just referred could be looked upon as having a yielding bed, whereas the chalk formed a more substantial bed; and yet the creep was greater in the middle third than in the other two sections. With regard to changes of temperature, no doubt they had a very great effect on creep, but not so much, perhaps, as some people imagined. He had under his charge several long tunnels ranging in length from $3\frac{3}{4}$ miles to 2 miles, and he found that although the temperature was more uniform in those tunnels the creep was about the same; in fact there was more creep at the centre of the long tunnels than at the ends. That he put down to the roads not being quite so efficiently maintained, as it was more difficult to carry out the maintenance there owing to the foulness of the atmosphere. With reference to creep not being so marked a few years ago as it was at the present time, a good deal of that had to do with the solidity of the ballast. In years gone by, engineers used gravel ballast, which, when spent, set not unlike concrete. It was not a good thing for the road or for the drainage, but it did hold the sleepers in position better than the stone ballast used to-day, which of course was rightly used, because it gave very much better drainage. Creep, he thought, was due entirely to heavy loads and the high speed of the traffic. Mr. Miles.

⁂ Mr. Reeves's reply will be found at p. 307.—SEC. INST. C.E.

Correspondence.

Mr. Ball. Mr. J. B. BALL remarked that while Mr. Reeves's experiments were interesting, he thought no great reliance should be placed upon the deductions, because of the great difference in the conditions obtaining between actual practice and the experimental conditions. He supposed that in the experiments the temperature at all times was approximately constant and that the only preventive of the tendency to creep would be the friction between the various parts. Then—and this appears to him to be one of the chief factors in the problem—there came the fact that all these experiments had been made on a straight lath without joints. If his assumptions were correct, these facts, coupled with the starting and stopping of the wheel at what must be relatively low speeds, were not in any way comparable with the conditions which obtained in usual railway practice. With Mr. Reeves' conclusions and observations gathered from actual experience he was in accord, except in regard to remedies, and while anti-creep appliances might be desirable and necessary

Mr. Ball. with flat-bottomed rails in countries subject to extreme variations of temperature, such as did not occur in the British Isles, they did not appear to be a desirable remedy to apply to permanent way laid with chairs, as ordinarily in use at home. Mr. Miles's Paper had therefore, in his opinion, a closer bearing on the problems with which the English railway engineer was more or less troubled.

The three principal causes of rail-creep, as it affected permanent way in the British Isles, were defined in paragraphs 4, 5, and 6, on p. 244. Assuming that the rails were, say, 45 feet in length, with joints about $\frac{3}{8}$ inch apart when laid at a temperature of 60° to 70°, usual practice gave about 44 inches for expansion in 1 mile of road. Taking the usual coefficient of lineal expansion for rail-steel and allowing for a maximum range of temperature of 100° F., this meant a difference of 41 inches in 1 mile of rails between the lowest and the highest temperature; but here again the actual physical conditions were not at all uniform, the difference in temperature on a hot summer day being very marked between a shaded cutting and an exposed bank. One of the principal factors in creep appeared to be the degree of care taken with the fish-bolts and plates dan the efficiency of the packing of joint sleepers. It would be generally acknowledged that creep took place principally in the direction of traffic, and he thought the causes were clear. After a few years' wear with the heavy traffic, high speeds, and heavy engine axle-loads, and with the present universal method placing the rail-joints opposite each other, and owing to imperfect platelaying, due to perhaps not an ideal road-bed, to carelessness on the part of the platelayers, and to the joint sleepers not being properly packed, wear took place in the fish-plates and the slackening of fish-bolts during the summer months to allow expansion to take place, and neglect to tighten them when required, all tended to render the joints the weak spot in the track. The results were distinctly noticeable in many cases by the audible "knock," or thrust, which might be observed in travelling over the railways in various parts of the country, and creep was in his judgment due principally to these two causes, namely, defective joints and the somewhat crude methods adopted to provide for expansion and contraction. The facing or "running on" end of a rail received a distinct blow, which tended to drive it forward and was emphasized in many cases by flat tires, imperfectly balanced locomotives, high speeds, and, when running on a down gradient, by the effect of heavy braking; and until more efficient methods of dealing with joints and expansion-effects could be devised, creep would continue to trouble engineers. The reasons why very striking cases of creep did not occur in the

British Isles were probably the lower range of temperature and the fact that with well-designed chairs a better hold was obtained on the rail than was the case with flat-bottomed rails fixed by dogs or fang bolts and having no chairs to support them. An ideal joint would appear to be one totally independent of bolts, with fish-plates carried through to the jaws of the chairs on either side of the joint, and keyed with suitable steel keys, so that the rails were free at either end for expansion and did not depend upon the somewhat careless manipulation of the platelayer. If such a joint were satisfactorily designed, the major portion of the trouble in this country would probably be cured. He suggested that, given a suitable joint, free to expand, and not needing the constant attention of the platelayers, a track laid with, say, 45-foot rails, with twenty sleepers per length on straight road and twenty-two sleepers on curves, keyed with suitable steel keys like the Stuart key or with some other equally efficient and alternate keys of teak driven in the direction of the traffic, and with the sleepers well ballasted and packed on a good drained road-bed, the trouble in this country would be largely eliminated. It might be added that in 1912 some interesting facts were collated on the question of creep from about a dozen different English railways, the records extending over twelve months, and these were reported by Mr. Treacher, an Associate Member of this Institution, in a Paper read by him to the members of the Incorporated Permanent Way Institution. From those records was deduced the fact that in almost every case the movement was in the direction of the traffic, and that such movement took place in the spring and summer months the fact is rather emphasized that creep is principally due to expansion troubles, assisted by imperfect joints and loose keys in the chairs due to the shrinkage brought about by the hot weather. Mr. Ball.

