per hour and round a 15-chain curve. He thoroughly agreed with the remark one speaker had made about the important influence that sinuosity of motion had. He confessed that it was a matter to which sufficient attention had not been paid in the balancing of the machine. He had had many opportunities of watching trains running at high speed on straight and other lines, and had noticed that the swaying, and the period of the swaying, varied very much indeed. That was one of the things that he hoped would be gradually overcome, when running at high speed, by the use of four-cylinder engines; whether they should be compound or simple was another matter.

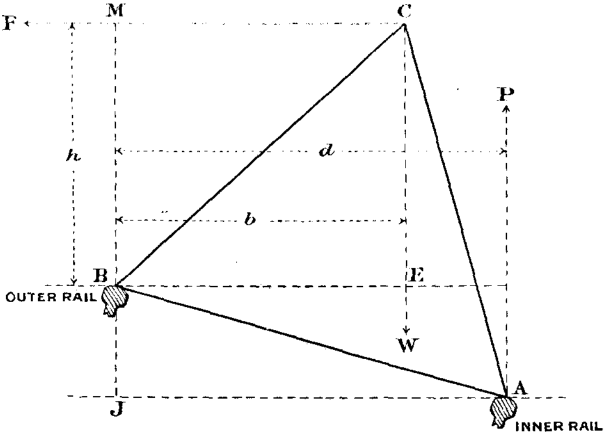
Mr. Shortt. Mr. Shortt stated that in the case of the curve entered from the straight and the reverse curve illustrated in his Paper the actual cant used was 4½ inches. As the improved alignment was, and should be always, settled entirely without reference to cant, except in so far as it was liable to cause fouling of the construction gauge, cant had not been shown on the diagrams.

Correspondence.

Mr. Rollo Appleyard. Mr. Rollo Appleyard remarked that although the equations at which Mr. Spiller arrived were, in some respects, out of agreement with results observed in practice, his method of examining the general conditions that determined derailment at curves was helpful as a basis for further research as to the direction and magnitude of the complex forces concerned in these disasters. Details of serious derailments were recorded by the Board of Trade and by railway-companies, but before they could be rendered available for such generalizations as those at which Mr. Spiller sought to arrive, they required to be co-ordinated and brought into conformity with modern conditions as to speeds and roads. Until this was done there must be great difficulty in evaluating the constants and the variables of any equation that was to predetermine critical speeds. Nevertheless, Mr. Spiller had succeeded in indicating the nature of the problem, and he had given a fair approximation to one of its partial solutions. It might be useful to suggest how a further step

Mr. Rollo Appleyard. towards accuracy might be taken. In his equation (26) Mr. Spiller expressed V, the critical speed of climbing, as a function of w/W, where w was "the weight of wheel and load," and W was "the total weight of the engine"; and in order to interpret V numerically, he estimated the minimum value of w as being $W/15$. Next, by assuming that the minimum value of w/W, corresponding with this minimum value of w, might be regarded as constant, Mr. Spiller obtained equation (27), and he applied this equation as a general criterion of the limiting speed for climbing, for comparison with the limiting speed for overturning. He then went so far as to conclude that in the case of the Salisbury accident—which otherwise was clearly at variance with his result—derailment by climbing was prevented by the inside check-rail. This conclusion appeared to be unproven. In the Board-of-Trade official account of the Salisbury accident it was stated that neither the outer rail nor the check-rail showed marks such as would be made by the flanges of engine-wheels crossing them; and it explained that on the check-rail especially, which was covered with the usual dirt and grease, such marks would have been easily visible. This was proof that there had been no climbing, but it was not proof that the check-rail had prevented derailment by climbing, or that it had modified the accident in any way whatever. It might have done so, or it might not. Without either accepting or rejecting Mr. Spiller's conjecture, however, the case was sufficiently important to be examined in further detail. For a proper understanding of the matter, it was necessary to realize that although

Fig. 10.



Mr. Rollo Appleyard.

the critical speeds of climbing and of overturning might differ considerably, and although the equations used in the attempt to predetermine them might be deduced by almost independent lines of reasoning, yet before the conditions for derailment could be calculated accurately, the two sets of phenomena must be regarded as acting together, with consequent mutual effect upon critical speed-values. The inapplicability of equation (27) depended upon the fallacy that, in deriving that equation from equation (26), w was taken as constant. It was obvious that w varied with the speed of a given vehicle at a given curve, and the way in which it varied could easily be examined to a first degree of approximation. From *Fig. 4* (p. 84), disregarding secondary forces, *Fig. 10* could be drawn, in which the mass of the vehicle was supposed to be concentrated at the centre of gravity c. In this diagram let

F denote the overturning force, in tons;
h, = M B, denote the height of the centre of gravity above the outer rail, in inches;
b denote B E, in inches;
d ,, the horizontal distance from J to inner rail, in inches;
P ,, the total vertical pressure distributed over all the inner-rail wheels, in tons;
r ,, the radius of the curve, in feet;
V ,, the velocity of the vehicle, in miles per hour.

As regarded overturning, taking moments about B, the condition of equilibrium for the vehicle was then

$$\mathrm{P}\,d + \mathrm{F}\,h = \mathrm{W}\,b,$$

where

$$\mathrm{F} = \frac{\mathrm{W}}{r\,g}\left(\frac{\mathrm{V}}{0\cdot6818}\right)^2.$$

Hence

$$\mathrm{P} = \frac{\mathrm{W}}{d}\left(b - \frac{h\,\mathrm{V}^2}{14\cdot965\,r}\right) \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{i})$$

Incidentally, it was seen by inspection of equation (i) that when P = 0, that was, when V reached its critical value for overturning, V was independent of W, and this critical value was

$$\mathrm{V} = 0\cdot6818\sqrt{\frac{b\,r\,g}{h}} \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{ii})$$

which compared with Mr. Spiller's equation (9), neglecting all secondary forces of which he took account. In the limit, therefore, it was the ratio b/h, and not W, that determined overturning. Equation (i)

Mr. Rollo Appleyard.

enabled one to trace, approximately, the changes of pressure upon the inner and outer rails respectively as V increased, for any given vehicle on any given curve; and thus the corresponding values of w, now regarded as a variable, could be estimated to replace w (constant) in equation (26). For this purpose, in order to be in agreement with Mr. Spiller's conditions as nearly as possible, his assumption that $w = \frac{W}{15}$ might be adopted could be regarded as being true when the vehicle was at rest. If the weight W, in the static condition, was assumed to exert about equal pressures on the two rails, and if $(W-P)$ was the actual pressure on the outer rail, then it was a reasonable assumption that, approximately, for all speeds, including $V = 0$,

$$w = \frac{W - P}{7 \cdot 5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

where P, and therefore w, was variable. By using this value of w in equation (26) for successive values of V, as g, r, V, and W were determinable with considerable accuracy by direct measurement, a few practical tests should enable a check to be made of Mr. Spiller's coefficients, $1 \cdot 3608$ and $\frac{1}{25}$, and a valuable formula for the guidance of engineers might be obtained. To investigate the matter a stage further, however, Mr. Spiller's coefficients might be accepted provisionally, and an endeavour could be made to trace the results to which equation (26) led when w was regarded as a variable. It was convenient to write equation (26) in the form

$$V = 1 \cdot 5472 \sqrt{r\left(34 \cdot 022 \frac{w}{W} - 1\right)} \quad . \quad . \quad . \quad \text{(iv)}$$

which reduced to equation (27) in the particular case where $\frac{w}{W} = \frac{1}{15} = 0 \cdot 0667$. In *Fig. 10*, to take a particular case, representing approximately the Salisbury derailment, let $b = 33$, $h = 57 \cdot 25$, $W = 53 \cdot 2$, $d = 59$, $r = 528$. Then, making use of equations (i), (26) or (ii), and (iii), the Table on p. 173 could be prepared.

In the eighth column, it was seen that, on the basis of Mr. Spiller's coefficients, if w had remained constant in the Salisbury case, derailment by climbing would have wanted to occur at 40 miles per hour. If, however, w was regarded as a variable, the matter could be interpreted in another manner, probably much nearer to the actual conditions. Thus, comparing the speeds in the first and last columns, it appeared that if the value of w corresponding with $V = 0$ had by chance been maintained up to

Mr. Rollo Appleyard.

Miles per Hour V	Pressure in Tons for Salisbury Curve. [From Equation (i).]		w assumed Constant, as in Equation (26). $W = 53\cdot2$.		w assumed Variable, P calculated from Equation (i).		V_c from Equation (26), i.e., Critical Speed for Climbing.	
	Inner Rail P	Outer Rail W—P	$w = \frac{W}{15}$	$\frac{w}{W}$	$w = \frac{W-P}{7\cdot5}$	$\frac{w}{W}$	Assuming $w = \frac{W}{15}$ Constant.	Assuming $w = \frac{W-P}{7\cdot5}$ Variable.
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	29·8	23·4	3·55	0·0667	3·12	0·0586	..	35·4
30·0	23·9	29·3	3·55	0·0667	3·91	0·0734	..	43·5
40·0	19·3	33·9	3·55	0·0667	4·52	0·0850	40·0	48·9
50·0	13·4	39·8	3·55	0·0667	5·31	0·0997	..	55·0
60·0	6·2	47·0	3·55	0·0667	6·27	0·118	..	61·7
67·5	0	53·2	3·55	0·0667	7·09	0·133	..	66·7

$V = 35\cdot4$, climbing would have begun. Similarly, if the value of w corresponding with $V = 30$, had been maintained by chance up to $V = 43\cdot5$, climbing would have begun. Each successive value of V in the Table could be interpreted in a similar manner. It was seen that at $V = 60$ the loading corresponding with that speed could only have been maintained up to 61·7 without climbing. Assuming the accuracy of Mr. Spiller's coefficients, therefore, and w variable, derailment by climbing, in the Salisbury case, would have been imminent at about 61 miles per hour. At $V = 67\cdot5$ only the check-rail could have prevented climbing, even if there had been no other cause for disaster. A table prepared in this manner afforded a clear explanation of some of the mysterious cases of climbing that occurred even at low speeds. For if there was unequal loading, or swaying, rolling, or pitching, sufficient to reduce w by an amount such that the pressure upon the rail for the speed shown in column 1 was maintained up to the speed shown in column 9, climbing would be likely to result. From equations (i), (iii), and (iv), a similar Table could be prepared for any given curve, for any class of rolling stock, and for any variety of loading; and the conditions could then be examined by inspection. Of course, if gyrostatic action of the wheels, flange-play, wind-pressure, and balance of reciprocating parts were taken into account, there would be modifications of the second order of magnitude; but as a rule, for computations of this kind, the factor of safety covered such effects. In the case of the Salisbury accident these secondary actions probably did not affect the critical value of V by more than 3 or 4 miles per hour.

Prof. Eustice.