Mr. W. G. Coughlin stated that the experience of the Pennsylvania Railroad with the creeping of rails had been very similar to Mr. Reeves's, and he fully agreed (1) That the practice of spiking through notches on the fish-plates should be avoided, as the joint sleepers had enough to do without fulfilling the additional function of anchorage against creep; (2) That frictional rail-anchors were adequate and preferable to the positive type, on account of the greater expense of applying the latter; (3) That the ordinary spike offered practically no resistance to rail-creep and the screw-spike was little (if any) better. Mr. Coughlin.

Mr. Wm. Dawson remarked that his experience on the London and North Western Railway enabled him to corroborate generally the remarks made by Mr. Miles, except that he had not found any sign of rails "crippling" under the effect of creep. Only in the Mr. Dawson.

Mr. Dawson. following seven instances had he found rails to creep in the opposite direction to the traffic in track-mileage of more than 4,000 miles:—

(*a*) The inner rail on a 10-chain curve near Leeds (the outer rail crept in the same direction as the traffic).
(*b*) Both rails crept $\frac{1}{4}$ inch to 1 inch on a 2-mile length in Anglesey.
(*c*) Over a mining subsidence in Yorkshire.
(*d*) The outer rail on a check-railed curve and a rising gradient of 1 in 40.
(*e* and *f*) Both rails of one line on 10- and 12-chain curves and rising gradients of 1 in 37.
(*g*) On a reverse curve of 15 chains radius in South Wales, gradient rising 1 in 40 in the direction of the "down" traffic, to a point about 250 yards beyond the change of curvature, and thence rising 1 in 38. On the down line the outer rails on the rising gradient crept downhill near the change of curvature, whilst the inner rails crept uphill. At a point on the down line, about 600 yards before the change of curvature, the reverse was the case. On the up line the creep was in the direction of the traffic throughout.

Mr. Miles's statement that during 5 years of observation it had been found necessary to adjust or pull back approximately 10 per cent. of the rails annually or about 85 miles of road, was a considerably larger percentage than had been found on the London and North Western Railway during a period of observation of 15 years. At the beginning of this period about 100 miles per annum was adjusted, or 2·7 per cent. of the total mileage of the line. In 1917, 172 miles or 4 per cent. of the mileage was adjusted at a cost of £903, or £5 11*s*. 6*d*. per mile. This was not altogether actual cost to the Railway Company, as the work for the most part was done by the platelayers during working hours without interference to any extent with their ordinary duties. Not much work was done on Sundays. The maximum creep that had taken place amounted to 5 inches in a period of 4 months on both roads of a fast line at a station, on a length of 350 yards. In each case the creep was in the direction of the traffic. It was not found that creeping took place to any extent on single lines. Out of an aggregate length of 425 miles only two instances were recorded, within a mile of each other, where on a flat, straight piece of road, the rails crept 3 inches in a year in a length of 264 yards. Creep occurred mostly in hot weather and on newly relaid roads.

About 14 years ago the Company tried some rails rolled with corrugated webs, the jaws of the chairs being cast with corrugations to fit. These stopped creeping to a large extent, but it was not considered that the additional expense of rolling these rails compensated for the inconvenience which ordinary creep entailed. They had also tried anchor devices of an American type, but the result had not been satisfactory. If creeping was as serious as some of the devices implied, it appeared to Mr. Dawson that it might be stopped by drilling holes in the web of the rail, say, every 10 feet, and inserting a bolt to rest against the jaw of the chair. Lubricating the fish-plates had been the practice on the London and North Western Railway for some years past, not only to assist the rails in sliding along the plate but incidentally to lengthen the life of the bolts by preventing corrosion. This had had a marked effect. Mr. Dawson.

Mr. Reeves's Paper referred more particularly to the Vignoles or flat-bottomed section rail of comparatively light weight where creeping was evidently much more pronounced and difficult to deal with than on 85-lb. or 95-lb. bull-headed rails. If it were not so, he would scarcely advise the drawing-office to take special precautions against it when designing bridges, turntables, points, and crossings, etc. Mr. Dawson found no such inconvenience in practice.

Mr. Miles's experience, that where chaired roads were used and well maintained, the gradients moderate, and the curves of fairly large radii, the effect of high speeds and heavier axle-loads had little influence on the amount of creep, was not quite borne out by the information Mr. Dawson had given which showed that the amount of creep on the London and North Western Railway had increased from 2·7 per cent. to 4 per cent. within the last 15 years, although it was still only about one-third of what Mr. Miles experienced.

Mr. R. W. Egerton observed that the investigation of the phenomenon of creep as a problem of applied mechanics was one of great complexity, for the rail had to be considered as a continuous beam with a large number of supports none of which was rigid. The behaviour, however, of girder spans under moving loads had been dealt with,[1] and it had been shown that when those girders were not fixed down to their bearings at either end of the span they were liable to creep. In the case of girders supported on the bottom chord, such as an ordinary parallel-sided plate girder, the creep was in the direction of the traffic. When supported on the top chord, such as an inverted bowstring girder, the creep was in the opposite Mr. Egerton.

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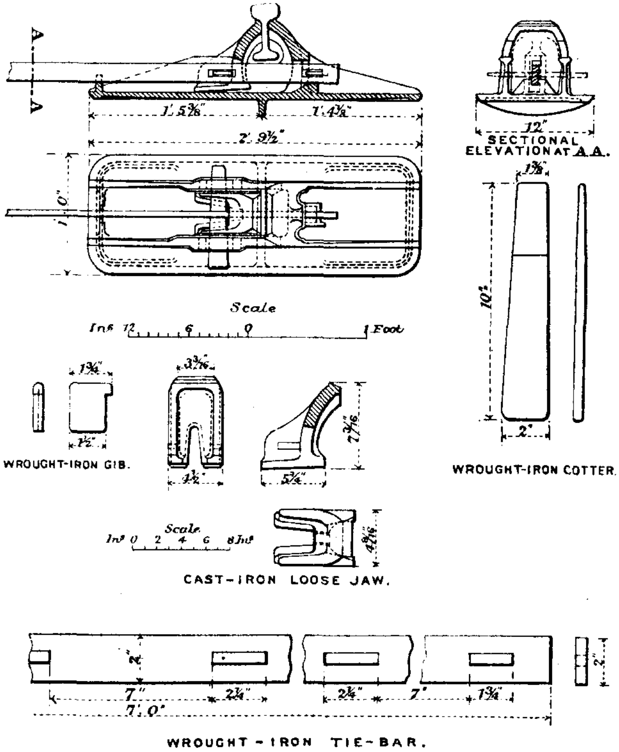
[1] J. B. Johnson, "The Creeping of Rails on the St. Louis Bridge." Journal of the Association of Engineering Societies, 1884, vol. 4, p. 1.

Mr. Egerton. direction to the traffic; while in the case of the double bowstring girder when the points of support corresponded with the neutral axis of the girder, no creep took place. The explanation of the creep in the first two cases was simple. Taking the first example, the bottom chord of the girder was in a condition of tensile stress during the passage of the moving load, and there was in consequence a proportionate elongation of that chord. Assuming the series of concentrated moving loads passed over the span from left to right the bottom chord was pinned down on the left abutment by the pressure of the moving loads and the whole of the elongation was imparted to the right hand or free end of the girder and pinned there as the leading load arrived at that end of the span, and after the passage of the whole train the chord resumed its original shape and the girder had crept forward by some minute distance. Taking the second illustration, the top chord being in a state of compressive stress, a contraction of that chord occurred and the chord was shortened. The creep was thus in the opposite direction to that of the traffic. The case of the rail was, it was admitted, by no means analogous, nevertheless it was submitted that the same reasoning might be applied to the behaviour of the rail under traffic. The bottom flange of the rail was undoubtedly under tensile stress during the passage of the train, and this tensile stress was greatest when the rail was of light section and when the sleepers were few and badly packed. The corresponding elongation of the rail was imparted to the free or unloaded end of the rail as the train advanced. The fact that creep invariably occurred in the direction of the traffic was thus accounted for. If this reasoning were admitted, it would follow that if a rail were supported at its neutral fibre, creep would at any rate be reduced, and this reduction would be greatest when the sleepers were closely spaced and well packed.

Curiously enough, when in charge of a section of the Indian frontier railways, he had had experience of a rail which approximately corresponded to this description. It was a double-headed 75-lb. steel rail laid on Denham-Olpherts sleepers. This sleeper (*Figs. 1*) (designed by two engineers on the East Indian railway), consisted of two cast-iron plates connected by a wrought-iron or steel tie-bar. The outer jaw of the chair on each plate was cast in one piece with the plate. The inner jaws were separate castings and were held in place on the inside of the rail by a jib and cotter fastening driven through a slotted hole in the tie-bar and through two feathers or lug on each of the plates. The web of the rail was thus gripped between the two jaws and the rail was suspended by the top bulb. The lower bulb of the rail was clear of the sleeper.

Mr. Egerton. The idea underlying this design was the avoidance of chair galls on the rail, and the possibility of reversing the rail when one surface was worn. He had been in charge of a good many miles of single line of this type of road and had never detected any creep. The traffic, however, was not frequent, although the engines were very heavy, and the loads all in one direction. This was on the frontier section of the North Western Railway of India.

Figs. 1.



Mr. Miles's statement, referring to a bull-head rail and cast-iron chair road, that "it was seldom that rails on opposite sides of the road crept to the same extent," presumably applied to a road laid with wooden keys driven on the outside of the rail and in opposite directions. If this assumption were correct the reason for this unequal movement was not far to seek. The creep being in the direction of the traffic, the movement tended to loosen the keys in

Mr. Egerton. the one rail and to tighten them in the other. The creep was in consequence greater in the former than in the latter.

Taking the same class of permanent way on a single line of railway, the trains in one direction would produce creep in that direction in the rail whose keys were being loosened, and the trains in the opposite direction would produce a similar creep in the other rail. In consequence the joints would get more and more out of square. When in charge of a section of the North Western Railway of India at Saharanpur he had considerable trouble with a road of this description many years ago. On the Agra-Delhi chord railway the chairs were of two patterns, and tapered to take keys in opposite directions. These chairs were laid alternately so that the creep in either direction might be checked by the tightening of half the keys. The line was a single one.

From Mr. Reeves's Paper it would appear that his experience was more or less confined to flat-bottomed rails. With rails of this description the only resistance to creep was that due to the friction between the rail and sleeper. In consequence, anchorages, or spiking through notches in the fish-plates had to be resorted to. In Mr. Egerton's experience the only satisfactory sleeper to use with flat-bottomed rails which would prevent creep was the hollow steel sleeper illustrated in *Figs. 4* of Mr. Reeves's Paper. This type of sleeper had been largely used on Indian state railways, especially on the frontier. It was, however, very liable to corrosion in salt soils and near the sea, and had fallen into disuse. He had had a very extended experience with this class of sleeper, both on double and single lines, and with good ballast and a full complement of sleepers to each pair of rails creep was practically a negligible quantity. This absence of creep might be ascribed to the rigid attachment between rail and sleeper.