Professor J. Eustice observed that after the Salisbury railway-accident he made some calculations on the effect of the action of centrifugal force around railway-curves, both in the tendency to cause overturning and in the possibility of producing derailment without overturning. Mr. Spiller's Paper had confirmed the opinion which he then formed as to the probability of the leading outer wheel of the locomotive taking most of the thrust on the rails, due to the centrifugal force. There were, however, causes in operation when the train was being accelerated or retarded which seriously affected the pressure of the wheels on the rails, as well as the possibility of overturning. The following summary of the results obtained by him might be of interest in connection with the discussion of Mr. Spiller's Paper. The symbols used had the following meanings:—

K denoted the superelevation in feet;
G ,, ,, breadth of gauge in feet;
r ,, ,, radius of the curve in feet;
F ,, ,, centrifugal force in pounds;
W ,, ,, weight of the locomotive;
V ,, ,, speed in miles per hour;
R ,, ,, radius of the curve in chains.

A. *Effect of Centrifugal Force unaccompanied by Acceleration or Retardation.*—A locomotive would run around a curve of radius r under conditions which would give equal pressure on both rails when

$$\tan \alpha = \frac{K}{G} = \frac{F}{W} = \frac{\frac{W v^2}{g r}}{W} = \frac{v^2}{g r} = \frac{V^2}{983 R};$$

that was $$V^2 = \frac{983 R K}{G} \qquad (g = 32)$$

If K = 0·292 foot (3·5 inches), G = 4·67 feet (56 inches) (say), and R = 8 chains,

$$V = 22 \cdot 2 \text{ miles per hour.}$$

If the effect were taken to be analogous to a pressure F_1 acting on a stationary body, the flange of the wheel would not press against the rail until the force F_1 was sufficient to overcome the lateral friction of the wheel on the rail; but the effect was not analogous to a stationary body, for, as the wheel advanced along the curve, a very small force would cause the flange to approach the rail when the limit already considered had been reached. It was probable that, except at very low speeds, the flange of the wheel, immediately

Prof. Eustice.

the wheel entered a curve, exerted a pressure on the rail, and it was conceivable that at low speeds the tapering of the tread and the curvature of the flange-fillet might be sufficient to keep the flange from touching the rail. Assuming that the tapering of the tread had its full effect up to the speed v for the value of F previously considered, an increase of speed to v_1 would produce a horizontal thrust P on the outer rail.

$$P = F_1 - F = \frac{W v_1^2}{g r} - \frac{W v^2}{g r} = \frac{W}{g r}(v_1^2 - v^2)$$
$$= \frac{W}{983\, R}(V_1^2 - V^2).$$

At 50 miles per hour for a locomotive of 54 tons, with $R = 8$ chains, $P = 13 \cdot 8$ tons: at 60 miles per hour, $P = 21 \cdot 4$ tons. If, as Mr. Spiller had shown, the effect of conicity was not realized, this pressure on the outer rail might be anything between these values and 17·2 tons and 24·8 tons, for 50 miles and 60 miles per hour respectively. This force—which for the example taken, neglecting all effects of wind-pressure or unsteady motion, amounted to 20 to 25 tons—might be distributed between the wheels, and might possibly be taken under certain conditions by one wheel only. Fracture of the rail, or its displacement by sliding of the chairs might then be possible. But it could be shown that this pressure on the rail might be greatly increased by the effect of acceleration.

B. *Effect of Acceleration and Retardation on a Locomotive and Carriages at speeds in excess of that giving equal pressure on the inner and outer rails.*—A probable cause of some of the derailments which occurred at high speeds was the following:—In curves of small radius it rarely happened that the superelevation was sufficient for the distribution of pressure on the inner and outer rails to be equal when the train was travelling at high speed. The line of action of the resultant R of the centrifugal force F and the weight W of the locomotive (or of a carriage) was often nearer to the outer rail than to the inner rail of the curve,[1] thus giving an increased pressure on the outer rail with a correspondingly diminished pressure on the inner rail. (1) If, under these conditions, the locomotive was pulling the train, a couple was produced which tended to slue the carriage next to the locomotive about the outside wheels as a pivot, and the carriage might leave the rails on the outside of the curve. A similar effect would be produced on the locomotive if, when running

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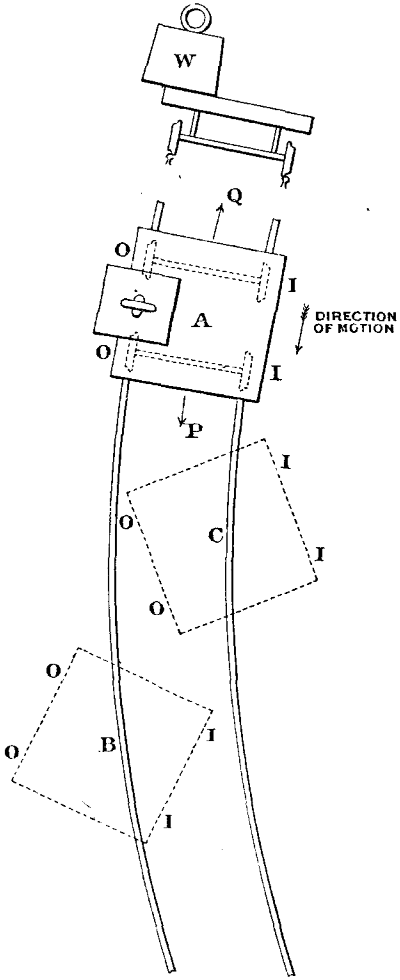
[1] In *Fig. 4* of Mr. Spiller's Paper, the resultant R cuts the line B D E between E and B, approaching B as the speed reaches the limiting speed.—J. E.

Prof. Eustice. at high speed, the brakes were suddenly applied to the locomotive only, or if the steam was turned against the engine so as to check the train; the pressure of the train on the locomotive would tend to slue the locomotive into a position to leave the rails on the outside of the curve (the preponderance of the pressure on the inside buffers would increase this effect). (2) Under the same conditions of speed when the locomotive was retarding the train, the carriage next the locomotive would tend to slue about the outer rail, and might possibly leave the rails inside the curve. He had made a series of experiments on a model carriage loaded so as partly to fulfil the conditions of the problem suggested in the foregoing. *Fig. 11* showed the arrangement adopted. A carriage was loaded so that the pressure on the outer wheels O O was greater than the pressure on the inner wheels I I.

Fig. 11.



1. A pull on the hook at P in the direction of motion of the carriage caused the carriage to take up the position shown by B, that was to say, it would leave the rail on the outside of the curve.

2. When the pull was in the direction Q the carriage took up the position C, that was to say, it would leave the rails on the inside of the curve. In some of the recent railway-accidents it had been impossible to determine whether the conditions which existed at the time of the accident were those assumed or not, but the consideration of the possibility of such sluing action was

Prof. Eustice.

very important, for if the pressure on the outer rail might be excessive when travelling at high speeds when there was no acceleration or retardation of the train, the effect of, for example, turning steam against the engine was to greatly increase the pressure of the flange of the leading wheel on the outside rail. In the Salisbury accident, even if the wind-pressure as well as the effect of acceleration were neglected, it could be shown from the data supplied at the inquiry that a speed of about 60 miles per hour would cause overturning of the locomotive. For if H denoted the height of the centre of gravity $= 5 \cdot 25$ feet (63 inches), K was $0 \cdot 292$ foot ($3 \cdot 5$ inches), and G was $4 \cdot 67$ feet (56 inches); and if in *Fig. 4*, p. 84, the centre of gravity were called C and the angle B C D were denoted by β,

$$\frac{\text{Centrifugal force}}{\text{Weight of locomotive}} = \frac{\mathrm{F}}{\mathrm{W}} = \tan \mathrm{BCE} = \tan(\alpha + \beta)$$

hence
$$\frac{\mathrm{F}}{\mathrm{W}} = \frac{\tan\alpha + \tan\beta}{1 + \tan\alpha\tan\beta} = \frac{\dfrac{\mathrm{K}}{\mathrm{G}} + \dfrac{\mathrm{G}}{2\,\mathrm{H}}}{1 + \dfrac{\mathrm{K}}{2\,\mathrm{H}}} = \frac{73}{148} = \frac{v^2}{g\,r}$$

or
$$\mathrm{V}^2 = 983\ \mathrm{R} \times \frac{73}{148}$$

$$\mathrm{V} = 62 \cdot 8 \text{ miles per hour.}$$

Thus a speed of $62 \cdot 8$ miles per hour, when the motion was steady, would be sufficient to cause overturning of the locomotive on a curve of 8 chains radius.

Mr. Maurice FitzGerald.

Mr. MAURICE F. FITZGERALD observed a strong divergence of opinion between Mr. Spiller and Mr. Shortt regarding the propriety of beginning the gradient of superelevation on the tangent approaching a curve. With regard to the desirability of introducing a more extensive use of curves of adjustment than had hitherto prevailed, and to the value of developing convenient methods of planning them, so as to facilitate their application to existing cases where required, he thought there could be only one opinion, and he regarded both Papers as very useful contributions to the advancement of engineering on lines carrying high-speed traffic, the first as regarded stability on curves, and the second as to the conditions at their ends. With regard to the latter, Mr. FitzGerald wished to point out that, if a carriage entering a curve were guided by the rails alone, there was a period during which it had one axle or bogie on the curve and one still on the tangent, and during this period, which might be called the period of entrance, the carriage was subject to a practically constant angular acceleration about a vertical axis passing through the after bogie pin, or the centre of the trailing axle in plan, which, Mr. Maurice Fitzgerald. on account of the moment of inertia of the carriage in a horizontal plane, required a couple to be applied by forces at the wheel-flanges. These were cumulative, algebraically, on the ordinary centrifugal force. The force at the leading end was towards the centre of the curve, and that at the trailing end was from the centre. They both came into existence the moment the leading bogie entered the curve, and ceased abruptly when the trailing bogie did the same, so that there were really two shocks. If, as often happened, the overall length of the carriage was about one-and-a-half times its wheel-base, their magnitude was about one-half of the ordinary centrifugal force. It might even be contended, if this were the whole account of the matter, that the superelevation at the entrance to a circular curve ought to be greater than elsewhere; but there were really at least six other causes which combined, or might combine, with the rail-pressures against the wheel-flanges, namely: (1) Superelevation differing at the two ends of the carriage or not, as might be; (2) oblique pulls of couplings; (3) unequal buffer-pressures; (4) coning of tires; (5) slip of wheels; (6) dynamical forces arising from periodicity of oscillations on the springs. It appeared to Mr. FitzGerald very difficult to disentangle among all these the effects of superelevation, especially because the obliquity of the coupling pulls on the middle one of three carriages, of which the front one had its wheel-base wholly on the curve, and the second had its wheel-base about to enter the curve, while the third was wholly on the tangent, varied in a complicated way. He would suggest that two or three seismometers, placed in different parts of a carriage forming one of a train, would be able to give better records of the actual march of events than the confused impressions and agitated staggerings of a passenger could supply. His own impression was that Nos. (2) and (6) of the foregoing list of causes were often influential in a marked degree in the carriage, though they might not be marked in their effects at the points of contact of rails and wheels, on which safety principally depended. He believed that seismometers were used for the purpose of detecting defects in the permanent way of railways, on inspecting-cars, but he could not recall any record of their use for the purpose above mentioned, though he thought it very likely his suggestion had been anticipated elsewhere.

Mr. Mallock. Mr. A. **Mallock** observed that both the Authors came to correct conclusions as to the form to be given to transition-curves. The same results, with examples, were given[1] about 50 years ago by

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[1] Transactions of the Institution of Engineers and Shipbuilders in Scotland, vol. iv (1861), p. 23.

the late Mr. W. Froude, F.R.S., in an early Paper "On the Junction of Railway Curves at Transitions of Curvature." Mr. Shortt, in referring to the length to be given to transition-curves (p. 99), omitted one rather important factor which had a marked effect on the sensations of the passengers, namely, the ratio of the time occupied in passing from one curve to another to the natural periods of the carriage on its springs. If any one of the modes of vibration of the carriage had a period twice to three times as long as the time taken to pass from one curve to the other, a large oscillation might be set up. Mr. Spiller also omitted to refer to the possible effects of equality of spring-periods and the rate at which inequalities of the rails were passed. Mr. Spiller's treatment of the forces acting on a truck running on a curve was not quite satisfactory in several respects. Mr. Mallock would not occupy space by going into all these points, but he might mention that the contact between the wheel and rail in such a case was not a point (as indicated in *Fig. 6*, p. 88), but a line extending forward (for the outer leading and inner trailing wheel) from the foot of the vertical through the axis, in a direction and for a length depending on the form of the rail-surface and of the flange of the wheel, and also on the radius of curvature of the rail. The form of the line of contact was therefore to some extent arbitrary. The vertical resultant of the reaction through the line of contact did not pass through the axis of the wheel but in front of it, and it, together with the load, formed a couple tending to resist the rotation of the wheel. The tendency of the wheel to mount the rail could not be expressed in the manner given in equation (25), p. 89. He would be happy to supply the Author, if he desired it, with details as to this or other matters alluded to. Mr. Mallock.

Mr. E. H. Morris remarked that the six examples[1] in England of pure derailment at high speed during recent years all seemed to point to the coincidence of the critical speeds of derailment and overturning. It was noticeable that in every case the radius of the curve was less than 10 chains: yet in only two cases did the engine overturn near the point of derailment. The probability was that in the other four cases the engine heeled over slightly until the flange was liberated, and the flange being freed, centrifugal force automatically ceased, when, unless the impulse had been too great, the engine righted itself. This was a sufficiently reasonable explanation Mr. Morris.

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[1] Poulton-le-Fylde, 1893; Preston, 1896; Wigan, 1900; Salisbury, 1906; Grantham, 1906; Shrewsbury, 1907.—E. H. M.

N 2

Mr. Morris. why the overturning of the engine at the moment of derailment was uncommon. The low result given by Mr. Spiller's equation (27), conflicting as it did with experience, might be attributed to several incorrect assumptions. In the first place F_2, the adhesional component of flange-pressure, would hardly seem to be independent of the speed of the engine; because in a case where the axis of rotation lay in the midst of three or more fixed axles, centrifugal force at the trailing axle acted in a contrary sense to the adhesional resistance to sliding, and consequently must tend to reduce the pressure on the outer leading flange; that was to say as F_1 increased, F_2 somewhat decreased. This argument afforded some support to the Author's contention that excessive cant was objectionable. With a given angular velocity, the less the superelevation the more the value of F_2 was reduced, while at the same time the weight available upon the tread to overbalance the derailing pressure was increased, the primary action of centrifugal force being to create an unequal distribution of the axle-load and to throw the greater weight upon the outer wheel. In other words, w/W varied with the angular velocity and with the superelevation, but equation (27) assumed that it was constant. Also F_1 varied with the superelevation and the angular velocity, because F_1 was obviously that pressure between the leading outer flange and the rail which was due to centrifugal force alone. When the road was canted, the weight upon the axle might be resolved into two components, one normal to the plane of the rails and the other parallel to it; the latter component formed a centripetal force, and reduced F_1 accordingly. Again, θ was assumed to be constant at 65°. This figure seemed to be too small, except, perhaps, in some exceptional cases which must be judged on their merits. In any case, θ varied with the superelevation. On a well-known curve of 12 chains radius the regulation speed was 45 to 50 miles per hour, and was sometimes exceeded. The superelevation was $8\frac{1}{4}$ inches. The worn face of the rail made an angle with the plane of the rails of 72°, and with the horizontal 80°; while on a curve adjacent thereto, with a radius of 45 chains and a superelevation of $2\frac{1}{2}$ inches, the respective angles were 72° and 75°. The rails had been laid 15 years. So far as he could ascertain, there had never been a derailment on this curve. Mr. Spiller rightly pointed out the tendency of the outer leading flange to mount with excessive superelevation, but he omitted to say that this tendency was greater at low speeds than at high speeds, owing fortunately to the increase of the load upon the outer wheel by the action of centrifugal force. Practically the cant could never be so great as alone to

Mr. Morris. become dangerous under this head, but the conjunction of a defective engine-spring might have a serious result. A greater danger lay in the want of firm packing to the outer rail, because the weight on the outer leading flange that was necessary to stability must be met by a corresponding reaction of the rail; otherwise, should the rail yield suddenly and considerably under the impact of the wheel, the effect would be the same as if the weight were suddenly removed, and the consequences would be disastrous. Though, as he had endeavoured to show, it was impracticable to deal with the matter by a general formula, still Mr. Spiller's mathematical considerations pointed, to his mind, to some interesting conclusions, when viewed in the light of everyday experience. Though superelevation was beneficial, for both the comfort of the passengers and the uniform wear of the rails, yet its amount was quite immaterial to the safety of the train, provided that it was sufficient on the one hand to guard against the danger of overturning at high speeds, and on the other, not so great as to create a risk of derailment at low speeds. Thus a formula for superelevation varying regularly with v and r was unnecessary and inapplicable. Every case should be judged on its merits. For a curve compounded of two or more radii a uniform cant throughout, if generally convenient, might be adopted, while in an easy junction, where circumstances required the rails to be laid at a uniform level, there was no danger in abandoning superelevation altogether. The stability of the train against overturning would, in Mr. Morris's opinion, be sufficiently safeguarded if the outer rail were so raised that, at the highest possible speed, the portion of the axle-load distributed by centrifugal force upon the outer rail might not exceed twice that on the inner rail.

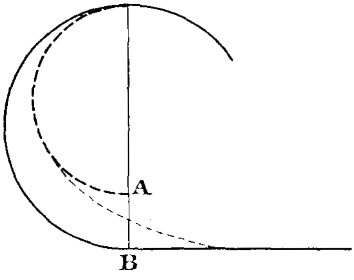
Mr. Read. Mr. R. J. G. Read observed that the Authors appeared to take quite opposite views on the point whether the cant should be run up and tailed off on the straight or on the curve, and the question was—who was right? He was of opinion that the cant should be commenced on the straight and finished on the curve. It was not always easy or desirable to give the maximum cant required for a given curve and speed. Some years ago he had to work out the cant to be given on the curves of a high-speed railway on the mono-rail system, which was constructed near Brussels. It was an experimental line about 3 miles long, in plan somewhat egg-shaped, and the speed was to be 100 miles per hour. A large cant was required on the small curve in order to counteract entirely the effect of centrifugal force, but only a portion of this cant was given, the remainder of the outward force being resisted by the strength of the rails and trestles, which acted as a continuous ring girder. In considering the

Mr. Read. best transition-curves to adopt, he plotted various curves and exaggerated the curvatures, somewhat in the manner adopted by Mr. Shortt. Having selected one, he then gave the ordinates for setting it out by scaling from the exaggerated figure.

Mr. Shand. Mr. A. C. SHAND, of Philadelphia, stated that some years ago the Pennsylvania Railroad used quite extensively the spiral or, as it was called in the United States, elastic curve at points where the existing curve was too heavy for high-speed traffic; but in recent years little use had been made of such curves. On important changes of line, of which a great many had been made, an endeavour was made to keep the curvature down to a limit which would permit of running at a speed of 70 miles per hour. On the mountain division, and at points where it would be exceedingly expensive to improve the curvature, and where there were practically four tracks at all points on the main line, it was found to be very expensive to throw the tracks to form a spiral curve, and this practice had to be abandoned to a large extent. Where spiral curves were introduced it had been found difficult to keep the exact alignment; and, unless they were laid out to exact alignment and kept in that condition, these curves rode no better than the ordinary curve.

Mr. Stewart. Mr. P. C. STEWART observed that the method of using distorted diagrams for dealing with improvements in alignment was certainly ingenious, and would be very useful if the principle held good with sufficient accuracy for practical purposes; but in what followed it would be shown that considerable errors might arise from the use of the method. Of course, the amount of distortion could be varied indefinitely, and the less the distortion the more accurate would be the results; but unless the distortion were fairly large, the method would not be of much service. Mr. Shortt fixed the amount of distortion by selecting his scales in the ratio of 1, 10 and 100 feet to the inch. On this basis the angle at the centre of the circle subtended by a given arc on the distorted diagrams was ten times the angle subtended by the corresponding actual arc. Suppose *Fig. 12* to be a distorted diagram, plotted in the manner described in the Paper, the full line representing an existing simple curve of radius r feet entered directly from the straight, and the

Fig. 12.



Mr. Stewart.

dotted line a proposed improvement, introducing a transition-curve between the circular arc and the straight, the circular arc now being sharpened to r_1 feet. It would be seen from the diagram that the maximum amount of "shift," A B, that was possible with the given radii had been given. The radii in inches of the circular arcs in the diagram were evidently $\frac{r}{100\,n}$ and $\frac{r_1}{100\,n}$, where n was a constant depending on the actual scales used, so that $A\,B = \frac{2}{100\,n}(r - r_1)$ inches, which represented $\frac{2}{100}(r - r_1)$ feet. It was easily seen, however, that in reality the maximum amount of shift that could be obtained was $2\,(r - r_1)$ feet, or 100 times the amount possible in the distorted diagram. It followed that the method failed if the shift required was greater than $\frac{1}{50}(r - r_1)$ feet. Again, if *Fig. 13* was a diagram drawn to a natural scale, in which it was proposed to alter the curve as shown by dotted lines, it would be found that it was impossible to draw a distorted diagram of this case; for since C D was a quadrant, on a distorted diagram the angle subtended at the centre would be 90° × 10, or 900°; and although a circle could be drawn which might be supposed to represent the existing curve, one part being superimposed on the other, the arc shown by dotted lines could not be drawn in. It might be urged that these were extreme cases, and that the proposed method was not intended to apply to such. But if an ordinary practical case were examined it would be seen that the method still involved a considerable amount of error. Let *Fig. 14* represent a distorted-scale diagram in which the radius of the curve A B was 31 chains, and suppose it was desired to sharpen this curve to 28 chains radius, and insert a transition-curve between the sharpened curve and the straight. Then on the diagram—

Fig. 13.

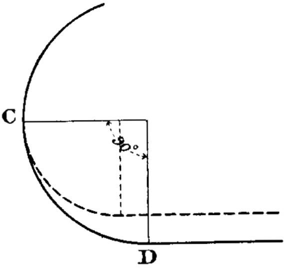
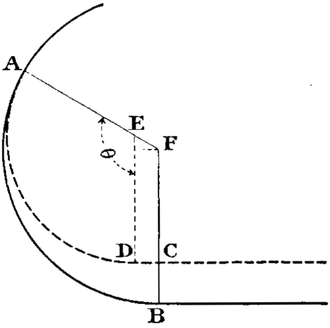


Fig. 14.