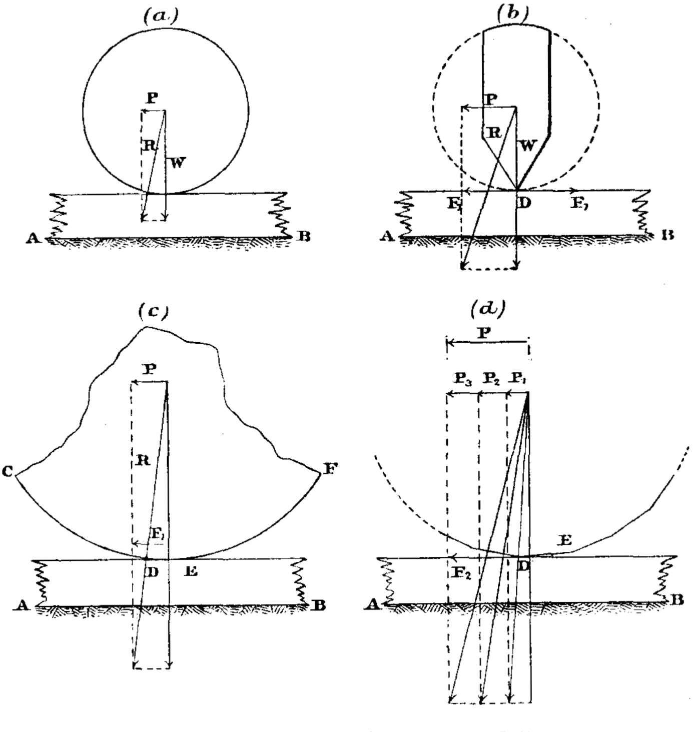
Mr. Elder. Mr. Arthur W. Elder submitted the following investigation as confirmatory of the theory, advanced in both Papers, that when creep was observed along stretches where brake action might be considered to be negligible, it was due, apart from erratic effects caused by temperature changes, to the deformation of the rail or "wave action"; for the investigation showed that, if the rail was assumed to lie on a continuous unyielding support in which wave-action did not take place, the forward push on the rail, even if the counteracting backward thrust of the locomotive were neglected, was a comparatively small amount (about 800 tons per rail with acceleration in the speed of the train) which would be insufficient to move forward a rail which was held down to the sleepers. In *Figs. 2* (*a*) if P was quite small compared with W no movement of

Mr. Elder.

the wheel would take place on account of the existence of a surface of contact between the wheel and its support, but however small P might be, there would always be some such resultant as R acting on the wheel. A weight balanced on a knife edge was shown in *Figs. 2* (*b*). The smallest conceivable force P would cause a resultant R which fell outside the point of support D, with consequent movement of the weight.

Without in any way altering the conditions there might be introduced two equal and opposite forces F_1 and F_1 at D, each equal to P, then PDF_1 was the couple tending to rotate the weight and $DF_1 = P$ was a force acting on the support in the direction of P. In *Figs. 2* (*a*) a resultant R was introduced by means of a force P too small to cause movement. Until movement took place the resultant R must pass through the surface of contact between the wheel and its support (DE, in *Figs. 2* (*c*)). Now as there was no movement between ABDE and CDEF, *Figs. 2* (*c*), they might be

Figs. 2.



Mr. Elder. considered as consisting of one piece with, as it were, a weak "shearing surface" at DE supplied by the frictional contact. If this "shearing value" was less than P, CDEF would slide or roll on ADEB provided the latter were held in place. On the other hand, if this "shearing value" was equal to or greater than P and the surface AB was frictionless the wheel and its support would move forward as one body.

If P were increased so that R passed through D, the wheel was on the point of motion, and if P was applied at the centre of the wheel the value of the force $F_1 = P$ tending to make the support creep was given by the formula

$$F_1 = \frac{Wd}{D}$$

Where W = Load on wheel;
D = Diameter of wheel;
d = Length of DE (the contact surface).

Let P be again increased so that R fell outside D (*Figs. 2* (*d*)). P might be considered to consist of three forces P_1, P_2, and P_3, and the perimeter of the wheel to be made up of a large number of small flat surfaces as DE. Due to the part P_1 of P the wheel was continuously in the condiiton shown in *Figs. 2* (*c*), and P_1 was transferred to the support. P_2 and P_3 replaced the P of *Figs. 2* (*b*), and as in the discussion of *Figs. 2* (*b*) there was also a force $P_2 + P_3$ tending to make the support creep in the direction of P_2 and P_3. The force tending to cause creep in the support was then always equal to P (the total force applied to the wheel).

Of this force $P_1 = \frac{Wd}{D}$ might be taken as constant with a given wheel-load for all speeds, P_2 and P_3 represented respectively the force required to accelerate the wheel and the force required to overcome friction at the axle.

In any case, $F_2 = P_1 + P_2 + P_3$ could never exceed μW where μ was the coefficient of friction between the wheel and its support. Taking metal on metal and a value of μ of, say, 0·18, then F_2 max. = 0·18 W. Unless there was great friction at the axle F_2 would never approach the limit, for an immense acceleration would be required to get the wheel to slide if the axle-friction was small. When $F_2 = 0{\cdot}18$ W the case was analogous to that of a wheel sliding under brake action.