Mr. Stewart.

$$A\,F = \frac{31 \times 66}{100\,n} = \frac{20 \cdot 46}{n} \text{ inches,}$$

$$A\,E = \frac{28 \times 66}{100\,n} = \frac{18 \cdot 48}{n} \text{ inches,}$$

and therefore

$$E\,F = \frac{1 \cdot 98}{n} \text{ inch,}$$

where n was a constant, as before. Fixing the amount of the shift at 2·75 feet, C B $= \frac{2 \cdot 75}{n}$ inches, and the angle θ at the centre was given by $1 \cdot 98 - 1 \cdot 98 \cos \theta = 2 \cdot 75$

or $\theta = 112^\circ\ 53'\ 7'' = 1 \cdot 9702198$ radian.

It followed that the length of the arc A B, which subtended this angle was $\frac{20 \cdot 46}{n} \times \theta = \frac{40 \cdot 31}{n}$ inches, which represented 403·1 feet. Also, C D $= \frac{1 \cdot 98}{n} \times \sin\ \theta = \frac{1 \cdot 824}{n}$ inch, which represented 18·24 feet. Now compare these values with the correct calculated values. Let A′, B′, C′, D′, θ' refer to a diagram similar to *Fig. 14*, but drawn to a natural scale. Then θ' was given by

$$198 - 198 \cos \theta' = 2 \cdot 75$$

or $\theta' = 9^\circ\ 33'\ 38'' = 0 \cdot 1668631$ radian,

and therefore the length of the arc A′ B′ $= 2046 \times \theta' = 341 \cdot 41$ feet, and C′ D′ $= 198 \sin \theta' = 32 \cdot 88$ feet. It would thus be seen that the distorted diagram threw the tangent-point A too far back to the extent of 61·7 feet, and the tangent-point D was displaced to the extent of 14·64 feet in the opposite direction. From what preceded it appeared that many cases might arise to which Mr. Shortt's method would be wholly inapplicable, and others in which errors of some magnitude would occur if the method were used.

Mr. Sweetman. Mr. WALTER SWEETMAN observed that in Mr. Spiller's Paper the forces acting upon a vehicle passing round a curve were stated (p. 84) to be four in number; but if he understood the problem correctly there was certainly a fifth, which was not only determinable, but also seemed, when the track was canted, to be of the highest importance. That force was the reaction normal to the plane of the road-bed which was exerted upon the vehicle through the rails. When the track was laid level, this acted vertically upwards, but when it was canted, the normal reaction was tilted at a slight angle determined by the superelevation, and could therefore be resolved

Mr. Sweetman.

into a vertical component equal to the weight of the vehicle and a horizontal component equal (if the cant was proportional to the speed) and opposite to the centrifugal force. This horizontal component could therefore be termed the centripetal force acting upon the vehicle. Although this omission did not affect the calculation of the overturning-point, arrived at by taking moments about the high rail—for at the instant of overturning this reaction would be applied entirely through the high rail, the weight upon the lower rail becoming zero—yet in the consideration of the other problems it could not be so lightly put aside. As it was ignored throughout the Paper, the subject seemed to call for further consideration, which might throw light on the reason why the results arrived at on p. 90 in the curve of maximum safe speed were so much below actual practice. For instance, ignoring the centripetal force, it might seem contrary to axiomatic principles of dynamics that cant alone could counteract the tendency of a moving truck to continue its motion in a straight line, and it might therefore be assumed, as in the Paper, that the force which deviated it from this course was entirely due to the lateral pressure of the outer rail upon the flanges of the wheels. But, taking into account the centripetal force, it would be evident that the forces upon the vehicle due to the normal reaction of the canted track could—and if the axles were free to take up radial positions would—cause it to assume a curved course. The entire neglect which this normal reaction received from the Author forced such questions as the following upon the mind of the reader. If this very considerable force, which certainly must exist according to the ordinary law of action and reaction, did not tend to counterbalance the centrifugal force upon the vehicle, what was its effect? How was it counteracted? Was its effect lost in friction? In short, what was the contention with regard to this force of those holding the opinion that cant was of very little avail in reducing the tendency of a vehicle to leave the road on the outside of a curve? Considered as having reference only to the motion of a vehicle upon a level road-bed the Paper was excellent, but the introduction of super-elevation seemed to alter the entire problem. In discussing the lateral force exerted by the outer rail the deviating force F_1 (p. 79) might then be omitted entirely, and the only one that counted was that sufficient to produce rotation. Whether the Author's formula for F_2 was based upon sound hypothesis was open to question, but in any case the foregoing considerations would alone greatly increase the safe speeds obtained later in the Paper, and, unless evincing a misconception of the entire problem, were certainly sufficient to

Mr. Sweetman. recommend the adoption of cant for safe traffic. A striking illustration of the practical advantage of cant occurred during the construction of the Stuartstown Railway, Natal, in 1908. The gauge of this railway was only 2 feet, the rails weighed 35 lbs. per yard, the length of the longest vehicle was 30 feet, and the weight of the locomotive was 26 tons. The rolling stock was of the bogie type. During the ballasting, many of the sharpest curves, of which the radius was 175 feet, gave great trouble by constantly "kicking out" from their proper alignment, and in many cases the permanent way had to be temporarily prevented from lateral movement by wedging it with sleepers between the sides of the cuttings. This was to obviate the danger of the track getting so far out of its proper position that the rolling stock would strike projecting rocks in the batters. The curves had to be negotiated at a very low speed, for it was found that when the speed exceeded about 6 miles per hour, the lateral movement of the track as the engine approached was not only visible, but was positively alarming, and the grinding upon the outer rail was such that a fine steel powder worn from it and from the flanges could be seen sprinkled upon the sleepers and ballast. These were the phenomena observed when the superelevation of the outer rail was 1½ inch, which theoretically corresponded with a speed of nearly 13 miles per hour. After a considerable time spent in vainly trying to keep the road in its place, it was decided to experiment with more cant, and after trials in a few places a superelevation of 2¼ inches for curves of this radius was decided upon, and adopted throughout the railway. The result was very satisfactory. The alignment gave little further trouble, and the trains passed round the curves without appreciable grinding or displacement of the road at a speed of about 12 miles per hour. In Mr. Sweetman's opinion this extra cant provided the necessary rotating force F_2 (though if the formula in the Paper was practicably applicable this could not be possible) and a creeping or slipping of the wheels on the rails was the result.

Mr. Treacher. Mr. E. TREACHER remarked, with reference to the design of main-line junctions, that Mr. Spiller rightly said that the limiting factor of curvature was the angle of the diamond crossings; but it was not the Board of Trade alone, but common prudence, that restricted the angle of these crossings to 1 in 8 or 7° 9′. Experience had proved, in English practice, that the use of diamond crossings of the ordinary type, of flatter leads than 1 in 8, inevitably led to derailments. The explanation of this was (taking as example a 1-in-8 crossing with 1¾-inch flangeways and a ¾-inch point to angle-rails), that there was a length of 3 feet 4 inches between the points of the

Mr. Treacher.

angle-rails in which the wheels had practically no constraint from moving in an angular direction, and, as the portion of the periphery of the wheel-flange below rail-level was considerably shorter than this, it was comparatively easy for wheels to swerve (especially on a curve) and to mount the nose of the angle-rail and come down on the wrong side. Mr. Spiller gave two examples of junctions, where a minimum curvature of 32⅓ and 50 chains radius was obtained respectively by using diamond crossings of 1 in 8; in both cases the lines diverged in opposite directions, and in the second case the 6-foot way was increased to 9 feet 6 inches. Now, unfortunately, neither of these two conditions was likely to obtain in actual practice, and if junctions had to be adapted to high-speed conditions at moderate cost, it was obviously impossible either to alter the curvature very extensively or to increase the 6-foot way. But there was ready to hand for the permanent-way engineer's use a fitting which had been recommended by the Board-of-Trade Inspector in his report on the Stafford accident, dated 12th May, 1906. Switch diamonds or actuating diamonds could be made of any lead, however flat, and consequently did not, in themselves, limit curvature in any way. In addition, they formed a solid road for the wheels of vehicles in each direction, and consequently lasted longer than ordinary diamonds; they were also quieter under traffic and did not harm the stock so much. They were not a new invention, having had years of proved efficiency, not only in this country but in America and the colonies. To illustrate their use, he would cite a branch line from off the straight, of 70 chains radius, where maximum speeds were required on the branch line, and there was only 6 feet between the lines of way. Diamond crossings of about 1 in 14½ would be required, whereas, if crossings of the ordinary type were used the curve would have to be sharpened from 70 chains to 20, or else the lines would have to be slued. Also the case of a junction with two lines curving in the same direction, of radius, say, 80 and 30 chains respectively. Diamond crossings of 1-in-12 lead would be required here if the space between the roads were 6 feet. It therefore appeared that the demand for high speed, coupled with cheapness of construction and safety, would demand the general adoption of switch diamond crossings. Switches appeared to form a serious obstacle to sweet running at junctions, the machined straight part of the switch, occurring as it did at the entrance to the curve, causing at times an unpleasant lurch. As an example, might be considered what was called an 18-foot switch, that was, a rail 2½ inches wide planed back about 10 feet (modern practice used 30-foot rails for this and curved the portion behind the planing).

Mr. Treacher. Mr. Shortt would designate this switch as an equivalent radius of 1,000 feet, that being the curve tangential to the stock-rail and also to the switch-rail at the heel of the planing. But the switch actually diverted the stock through an angle of 1° 9′ suddenly, whereas on a curve of 1,000 feet radius this angular deflection would be attained gradually through a length of 20 feet. Failing the adaptation of the old-fashioned stub switch to modern practice it seemed that the only practical method of avoiding the sharp knock at the point of the switches was to so lay the switches and divert the road that the route of fastest traffic was favoured.

Mr. Warner. Mr. J. SUTHERLAND WARNER both admired and sympathized with Mr. Spiller in his able and plucky attempt to deal with such a complex subject without the aid of any one general definition. For example, on p. 79 he said: "This is due to the movement of rotation which all vehicles undergo when passing round curves, and is analogous to that of a locomotive revolved on a turntable." The Company with which Mr. Warner was associated had drawn up a set of definitions, without which they found it impossible to substitute for rule of thumb scientific handling of the subject, and to obtain definite results. A truck was assumed to be taken from the track and placed on a plane floor, and the natural line along which that truck would move was called the "rolling-line." Thus F_2 was the force which must be applied to the leading axle to disturb the rolling-line. On good straight track the rolling-line was disturbed perpetually and at a tolerably short pitch; indeed, the axles of the leading and trailing bogies were practically never parallel to each other, and Mr. Spiller's force F_2 was applied perpetually, constituting an important factor in train-resistance. The exact position of the rolling-line of a truck when entering a curve was ignored by Mr. Spiller, although it was of grave importance. The Warner Company designed all carriages so that each vehicle was balanced, so to speak, on an ideal centre-line over the track, which was the "conformity-line." This gave a fair start on the transition-curve and prevented those disturbances due to the vehicle being to one side or the other of the ideal centre when entering the curve. Mr. Spiller's figures and curve for maximum safe speed were quite unreliable, since, in his estimate of the force (F_2) disturbing the rolling-line, he had omitted entirely an important factor tending to cause a wheel to climb the rail. He should have included in his estimate of F_2 the force necessary to overcome the friction of bogie centre plates and side bearings. So important was this that the Master Car Builders' Association in 1907 appointed a special committee upon the matter, Mr. Warner. who had made their first report, in which they stated that the subject was of such importance that they found considerable further investigation necessary. The Report[1] said:—

> "There is evidence that derailments have in many instances resulted from the use of side bearings carrying too great a proportion of the load when used with rigid underframes, and from the binding of improperly-constructed centre plates and side bearings, which causes the wheel flanges to crowd and climb the rail.
>
> "The greatest practical freedom of movement of the trucks which allows of their adjusting themselves to curvature and inequality of track is believed by your committee to be of vital importance, not only because there is less probability of derailment, but also because wheel flange wear and danger from broken wheels is diminished. . . .
>
> "While the resistance of the trucks to turning might perhaps be reduced by placing the side bearings nearer to the centre plate than is the common practice, the tendency of the car to roll would be increased. . . .
>
> "The investigations of your committee warrant them in stating that the use of anti-friction side bearings will reduce flange wear and lessen the probability of derailment."

He would be glad, therefore, if Mr. Spiller would amend his figures by giving a formula for the friction of bogie centre plates. Another formula was necessary for the friction of side bearings, and while these were extremely important it was difficult to give a general formula that would be of any use, because these side bearings varied in design and clearance with different types of bogies. In some types of bogies corner-links did the work of side bearings, and in the Warner non-parallel-axle bogie this work was performed by two sets of circular swinging links in series. It was possible that Mr. Spiller intended his formula to apply to corner-link bogies, in which case the particular type would probably be without any centre bearing; but Mr. Warner thought that a definite allowance ought to be made for the restraint the links would impose upon the turning of the bogie.

Mr. Wells. Mr. L. FORTESCUE WELLS was of opinion that many of Mr. Spiller's conclusions were not in accordance with admitted safe practice; but he did not suppose the Author contemplated their adoption in actual working, or that he intended to suggest that the safe speed on a curve of 40 chains radius should be limited to 45 miles per hour in practice. If this was a correct assumption of the Author's position in the matter, it should be borne in mind in discussing his Paper; and in this case it was to be regretted that the Author did not include a qualifying statement to such effect. On p. 80 Mr. Spiller said that superelevation had no effect on the force F_1: now $F_1 = \frac{W v^2}{g r}$ = the centrifugal force. Theoretically,

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[1] Report of the Proceedings of the . . . Master Car Builders' Association 1908, pp. 291 and 292. Chicago, 1908.

Mr. Wells. the correct superelevation for a particular speed was such that there was no pressure on the wheel-flanges, the resolved component of the combined reactions of the rails supplying the force to cause the acceleration towards the centre of the curve inherent to the motion of a body in a circular path. Superelevation did not alter the force necessary to cause this acceleration, but it did affect the method of application and the magnitude of the force exerted by the outer rail, and therefore the lateral pressure on, or reaction of, the outer rail. The motion of a train on or entering a curve was so complex that it was not capable of satisfactory mathematical treatment. It seemed to Mr. Wells that regard must be had to the motion of the train as a whole. The conditions for the locomotive, which might be said to be always laying the road, were different from those of the coaches behind. The height of the centre of gravity of the locomotive had a material bearing on the problem, and on the tendency of the locomotive to spread the road, whether on the straight or at the entrance to a curve. When a train was entering a curve, the coaches in the rear, which had not yet reached the tangent-point but were coupled up, must have some effect on the motion of the coach which was passing the tangent-point. Mr. Spiller's statement that it was invariably found that the running face of the outer rail was cut away most where the cant was greatest did not agree with Mr. Wells's experience.

Mr. Shortt stated that transition-curves were more necessary with large than with small radii: it must, however, be borne in mind that, except at special places, the speed of a train was not varied to suit the radii of curves. The Report of Mr. W. B. Worthington, now Engineer-in-Chief of the Midland Railway, to the Sixth International Railway Congress, held at Paris in 1900, should be studied in connection with the two Papers under discussion. In that Report[1] Mr. Worthington dealt with the design of junctions for fast running, and gave various examples of what might be done by increasing the standard 6-foot and using diamonds not slower than 1 in 8, pointing out that leads might be improved by the insertion of transition-curves. Information was also given showing the actual space required for the passage of train-wheels, as determined by observations over a period of 24 hours on lines with heavy traffic. Some years ago, when Mr. Wells was on Mr. Worthington's staff, he had to do with the reconstruction and enlargement of an important junction designed for fast running. The best junction possible under the circumstances was laid. The

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[1] Bulletin of the International Railway Congress, vol. xiv, p. 2277.

Mr. Wells.

slowest V crossings were 1 in 16, and, of course, there were no diamonds slower than 1 in 8. No lead had a less radius than 25 chains, some being of 30 chains and some of 36 chains radius. Wherever possible, both roads should be straight through the diamond, and to attain this was worth some sacrifice. Figs. 10 and 11, Plate 2, were open to criticism. The roads were not straight through the diamonds. In spite of the long leads, the safe speed, according to the Author's diagram (p. 90), was only 50 miles per hour in one case, and rather less than 40 miles per hour in the other. Mr. Wells would rather sacrifice a little of the 100 chains radius and improve the 32⅓ chains radius; and, after all, the switches were straight. As a rule, standard lengths of switches were used, and he doubted if 28 feet 9 inches was a length used by any company. Some companies used curved switches for the shorter ones. Accuracy in permanent way was very important, and transition-curves should be adopted wherever they were seen to be beneficial. At the same time, Mr. Wells ventured to suggest that their application might be carried beyond the bounds of practical advantage and utility. Above all things maintenance was important, and if the determination and means to ensure first-class maintenance were lacking, it was useless to trouble about cubic parabolas or spirals. Where it was impossible to insert a length of straight road between two reverse curves, even by reducing the radii to admit of this, a check-rail might be provided with advantage at the point of reversal of curvature. Mr. Wells had laid a junction, crossing from an up slow to an up fast line, where the latter was on a curve of large radius in reverse sense to the junction-line at the trailing points. This was unavoidable owing to a bridge-abutment, and at the toe of the trailing points he put in a length of check-rail which he was convinced had been beneficial. Trains passed through the junction and on to the fast line at high speed without any discomfort to the passengers. An easy splay of the check-rail at the entrance was an important detail which often did not receive sufficient attention. It was not surprising that many curves existed with a sharp portion or kink near the end, because the ordinary plate-layer or walking ganger was very prone to, as he called it, "pull" the curve. The idea, which was very prevalent, was that the curve was eased and improved by this "pulling" and disregarding the pegs set to the true curve. The inevitable result of this "pulling" was to make the curve sharper than intended at some point, and the practice should not be countenanced.

Mr. H. M. Whitley.

Mr. H. Michell Whitley remarked that Mr. Spiller dealt exhaustively from a theoretical point of view with the forces

Mr. H. M. Whitley.

tending to derail a train passing around a curve, assuming that the *road and rolling stock were in perfect order*; and here theory and experience agreed. But the assumed conditions in practical working were not always realized, and derailments, which were greatly diminishing in number, were mostly due to defective permanent way or rolling stock, sometimes combined with an unsuitable engine—although in recent years especially some very serious derailments had been caused by excessive speed around a sharp curve with road and rolling stock in good order. The following Table (pp. 194–7), which was compiled from the Reports on railway-accidents made by the Inspectors of the Board of Trade, showed the accidents that had occurred on curves on British railways since 1880, excluding, however, those clearly due to defects in the road or rolling stock, and to other causes which did not bear on the question of fast running around curves. It would be seen from the Table that no accident from excessive speed alone had arisen on curves of more than 40 chains radius. He agreed with Mr. Spiller that the danger of a train leaving the rails by the leading wheel mounting was greater than that of overturning by the action of centrifugal force. He also concurred with him that in some cases on high-speed lines excessive cant increased the danger of derailment by throwing so much weight on to the inner rail that there would be a danger of the outer rail mounting; and his practice for such lines had been to give as little cant as possible—just sufficient to guard against the level of the outer rail sinking lower than that of the inner—as the centrifugal force would throw over the engine and keep the outer wheels hard down on their rail, and so prevent them from mounting. The tendency of modern practice had been towards diminishing the superelevation put on curves, which some years ago was so considerable, that when a series of sharp reverse curves was run over at a fair speed the alternate elevation of the outer rails caused the coaches, especially of the broad gauge, to roll from side to side like a ship at sea. The question of wind-pressure was also, as Mr. Spiller pointed out, a factor which must be taken into consideration in determining the amount of cant which diminished the moment of resistance of overturning of the train; and in his calculations he assumed a pressure of 20 lbs. per square foot as being sufficient. As a general rule this might be so, but far greater pressures were known to have existed. Several years ago, a London and North-Western mail-van was overturned whilst passing over an embankment crossing a narrow gorge, and on the 2nd November, 1903, a passenger-train on the Furness Railway, standing on the Leven viaduct, was overturned on to the up line during a terrific gale.

Mr. H. M. Whitley.

The stiffest vehicle in the train, a London and North-Western bogie brake, if fully loaded, would theoretically require a direct side-pressure of approximately 42 lbs. per square foot to overturn it, the six-wheeled vehicles 35 lbs., and the four-wheeled 32 lbs.; whilst if not fully loaded they would overturn with 3 or 4 lbs. less. The velocity of the wind measured by the anemometer at Barrow was 100 miles per hour, the direction of the wind was broadside on, and the train was entirely unprotected. Careful measurements at Bidston Observatory showed that a velocity of 70 miles per hour gave a pressure of 48 lbs. per square foot, 80 miles per hour a pressure of 60 lbs. per square foot, and 90 miles per hour a pressure of 71 lbs. per square foot. During a violent gale at Eastbourne about 12 years ago, Mr. Whitley had occasion to travel from Eastbourne to Lewes in Sussex. The wind was blowing broadside on to the train, which was in a critical position and on the verge of overturning during the violent gusts, the wind-pressure in this instance exceeding 25 lbs. per square foot. Instances had been known also on the light railways in Ireland, laid with a 3-foot gauge, where several trains had been overturned when running around curves with cant. In two of these cases the pressure per square foot which would overturn the carriages was reduced by the cant from 18 lbs. to 15 and 10 lbs. per square foot respectively; this diminution of stability on curves on narrow-gauge lines was an additional argument against the introduction of the metre gauge in countries liable to violent storms. For running around curves at high speed a substantial permanent way and good rolling stock, both maintained in the highest state of efficiency, were absolutely necessary, especially with heavy engines and trains of corridor-, dining-, and sleeping-coaches run at the high speed becoming more general. Mr. Whitley was of opinion that in many cases the present fastenings did not give a sufficient factor of safety. The weights of engines had increased very much of late years, and the fastenings as a rule remained the same. Such an engine as the Great Western Railway Company's "Great Bear," weighing 96 tons with 20 tons on each of the three driving-axles, running at a high speed, would strain severely a road of which the chairs were secured with three hollow treenails and spikes through them. Such a permanent way, after it had been laid for a few years, would show numerous signs of weakness, many of the chairs not being tight on the sleepers. The strongest method of fastening was by fang-bolts, as adopted by the Great Western Railway, and for the increasing speeds such a strong road, supplemented by good broken-stone ballast, was absolutely necessary. Several instances had arisen lately of drivers overrunning

TABLE OF ACCIDENTS

Mr. H. M. Whitley.