Applying the above reasoning to the practical case of wagons in motion it might be said that except in the case of violent braking F_2 would never approach the limit of 0·18 W, and a formula might be evolved to give a value for F_2 under general conditions. Say the F_2 to be expected on a single rail length. Mr. Elder.

$$F_2 = P_1 + P_2 + P_3.$$

$P_1 = \frac{Wd}{D}$ (for P applied at centre of wheel). P_1 must therefore be modified for P at the height of the couplings. This height in terms of D might be written 1·07 D, and P became $\frac{Wd}{2 \cdot 14\,D}$. If the train was running at a constant speed $P_2 = 0$, $P_3 = \frac{4}{\pi}\mu R$, where μ = coefficient of friction of the journal, and R was the resultant of W, and $(P_1 + P_2 + P_3)$. Assuming four wheels on a rail-length with axle-loads of 15 tons each, and d to be 0·04 inch—

$$P_1 = \frac{4 \times 7 \cdot 5 \times 0 \cdot 04}{2 \cdot 14 \times 37 \cdot 5} = 0 \cdot 015 \text{ ton},$$

a negligible quantity, whatever the actual true value of d might be, $P_3 = \frac{4}{\pi}\mu R$, where μ might be assumed to have a value of 0·002, and to be constant for all speeds. R also might be put = W

then $$P_3 = \frac{4}{\pi} \times 0 \cdot 002 \times 7 \cdot 5 \times 4 = 0 \cdot 076 \text{ ton}.$$

As the application of these forces to the rail might be considered to be instantaneous, the force tending to cause creep would be doubled, and the "creep force" for constant speed and 15-ton axle loads was—

$$2 \times (0 \cdot 076 + 0 \cdot 015) = 0 \cdot 18\text{-ton per rail}.$$

If the train accelerated from 0 to, say, 30 kilometres (18·6 miles) per hour in 5 minutes, $P_2 = \frac{Wa}{g}$,

$$\frac{30 \times 0 \cdot 091}{32 \cdot 2} = 0 \cdot 085 \text{ ton}.$$

Or total "creep force" per rail-length under above acceleration

$$= 2 \times (0 \cdot 076 + 0 \cdot 015 + 0 \cdot 085) = \underline{0 \cdot 352 \text{ ton}} \text{ (say 800 lbs.)}.$$

As W was 30 and $P_1 + P_2 + P_3 = 0 \cdot 176$ there was no error in writing W for R, and these results could be expressed in the general formula as follows:—

$$\text{“Creep force” due to one wheel} = 2 \times \left(\frac{Wd}{2 \cdot 14D} + \frac{Wa}{g} + \frac{4\mu W}{\pi}\right),$$

$$= 2W\left(\frac{d}{2 \cdot 14D} + \frac{a}{32 \cdot 2} + 0 \cdot 00255\right),$$

Mr. Elder. in which the almost negligible first term $\frac{\text{“}d\text{”}}{2 \cdot 14D}$ might be assumed to be constant and might be summed to the last term writing—

$$F = W\left(\frac{a}{16 \cdot 1} + 0 \cdot 006\right).$$

F = “Creep force” in tons due to one wheel
W = “Load on wheel” in tons
a = Acceleration in feet per second per second.

“Creep force” then under the given conditions was independent of the speed attained and directly dependent on the load and acceleration.

Mr. Fairbairn. Mr. J. M. R. Fairbairn, of Montreal, agreed that the most potent factor in rail creeping was a soft bottom, or, at all events, the other factors produced a much greater effect in the way of rail creeping on soft bottom than they did at other points, except under very special conditions.

In Canada many experiments had been made lately in the matter of laying rails on what was known as the “hit-and-miss” method, in which no attention whatever was paid to the relationship of the joint to the ties, but sufficient rail-anchors were used on the rail to prevent it from creeping in either direction, and so far it had been found that the results obtained were quite as good, in regard to both the riding on the track and the life of the rail, as under the old method. The result of these experiments had been the adoption within the past 2 years of a standard 100-lb. rail (heavier rails, of course, reduced the creeping under similar conditions), with angle-bars of such design that the flanges did not project beyond or even reach the edge of the rail-flange, and there was nothing whatever to prevent these rails when laid from creeping through the spikes past the joint, as the angle-bar could not engage the spike heads. It was intended to lay this rail, without any regard to where the joints came, in their relation to the ties, and to use sufficient anchors with it to keep it from creeping at all.

Mr. Hogg. Mr. C. P. Hogg desired to place on record an interesting and unique case of rail creep which he had come across in the course of his practice. About 5 years ago his firm made some alterations on a steelwork viaduct carrying a single line of rails (metre gauge) on a gradient of 1 in 50 rising up to a 10,000-ton phosphate store at Safaga Bay, on the Red Sea. From the store an aerial ropeway, with a capacity of 2,000 tons per day, was carried out to the ships in deep water. Two loaded wagons, each weighing 47 tons, were propelled at a time up the incline by a locomotive of the 0–6–2 type weighing 35½ tons. Only empty wagons were taken down the incline. A very considerable amount of rail creep took place up the incline in the direction of the heavy traffic. Mr. Hogg.

Mr. Jackson. Mr. HARRY JACKSON remarked that the two Papers, whilst primarily written to describe and explain the longitudinal movement in open-construction rail-tracks, did, at the same time, throw considerable light upon the action taking place in a rail when subject to rolling loads. The wave-action theory referred to by Mr. Reeves on p. 234 was introduced in a discussion before The Institution on the 11th November, 1902.[1] With sleeper track construction, the length of the wave was probably three to six times the distance apart of the sleepers, depending upon the rigidity of the rail, the ballast, and the weight on the wheel. The action in the rail was probably that of ordinary beam flexure with its comparatively large attendant displacements. It would be observed from the particulars of experiments (p. 229) that the creep of "lath on sleepers" was between two and three times that of the "lath on bare bench." In the case of a rail supported on a continuous unyielding foundation as in a tramway, a condition more nearly approximating to the "lath on bare bench" experiment obtained. Here, instead of rail flexure with its large displacements, direct compression of the rail occurred, with much smaller displacement. If, then, the wave action was set up, what became of the longitudinal movement corresponding with the observed creep in the lath experiment and the open track? Did the rails actually move along and give evidence of their movement at curves, or did the strain energy in the rail dissipate itself in some other way? Both Mr. Miles and Mr. Reeves placed temperature changes as being of secondary importance in producing creep, and Mr. Jackson was in perfect accord with that view, contrary as it was to the view held by many engineers. It had been said, at one time, that temperature differences produced the creep in open-sleeper tracks, but that in tramway construction the friction of the paving sets against the rails prevented this movement. To test this point, he had made, when on Sir Maurice Fitzmaurice's staff, a number of experiments, and with his permission would make the results public now for the first time. A length of straight track opposite the Greenwich Hospital was chosen. The rails weighed 104 lbs. per yard, and were of British Standard Section, each 45 feet long, jointed with Standard fish-plates and an inverted rail-anchor riveted to the under side of the rail-flange. After fixing and

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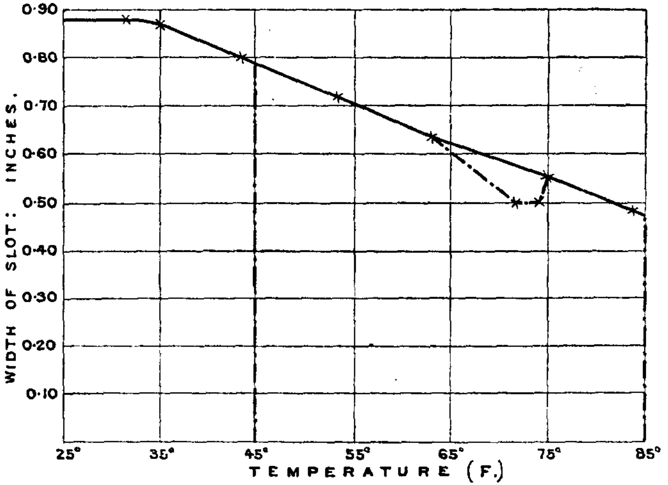
[1] Minutes of Proceedings Inst. C.E., vol. cli, p. 113.

Mr. Jackson. riveting up, and when the concrete was set, the rivet-heads were cut off and the rivets were withdrawn from the concrete; the fish-bolts were taken out and a strip of rail about $\frac{5}{8}$ inch thick was sawn off. The fish-plates were then replaced and tightened, and the fish-bolts were withdrawn before the paving was made good. As would be known by those having experience with the British Standard Section tramway rails, the fish-plates held tight in their position after the bolts had been withdrawn. Observations were then taken, over a period covering two winters and a summer, of the width of the joint gap and the temperature of the rail, the former by direct measurement with a steel rule, the latter by laying an ordinary chemical thermometer in the rail-groove and covering it with dirt scraped up out of the groove, care being taken that the street water-cart had not just previously wetted and cooled the dirt. The result was astonishing; the width of the gap went up and down with the temperature just as if it had been a thermometer. The next point to be ascertained was—what length of rail was expanding? Plotting the width of gap with temperatures (*Fig. 3*), and taking the coefficient of expansion of steel as 0·000,00665, the length of rail expanding was 97 feet. Allowing

Fig. 3.



Diff. in width of Slot .... 0·31 in.
" " Temp. .... 40°
Expansion per Degree .... 0·0078 in.
Coeff. of Expansion of Steel 0·000 00665
Length of rail expanding {About 97 feet
i.e. one rail-length
on either side of joint.

Mr. Jackson.

for the possible difference in the coefficient used, it might be taken that 90 feet of rail was expanding, i.e., two rail-lengths. This meant that the whole of the rail, as far as, but no farther than the next anchor, was expanding and contracting just as if it were not surrounded with sets. With anchored rails, then, expansion was not transferred from rail to rail past the anchor. What became of it? It might be taken up by compressive elasticity of the rail, but it seemed doubtful whether the rail acting as a long strut would compress sufficiently. More probably the rail bent upwards with the anchor as fixed points and left a slight gap under the rail between the points of anchorage.

Returning to the wave-action in the rail, it might be said that the temperature-effect was confined within the limits of two rail-joints. There was further no creep beyond these. There was, however, one phenomenon just as troublesome to tramway-engineers as "creep" is to railway-engineers. It was the hammering of the approached rail, at a joint. If this wave-action took place, when a joint was approached by the wheel, the crest of the wave would be higher at the joint than in the middle of the rail. Further, if the wheel travelled at such a rate that there was not time for the crest to be transformed into a trough, the wheel would jump the crest and drop on to the approached rail. Such appeared actually to take place, for no matter how strong the joint, all tram-rails with traffic running only in one direction soon become hammered at the approached end only. This wave-action might, too, be responsible, at all events in part, for the grinding of corrugations of about 3-inch pitch in tram-rails at places. Suppose the speed at which the wheel, with its attendant wave, travelled along the rail, coincided with the speed at which a natural vibration wave in the vertical direction travelled along the rail; then a condition would be set up in which excessive wear of the rail would take place at regular intervals along the rail and would lead to the roaring so common on some lines.

Creep of railway rails and corrugation of tramway rails, although vastly different in result, might be due to the same initial cause, and the Authors were to be congratulated on the data they had given, and Mr. Reeves in particular for the experiments and theory deduced therefrom.

Mr. Johnson.