Date.	Name of Railway.	Place of Derailment.	Description of Train.	Type of Wheel-Base.	Radius of Curve.	Cant.
					Feet.	Inches.
1880	Lancashire and Yorkshire	Facit Junction	Passenger	Bogie engine	990	$\frac{1}{2}$
1880	Cheshire lines	Manchester Central Station	Passenger	Bogie	255	2
1882	Great Northern	Chartley	Passenger	Rigid	660	..
1882	Lancashire and Yorkshire	Southport	Passenger	Rigid	726	$3\frac{1}{4}$
1884	Midland	Redditch	Passenger	Engine rigid, train bogie, and rigid	754	$4\frac{3}{8}$
1889	London and South Western	Between Mortehoe and Braunton	Passenger	Engine rigid	1,056	$4\frac{1}{2}$
1891	Great Eastern	Near Lavenham	Passenger	Bogie	2,600	$3\frac{1}{2}$
1893	Great Western	Upway Junction	Passenger	Rigid	560	4
1895	Midland	Near Clapham	Passenger	Engine rigid, train bogie	2,640	$2\frac{1}{2}$
1895	Great Western	Near Doublebois	Passenger	Bogie	1,980	3
1896	London and North Western	Preston Station	Highland Express	2 engines rigid, train bogie	462	$2\frac{1}{4}$
1897	London, Brighton and South Coast	Between Heathfield and Mayfield	Passenger	Rigid	1,584	$2\frac{1}{2}$
1897	London, Chatham and Dover	Between Sole Street and Rochester Bridge	Passenger	Engine bogie, train rigid	3,960	3
1898	London and South Western	Between Brent Tor and Tavistock	Passenger	Mainly bogie	1,914	4

on Curves, 1880 to 1907.

Mr. H. M. Whitley.

Fastenings to Sleepers.	State of the Permanent Way.	Speed-Limitations if any.	Estimated Speed.	State of Rolling Stock.	Reported Cause of Accidents.
			M.p.H.		
2 treenails and 1 spike	..	Gauge tight	12	Defective engine	Gauge too tight.
2 spikes outside and 1 inside	Good order	Special care hand brake	30	Good order	Excessive speed.
..	Good order	..	30	Good order	Excessive speed around loop line.
..	Good order	..	30	Good order	Excessive speed.
2 spikes and 2 treenails	Good order	10	10	Good order	Engine with wheel-base 16 feet 6 inches could not get around curve.
2 spikes and 2 treenails	Good order but tight to gauges	..	40	Good order	Too fast around curve with 14 feet rigid wheel-base, a stone on line.
2 spikes and 2 treenails	Good order	..	30 to 35	..	Unsteady engine with trailing bogie.
Fang bolts and dog spikes	Fair order	..	6	..	Curve too sharp for engine with 15-ft. 8-in. rigid wheel-base to run around without check-rail.
2 spikes and 2 treenails	Good order	..	40	Good order	Doubtful, perhaps break-up of frost.
2 $\frac{11}{16}$-inch fang bolts	Very good order	..	35	2 trailing bogie engines	Oscillation of unsteady engines at high speed, road knocked about by preceding train with similar engine at 60 miles per hour.
..	Good order	10	40 to 50	Good order	A reverse curve without any intervening tangent, without check-rail, with cant suitable only for very low speeds, combined with high speed.
3 hollow treenails and spikes	Rough	..	40	Good order	High speed and rough road.
3 hollow treenails and spikes	..	..	60	..	Running trains at full speed over road not fully ballasted.
3 hollow treenails and 3 spikes, $\frac{5}{8}$-in. diam.	Good order	..	over 40	Good order	Obscure, no conclusive explanation forthcoming, probably unsteady trailing bogie engine running at very high speed, oscillating violently.

TABLE OF ACCIDENTS

Mr. H. M. Whitley.

Date.	Name of Railway.	Place of Derailment.	Description of Train.	Type of Wheel-Base.	Radius of Curve	Cant.
					Feet.	Inches.
1900	London and North Western and Great Central	Amberswood	Passenger	Rigid	560	None
1900	South Eastern and Chatham	Between Wadhurst & Ticehurst Rd	Passenger	Bogie and rigid	5,472	3 and 4
1901	North Eastern	Bardsey	Passenger	Bogie	1,650	..
1904	London and North Western	Talycafin	Passenger	Engine 2 radial axles, coaches 6 wheels rigid	2,100 to 2,450	$5\frac{1}{2}$
1904	Metropolitan and Great Western	Aylesbury	Passenger	Bogie	540	Cant badly put on a lump of 3 ins.
1905	North Eastern	Gateshead	Passenger	Engine bogie, coaches bogie, and 6 wheels rigid	400 to 660	$1\frac{5}{8}$ to $2\frac{3}{4}$
1906	Caledonian	Strathaven	Passenger	Bogie	1,320	4
1906	Great Northern	Grantham	Passenger	Engine bogie, coaches bogie, and 6 wheels rigid	Reverse curves 445 to 660	None
1906	London and South Western	Salisbury	Passenger	Bogie	530	$3\frac{1}{2}$
1907	Tralee and Dingle	Lispole Viaduct	Goods	..	330 (3 ft. gauge)	$3\frac{1}{4}$ check rail
1907	North Eastern	Near Goswick	Goods	Engine bogie, wagon 4 wheels rigid	660	none
1907	London and North Western and Great Western	Shrewsbury	Passenger	Engine bogie, train bogie, and 6-wheel postal vans	610	1 to $1\frac{1}{2}$
1907	Midland	Dore	Passenger	2 engines, 1 bogie and 1 rigid, 2 4-wheel rigid base, horse boxes in front	620 but at switches 430	$\frac{5}{8}$-inch

on Curves, 1880 to 1907—*continued.*

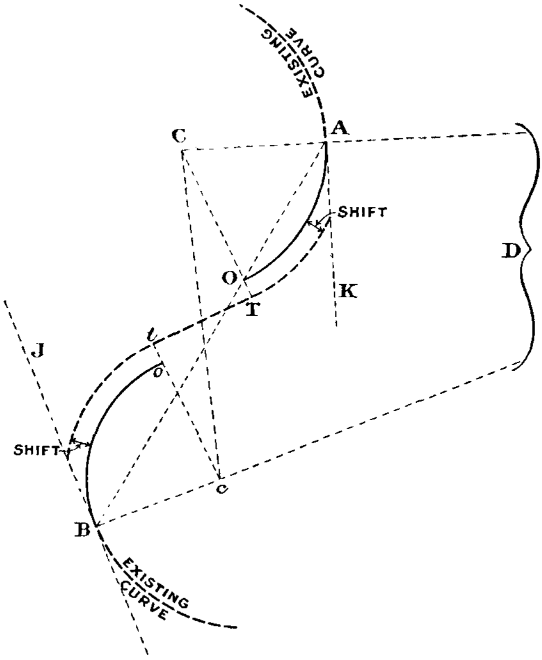
Mr. H. M. Whitley.

Fastenings to Sleepers.	State of Permanent Way.	Speed-Limitations if any.	Estimated Speed.	State of Rolling Stock.	Reported Cause of Accident.
			M.p.H.		
..	..	Standstill	over 30	Good order	Excessive speed combined with weakness of permanent way.
2 spikes and treenails	Ballast defective	..	..	Good order	Heavy engine disturbed permanent way owing to oscillation, excessive cant, and gravel ballast.
..	Good	25	about 35	Good	The curve was irregular; for about a chain it was only 462 feet radius where the derailment occurred; speed too great for such a curve.
2 coach-screws and 2 spikes	Good order but soft foundation	..	60	Good	Excessive speed for the type of engine, which is unsteady.
Fang bolts	Good order	15	60	Good	Excessive speed; could not possibly get around such a sharp curve.
..	Good	10	44	Good	Excessive speed around sharp curve, mounted check-rail when brakes were applied.
2 spikes $\frac{7}{8}$ inch diameter	Road weak	..	50	Good	Weak permanent way, road burst, 2 spikes not sufficient.
2 spikes and 2 treenails	Good	should have stopped	60	Good	Driver failed to stop at station, turned on to stopping line, and could not get round the 450-foot curve at such a speed. Driver failed to slacken speed for the curve, and ran through.
3 hollow treenails with spikes	Good order	30	60 to 70	Good order	Excessive speed, train overturned by centrifugal force.
Dog spikes	..	..	about 40	..	Excessive speed, train overturned by centrifugal force, train ran away.
..	Good order	should have stopped	60	Good order	Driver failed to stop at station and could not run through crossover road at such high speed.
2$\frac{7}{8}$-inch fang bolts	Good order	10	60	Good order	Driver failed to slacken speed for the curve at junction, ran through at excessive speed, engine overturned by centrifugal force.
..	Good order	20	35	Good order	Excessive speed, worn flange on outer leading wheel of second engine.

Mr. H. M. Whitley. signals, thus causing derailments on sharp curves. At junctions and stations where such danger-points occurred on a main line of railway, every effort should be made to improve the curves of the road over which trains travelled at high speeds; in some cases an avoiding-line might be practicable, and it was also a question whether a special signal should not be used to warn a driver to slacken speed, either by giving him an audible signal, or by specially marking the distant signal and keeping it at stop until he had slackened sufficiently.

Mr. Willet. Mr. A. W. Willet stated that the following method had been employed to set out improvements in the alignment of portions of the Lancaster and Carlisle section of the London and North-Western Railway. At these places the existing curves were in reverse directions, with pieces of straight or flattened curves near the reversing-point. The improvements had been effected by deviations of considerable lateral extent with long transition-curves between the circular curves, and they had involved the widening of cuttings and embankments, the alteration of bridges, etc. A survey was made wherever such an improvement was intended, and

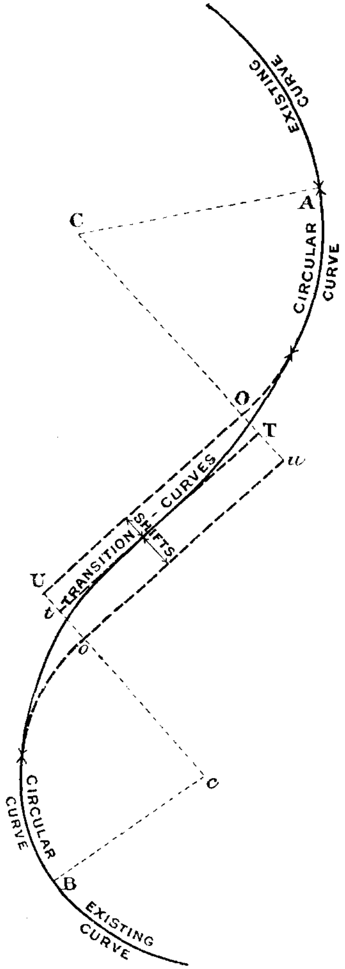
Fig. 15.