Mr. P. H. JOHNSON remarked that in his opinion the second and sixth factors mentioned by Mr. Miles had not much influence on the creep of rails in the direction of traffic. It was certain, however, on account of the wheels of vehicles being fixed to the axles, and therefore since two or more axles remained parallel to each other, that constant circumferential slipping of wheels took place

Mr. Johnson. in going round curves; this would account in many cases for one rail creeping more than another. In the case of the sixth factor, there did not appear to be any reason why the expansion of rail should cause the movement only in the direction of the traffic; if the rail were quite loose, this expansion would cause equal lengthening at each end. It appeared to him that the third, fourth and fifth factors were the chief causes of rail-creep and that the third was by far the most important. Another reason for unequal creep of rails, particularly on the straight, might probably be that the keys were much looser on one rail than the other; this would evidently tend to inequality of movement. In considering the question why rails crept at some portions of a line and not at others it would appear that, before any satisfactory conclusion could be arrived at, it would be necessary to analyse full statistics with reference to life of material, weight, section length of rail, particulars of road-bed, and other details. Increase of weight on the driving-wheels and decrease in the hardness in the rails would no doubt tend to increase the creep. There was very little doubt that creep could be practically eliminated by the use of steel keys giving greater frictional resistance to rail movement; and whether the provision of these would or would not be economical could be arrived at by a simple arithmetical calculation.

Mr. Reeves's method of rolling the wheel along the lath with the hands resting on the upper portion of the periphery, did not appear to be quite satisfactory when such small dimensions as 0·3 to 3 millimetres were quoted. If the load on the wheel were not quite vertical the results obtained would not be reliable. A similar experiment, with model soft metal rails or strips rolled over by two flanged wheels fixed on an axle and carrying a heavy vertical load, the rails in the first instance being free to move on bearings, and afterwards loosely, and then tightly, held by some form of key at sleeper distances, would probably throw a good deal of light on the problem of rail-creep. In cases where one rail crept more than another, the explanation might be that the frictional resistance of the spike or coach-screw in flat-bottomed rails was less on one rail than on the other, and if it occurred on curves, the circumferential slipping of the outer wheel, due to its being fixed on the axle, might be the cause.

Mr. Langley. Mr. A. E. Langley remarked that in his experience there was also one other cause which appeared equally responsible for creep besides those mentioned by Mr. Miles at the commencement of his Paper, namely, the present system of track-maintenance. A few years ago the track used to be ballasted up to the head of the

Mr. Langley.

rails or nearly so, whereas to-day the rails were quite uncovered; under the former conditions the track was kept at a more even temperature all the year round, with consequently less expansion and contraction. Where the traffic was all in one direction, as on double lines, the greater expansion and contraction now occurring was all driven along in that direction as far as the rail-joints would allow. In proof of this might be advanced the fact that in the majority of tunnels there was no creep, because no expansion or contraction took place. Again, at public road level crossings, where the rails were buried, creep was very much arrested; and on tramways, on which creep was totally absent, expansion and contraction was negligible, so much so that all joints were welded. This was possible because the rails were protected from excessive temperature-changes. As there were many good reasons why a return should not be made to a fully-ballasted road, another method of preventing creep might be considered. It was the present standard design of rail-joint, which allowed for expansion-spaces which were wholly and solely responsible for creep; railway track did not creep like an endless chain, but only between certain points; there were many places where the track did not creep, therefore whatever creep took place it was all obtained from the joint spaces between the fixed points, and the amount would be proportional to the distance or number of joint-spaces between those fixed points. On a double line of railway, creep took place in the direction of the traffic. On examining a piece of track which crept considerably between two fixed points, such as stations or junctions, walking in the direction of the traffic it would be found at the commencement of the creep, that was, on leaving the station, that all the joint-spaces would be open, but on approaching the far station all the joints would be closed (Mr. Miles, agreed; Mr. Reeves experienced the reverse). The maximum amount of creep would be found about half-way between the two stations. When this piece of line was put in, expansion-spaces would be left in accordance with the temperature at the time, but if this piece of track were examined a month or two after relaying, the joint-spaces at the first station would be found wider, no matter what the temperature was, and at the other end closer; in other words, at the commencement of creep the joints never closed, and at the end they never opened. It was obvious, therefore, that no expansion-spaces were necessary at the commencement of creep, because the loads passing over the rails prevented expansion and contraction from operating in the normal manner and caused the whole joint to move along; therefore all the joints at the commencement of the creep should be drilled so as to leave no expansion spaces, Mr. Langley. Towards the end of the creep, normal expansion spaces should be left to allow for expansion only; at the present time it was evident that space is left for expansion and creep. To carry out this scheme it would be necessary to order the rails without holes at one end; these holes would be drilled when relaying, through the fish-plates as templates, to give a tight joint or a space at the beginning or end of creep as the case might be. No alteration in the fish-plate was necessary.

Before treating a piece of track in this way it would be necessary to keep a careful record of the creep for at least a year, so that any adjustment of drilling for the joints through the middle portion of the creep could be allowed for.

With regard to Mr. Reeves's statement that in double track the outer rails (those rails near the edge of the ballast) ran more than the inner rails, Mr. Langley believed that this was more a peculiarity of foreign flat-bottomed track than of English bull-headed track. His experience on the latter was that the inner or 6-foot rails crept far more than the outer rails on straight track. On curves the outer rail, of curves to the right, often did creep more than the inner rails, which apparently was due to the side pressure on the outer rail. In the Bulletin[1] of the International Railway Congress there was an exhaustive article by a Dutch engineer on creep, dealing with the question of the locomotive, in which the writer claimed to prove both theoretically and by measurement and experiment that the wheels on the opposite side to the leading crank became less in diameter and unevenly worn, with the result that the locomotive ran or leaned to the side opposite to the leading crank. He said that foreign locomotives had the leading crank on the right-hand side, therefore the engine ran to the left-hand side, causing the left-hand or outer rails to creep most. He further stated that English locomotives had the leading crank on the left-hand side. This, however, was not the case so far as three main lines were concerned, and in spite of it the right-hand or inner rails crept most.