Mr. Willet.

plotted to a scale of 20 feet to an inch. The proposed deviation was drawn on this plan. The length of transition-curves was determined by adopting a flat gradient for running out the cant of the circular curves. The shifts and transition-curves employed were those of Mr. W. Froude, as described by Professor Rankine.[1] The two terminal points of the proposed deviation were marked on the ground by pegs in the centre of the 6-foot way. If a direct sight of each peg could be obtained from the other, the straight line joining them was carefully measured and the angles which this line made with the tangents to the existing curves at the terminal points were measured with a theodolite. These angles and the straight line were marked A B J, B A K, and A B in *Fig. 15*. If the terminal points A and B were not visible from each other, a third point, visible from both, was chosen and the angles and lengths were measured to it. From these the angles A B J, B A K, and the length A B were calculated. These measurements enabled the lengths A D, B D, and the angle A D B to be calculated. To A D add the radius A C of one of the proposed deviation circular curves, and from B D subtract the radius B c of the other. Thence the length C c between the centres of the circles was calculated. If this length exceeded the sum of the proposed radii and shifts, the length of the straight T t between the

Fig. 16.



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[1] "A Manual of Civil Engineering," p. 651 (22nd ed.). London, 1904.

Mr. Willet. proposed circular curves was calculated, after the shift had been added to each radius. If the length T *t* exceeded the sum of half the lengths of the two transition curves, the angles D C *c*, C *c* B, and T C *c* were calculated, and T C *c* was subtracted from D C *c* and C *c* B. The lengths of the circular curves A O, B *o* were then calculated. If they exceeded or equalled the half-lengths of the respective transition-curves they were probably adopted, and the number and dimensions of the offsets to the transition-curves were calculated from Mr. Froude's formula. If any of the calculated lengths were too small, other radii and shifts and possibly altered lengths of transition-curves were tried. The setting out was commenced at one of the terminal points A (*Fig. 16*), and a circular curve was pegged out with the theodolite as far as O. At that point a tangent-line was set out and a peg was put in on it at U, making O U = T *t*. Similarly the other circular curve was set out from B to *o* and the tangent *ou* was set out. It should be parallel to O U and the distances O*u*, *o*U should be equal to the sum of the two shifts. If this were not so, the tangent-points O and *o* had to be moved on the circular curves till the tangents were parallel. The points where the offsets to the transition-curves occurred were then set out and the offsets were measured and the pegs put in on the transition-curve.

Mr. De Rudder. Mr. E. **De Rudder** forwarded a note by Mr. Flamache, Engineer-in-Chief of the Belgian State Railways, entitled "Application du raccord parabolique aux alignements intercalaires trop courts." On the Belgian State Railways the changes necessary for the improvement of three junctions, namely at Schellebelle, Ledeberg, and Le Strop, all of them situated on the line between Brussels and Ostend and traversed by trains running at high speeds, had been investigated. He also forwarded diagrams showing the proposed improvements at these places, which had not yet been carried out as they necessitated the expropriation of additional land. The scheme for the improvement at Schellebelle was based upon the principles applied in the case of the junction at Hautmont on the Northern Railway of France.

Mr. Siegler. Mr. E. **Siegler** called attention to a memoir, "Nouvelle méthode de raccordement des courbes," published[1] recently by one of the engineers of the Eastern Railway of France, Mr. E. Hallade. The employment of the method in question had enabled the main lines of the Eastern Railway to be considerably improved at certain points where the running of trains over curves was not

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[1] *Revue générale des Chemins de fer*, vol. xxxi (1908), pt. 1, p. 261.

Mr. Siegler. satisfactory. Experience on that railway had shown that in course of time the alignment of curves became altered as the result of maintenance operations; and care was now taken to establish fixed points for the purpose of adjusting precisely the alignment of transition-curves.

Mr. Spiller. Mr. SPILLER, in reply, observed that he had read Mr. Appleyard's contribution with considerable interest, but he did not think the load-variations on the wheels of a bogie-truck when rounding a curve could be determined in quite the simple manner suggested. It was obvious to anyone who had watched the movements of an engine-bogie travelling at high speed that considerable variations in wheel-loads were constantly occurring, and while centrifugal force undoubtedly increased the load on the outer wheels, superelevation acted in the reverse way. Different equations were required for each type of bogie, and it was far from clear, having regard to the contrary effect of cant, that the loading on the outer wheels was materially increased by centrifugal force in some types. It was unquestionably an important point in connection with the subject, and probably the only satisfactory method of solution was by experiment. The check-rail at Salisbury would take up the lateral pressure of the leading axle otherwise borne by the outer rail, and it was obviously a more difficult matter for the inner wheel to climb the check-rail (where $\theta = 90°$) than for the outer wheel to climb the outer rail. A reference to the report on the Salisbury accident would show that the value of w for the engine derailed was 4·2 tons and not 3·55 tons as given by Mr. Appleyard, making the derailment-speed 46 miles per hour.

Both Mr. Fitzgerald and Mr. Read referred to an alleged divergence of opinion between the Authors of the two Papers in regard to the propriety of beginning the gradient of superelevation on the tangent preceding the curve, but the Authors' views in this respect should be considered in conjunction with the context of the paragraphs in which they were expressed. If this were done it would be seen that the practice of running the cant up on the straight was condemned as an alternative to the transition-curve. Assuming the impracticability of transitioning, it was undoubtedly desirable to attain a portion of the cant, if not the whole, on the tangent preceding the curve. Mr. Spiller could not understand how his Paper confirmed the opinion which Mr. Eustice had formed that the leading outer wheel of the locomotive took most of the thrust on the rails due to centrifugal force. If Mr. Eustice would refer to p. 82 he would see that one quarter only of the centrifugal force was considered as acting at the leading

Mr. Spiller. outer wheel. The Board-of-Trade report on the Salisbury accident gave 60 inches as the height of the centre of gravity of the locomotive, not 63 inches as assumed by Mr. Eustice. Mr. Mallock suggested that the "contact between wheel and rail was not a point but a line." In reality—especially with worn tires and rails—the contact was a surface, and it was the grinding on this surface which made it possible for a wheel to climb the rail.

In making the suggestion that "as F_1 increased F_2 somewhat decreased, owing to centrifugal force at the trailing axle acting in a contrary sense to the adhesional resistance to sliding," Mr. Morris had apparently overlooked the fact that there was longitudinal as well as lateral slipping at the rear axle. The value assumed for θ, namely 65°, was determined from actual measurement of worn rails. Superelevation certainly increased the value of θ, but formula (27) was put forward as a simple rule for fixing speed-restrictions irrespective of cant. As to the opinion, expressed by both Mr. Morris and Mr. Sweetman, that superelevation materially reduced the value of F_1, the question of cant could not be properly dealt with in quite the simple manner generally supposed; it was, in fact, as Mr. Jacomb-Hood had stated, one of the most difficult mechanical problems which railway-engineers had to face. The matter was complicated by the coning of the wheel-tread and the corresponding inclination given to the rail, and by the fact that the greater portion of the weight on the wheels was spring-borne; it was certainly not correct to assume, as was generally done, that the reaction of rails on flanged and coned wheels was exactly similar to that of a plane surface on a cylindrical body. Whatever the direction of the resultant reaction, its vertical and horizontal components must be equal to the weight of the vehicle and the centrifugal force respectively. The horizontal component of the reaction had been considered in discussing the question of climbing, the vertical component did not affect the question. Mr. Spiller quite appreciated the value of movable elbow-points referred to by Mr. Treacher, but these entailed a large increase in the cost of locking. If the friction of bogie centre-plates and side-bearings was so great as Mr. Warner supposed, the virtue of the bogie as a guiding truck would seem to disappear: Mr. Spiller believed, moreover, that some form of swing links was preferred to side bearings by most locomotive-engineers. Mr. Warner suggested that additional formulas should be given to include the friction of bogie-plates, but he would find the information he required in the *Engineering Review* of January, 1909.

With regard to Mr. Wells's remarks, the formulas in the Paper were based on the assumption that the curvature was so great that inter-

Mr. Spiller, mediate axles were not in flange-contact with the outer rail. When this occurred a reduction of lateral pressure between guiding wheel and rail resulted in a corresponding increase in the permissible speed. It was, however, difficult to say just where this occurred. He would refer Mr. Wells to his reply to the discussion in respect to the suggestion that it was possible to prevent flange-contact of outer wheels by superelevation. The statement that the outer rail was cut away most where the cant was greatest was based on actual observations of the wear of rails on curves, particularly in the case of reverse curves with no intermediate straight. Mr. Spiller quite appreciated the danger of curved elbows where the radius was small, but did not apprehend any difficulty with curves of 30 chains radius and over.

Mr. Shortt Mr. SHORTT, in reply, agreed with Mr. Fitzgerald that while a carriage was entering a curve it was subject to a practically constant angular acceleration about a vertical axis. But as the carriage was rotating about a point midway between the two bogie-pins when completely on the curve, it could not be rotating about the rear bogie-pin during the whole period of entrance as suggested. Allowing for this, it was difficult to see how the amount of the flange-forces due to the above cause could be more than about one-eighth of the ordinary centrifugal force. An increase of the cant at the entrance to a curve could hardly be expected to produce the required angular acceleration. It seemed little use pointing out causes that might possibly affect the pressure of the wheel-flanges against the rails, when the resulting forces were all of the second order of magnitude, as was certainly the case under ordinary circumstances with all the six causes mentioned by Mr. Fitzgerald and the inertia-effects due to acceleration or retardation mentioned by Mr. Eustice.

Mr. Shortt had looked up the Paper by Mr. Froude which Mr. Mallock had mentioned, but had failed to find any mention of the spiral $\lambda = m\sqrt{\phi}$. With regard to the omission from his Paper of any consideration of the ratio between the natural periods of vibration of the carriage on its springs and the time taken to pass from one curve to another, the time taken to pass over a transition-curve of length equal to $\sqrt{R}$ by a train travelling at the normal maximum speed of $11\sqrt{R}$ miles per hour was just over 4 seconds; hence there could be no danger of oscillations being set up unless one of the natural periods of vibration of the carriage was 8 seconds, and, as far as he was aware, the slowest mode of vibration of a carriage had a period of about 1 second.

If, instead of stating that the recognized formula for super-

Mr. Shortt. elevation was unnecessary and inapplicable, Mr. Morris had proposed, where there was a great range in the speed of the traffic over any particular curve, to adopt a cant about 3 inches less than that indicated as suitable by the theoretical formula for the fastest trains over the curve, Mr. Shortt could have agreed with him. Such a rule was in line with the fact that the ordinary passenger did not notice variations in cant amounting to 3 inches above or below that theoretically required, as evidenced by junctions and crossovers being run through daily without discomfort at speeds of $7 \sqrt{R}$ miles per hour, and by no one complaining of 3 inches of cant when a train was standing at a station. In connection with the method of derailment, Mr. Shortt's experiments described in his reply to the discussion had shown that it was possible for climbing to take place without overturning, and vice versa, at practically the same speeds. It was necessary for an engine to heel over nearly 20° before the flanges of the outer wheels would be released from the outer rail, and recovery was hardly to be expected once it had got as far as that; also, owing to its inertia, it was possible for the engine to travel a considerable distance during the process of overturning.

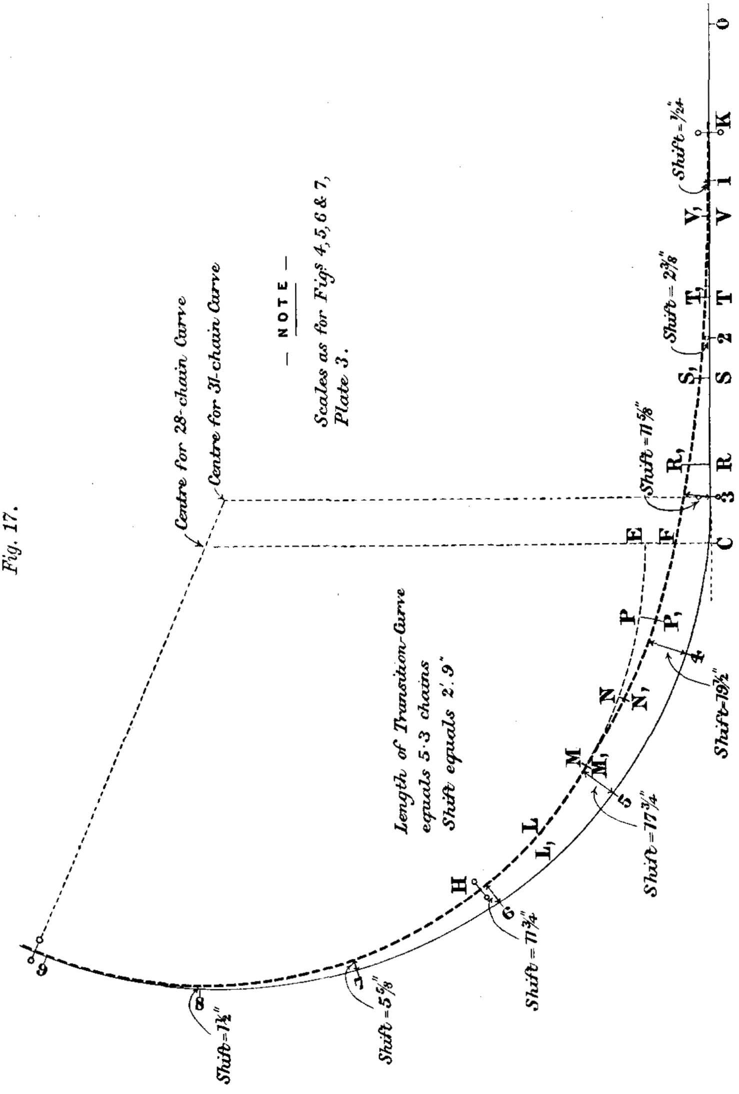
With regard to Mr. Shand's remarks, the sluing of the tracks to a spiral form at the entrance to a curve certainly involved expense, but Mr. Shortt's method enabled the maximum of advantage to be obtained with the minimum of expense. The ordinary circular curve got out of line just as badly as the eased curve. For first-class alignment reference-pegs were certainly required with the ordinary curve, and, if such pegs were used, there could be no more difficulty in keeping a spiralled curve to line than any other. Of course, when making important changes of line it was simpler to omit transition-curves, but it seemed a backward movement and the last thing to be expected of American practice.

Mr. Stewart's indirect statement that the principle of the Author's method of curve-improvement did not hold good with sufficient accuracy for practical purposes was not true, although the examples he cited might appear to warrant such a conclusion. The first two cases of failure mentioned were admitted by Mr. Stewart to be hardly practicable ones, and they were outside the limits laid down by the Author in the remarks made before the discussion on the Papers commenced. The third example, however, was just within these limits, and therefore required investigation. In the first place, the desired object was the insertion of the transition without sharpening the curve more than 3 chains, and provided the chord survey of the improved alignment proved satisfactory, the exact position of the tangent-points was immaterial. Assuming the 31-chain curve to have been

Mr. Shortt.

surveyed with a 2-chain chord, commencing on the straight (3 chains short of the tangent-point) at point No. 0 so that the tangent-point was point No. 3, the offsets obtained would have been:—Offset at points Nos. 0, 1, $2 =$ zero, at No. $3 = 6\frac{3}{8}$ inches, at Nos. 4, 5, 6, 7, 8, 9, $10 = 12\frac{3}{4}$ inches. These results had

Fig. 17.


— NOTE —
Scales as for Figs 4, 5, 6 & 7, Plate 3.

Mr. Shortt. been plotted to scales of 1, 10, and 100 feet to the inch (reproduced to a small scale in *Fig. 17*), the transition inserted in the manner required by Mr. Stewart and explained in the Paper, and the shifts at the various points scaled off. From these figures and the original offsets it was possible to determine the exact result of the sluing thus indicated; for instance, the original offset at point No. 5 was $12\frac{3}{4}$ inches, and points Nos. 4 and 6 were to be shifted inwards $19\frac{1}{2}$ inches and $11\frac{3}{4}$ inches respectively, while point No. 5 was to be shifted inwards $17\frac{3}{4}$ inches, so that the new offset at point No. 5 clearly equalled $12\frac{3}{4} + \frac{19\frac{1}{2} + 11\frac{3}{4}}{2} - 17\frac{3}{4}$, or $10\frac{5}{8}$ inches. The new offsets at the other points were obtained in a similar manner and were set out together with the original offsets and the shifts in the following Table:—

Number of Point.		Original Offset.	Shift.		Resulting New Offset.	Differences between Adjacent Offsets.
00	Straight.	0	0	St.	0	
0		0	0		0	0
1		0	(say) 0	Transition.	$1\frac{3}{16}$	$+ 1\frac{3}{16}$
2		0	$2\frac{3}{8}$		$3\frac{7}{16}$	$+ 2\frac{1}{4}$
3		$6\frac{3}{8}$	$11\frac{5}{8}$		$5\frac{11}{16}$	$+ 2\frac{1}{4}$
4	31-chain curve.	$12\frac{3}{4}$	$19\frac{1}{2}$		$7\frac{15}{16}$	$+ 2\frac{1}{4}$
5		$12\frac{3}{4}$	$17\frac{3}{4}$		$10\frac{5}{8}$	$+ 2\frac{11}{16}$
6		$12\frac{3}{4}$	$11\frac{3}{4}$	28-chains.	$12\frac{11}{16}$	$+ 2\frac{1}{16}$
7		$12\frac{3}{4}$	$5\frac{5}{8}$		$13\frac{3}{4}$	$+ 1\frac{1}{16}$
8		$12\frac{3}{4}$	$1\frac{1}{2}$		$14\frac{1}{16}$	$+ \frac{5}{16}$
9		$12\frac{3}{4}$	0	31-chains.	$13\frac{1}{2}$	$- \frac{9}{16}$
10		$12\frac{3}{4}$	0		$12\frac{3}{4}$	$- \frac{3}{4}$
11		$12\frac{3}{4}$	0		$12\frac{3}{4}$	0

This Table showed a satisfactorily uniform increase of offset throughout the transition, and the biggest offset occurred in the nominally 28-chain curve, but was slightly less than that corresponding to 28 chains. It was therefore submitted that an excellent improvement would have been obtained in spite of the

Mr. Shortt.

fact that the tangent-points were not where Mr. Stewart would have put them. Fully one hundred curves had been improved by this method on the London and South Western Railway, and while in certain cases the distortion had had to be reduced in order to prevent confusion through the curves curling on themselves when plotted, no case of failure had arisen.

Regarding Mr. Sweetman's experience with cant on the Stewartstown Railway, in the absence of any statement that special tests of the speed had been made, Mr. Shortt would observe that low speeds were very difficult to estimate by eye: if the speeds mentioned by Mr. Sweetman had been determined in that manner, the true speeds might easily have been twice as great as those given. The beneficial effect of increased cant in stopping a persistent outward sluing of the curve could be readily understood, but the reduction of the grinding of the flanges against the high rail was another matter; and in this connection he would cite a case which had come to his knowledge recently, where there was excessive cutting of the high rail by bogie rolling-stock with a low centre of gravity, and the engineer in charge was told by his superior officials that he had only to throw up his outer rail more and the cutting would be reduced. He did so, and the cutting was increased. It was only by reducing the cant to less than its original value that he was eventually able to reduce the cutting of the high rail.

He could not agree with Mr. Treacher's suggestion that there was no equivalent radius to a switch, as he maintained that if a circular curve or a set of switches was entered directly off the straight, the sudden application of the centripetal force in the one case or the divergence of the wheels from the straight in the other, set up similar swings in the spring-borne load (which with ordinary stock was about 85 per cent. of the total load). Therefore, for each different set of switches there was a corresponding curve such that the swings set up in any particular vehicle at any particular speed were of equal amplitude, whether it entered the switches or the curve. In Mr. Shortt's experience the curve that was tangential to the stock rail and to the switch-tongue at the heel of the planing was of such radius as to fulfil the foregoing conditions satisfactorily.

The method of curve-improvement described by Mr. Willet was of interest as illustrating the alternative to the Author's method. From the description given it appeared that in addition to making an accurate survey and plotting it to a scale of 20 feet to the inch a good deal of work had to be done before it was certain that a proposed improvement could be carried out; and should any of the

Mr. Shortt. calculated lengths come out too small, practically a fresh start had to be made. Again, each separate scheme appeared to require separate measurements on the ground, so that much work was necessary if it were desired to determine the effective improvement which would be the least expensive to carry out.

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19 January, 1909.

JAMES CHARLES INGLIS, President,
in the Chair.

The President. The PRESIDENT regretted to have to announce the death of an old comrade in The Institution, Dr. Francis Elgar. He was sure every member deplored the sudden loss of one who took a very active part in the deliberations of the Council and great interest in the affairs of The Institution. Dr. Elgar was a man not only fully equipped with theoretical knowledge but also having special talent for practical work, and his scientific attainments made him a powerful member of The Institution. The Council felt his loss exceedingly, as he was working most effectually, especially with regard to educational questions. The Council had that evening passed the following resolution, which he was sure the members would all heartily endorse: "The Council have learned with very deep regret the death of their esteemed colleague, Dr. Francis Elgar, F.R.S., and desire to convey to Mrs. Elgar an expression of warmest sympathy in her bereavement."

The discussion on the Papers by Messrs. J. W. Spiller and W. H. Shortt on "High Speed on Railway-Curves" and "A Practical Method for the Improvement of Existing Railway-Curves," respectively, occupied the evening.

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26 January, 1909.

JAMES CHARLES INGLIS, President,
in the Chair.

The discussion on the Papers by Messrs. Spiller and Shortt on Railway-Curves was continued and concluded.