Mr. E. W. Stoney's records showed that the right-hand or inner rails crept far more than the left-hand or outer rails, but it is only fair to state that Mr. Stoney attributed this to the keys being driven in a direction opposite to the creep instead of in the same direction. Mr. Langley's experience, however, was that in hot weather the wooden key had very little effect in resisting creep, even when it was driven with the creep; it was constantly

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[1] Vol. xviii, No. 3, March 1904.

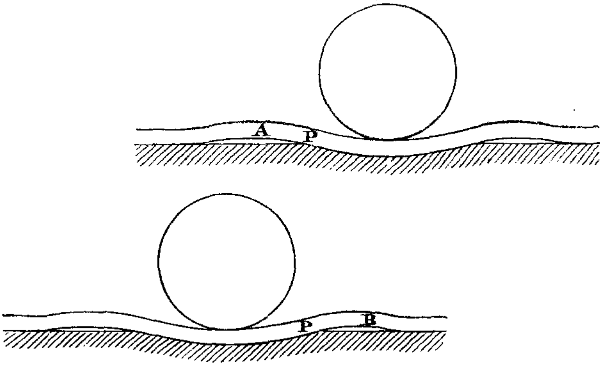
shrinking and crept back in the opposite direction to the rail until it fell out. Mr. Stoney's track was light flat-bottomed on pot sleepers. Mr. Miles did not describe his experience in respect to which rail crept most, but it might be gathered that he found the difference not very marked, since he seemed to speak of creep of rail and creep of road as one and the same thing. On p. 245, Mr. Miles said it was seldom that rails on opposite sides of the road crept to the same extent; in a few places the joints got as much as 5 inches out of square. It would be interesting to know which rail it was that crept most in these instances. Though Mr. Miles stated that rails on opposite sides of the track seldom crept to the same extent, Plate 7 showed both rails adjusted over exactly the same mileage. It would appear that the reasons for the inner rails of chaired track creeping most on English lines were two: first, the great heat attracted by the rails, which must be greater in the centre of the track than the outside (as proved by frost and snow melting in the 6-foot way first), therefore causing more expansion and contraction of the inner rails and more shrinking of the keys. Secondly, the outer rails were less solidly supported, and therefore more flexible, and when the rail bent it became jammed in the throat of the chairs; it also tended to tighten itself between key and chair, and by these actions it was somewhat prevented from creeping. In the "Bulletin of the International Railway Congress," vol. xxviii, No. 3, March 1914, there was a Paper on creep in which it was stated that "the general opinion now is that creeping is caused chiefly by the percussive action of the wheels at the joints, when the wheels leave the trailing end and strike the facing rail-end." Mr. Langley read this article in 1914, and from that time he had particularly, when out on the road, examined the conditions of the rail-ends, with the result that he had found very few of the facing rail-ends, that was to say, the actual end, struck at all; more often than not the wheels did not touch the end but appeared to drop off the trailing end on to the facing rail-end from about $\frac{1}{4}$ inch to 1 inch from the end. In his opinion, therefore, there was not so much creep from this cause as was usually attributed to it. In an article in the "Bulletin of the International Railway Congress," vol. xxv, No. 3, March, 1911, a somewhat different theory was put forward from that of Mr. Reeves. Mr. Langley.

Mr. J. N. D. La Touche remarked that it was noticeable that on the up line of the railway referred to by Mr. Miles, where the gradients falling in the direction of the traffic were on the average steeper than the rising gradients, creep was greatest on the rising gradients; while on the down line, Mr. La Touche.

Mr. La Touche. where the conditions were reversed, the creep was greatest on the falling gradients. This might possibly be accounted for by the fact that the average distance between stations was greater on the terminal portion of the line, between miles 33 and 50, where the gradients fell with the down and rose with the up traffic; creep would naturally be greatest where the stations were furthest apart. Mr. Miles's Paper proved that gradient did not much influence creep, where it was not steeper than 1 in 160; but his observations on the creep in slacks caused by subsidence would seem to point to a limit beyond which creep would always take place "down bank," even against the traffic. It would be interesting to know where that limit lay.

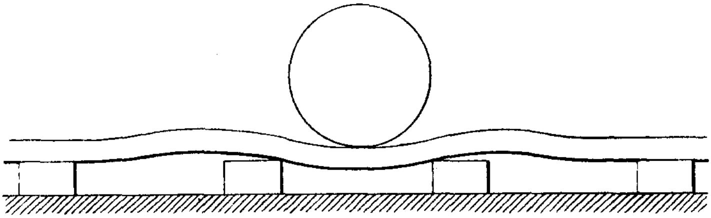
While fully appreciating the interest and value of Mr. Reeves's experiments, he felt that in the first place, the conditions under which the experiments had been made were in one respect at least quite different from those obtaining in railway practice. The whole of the force applied to the moving body was in the forward direction, while in the case of a train the internal forces when the train was running under steam very nearly balanced. There was also nothing answering to the application of the brakes, which caused a direct forward pull on the rails, or to the resistance of the air, which creates a pull in the opposite direction. This last, under ordinary conditions, would probably have very little influence on the creep.

Figs. 4.



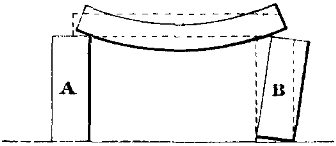
Again, he did not think that *Figs. 3* gave an exact picture of what took place. The curve of the lath would surely not follow the shape of the depression in the base all along, but would leave it at the sides, thus (*Figs. 4*), so that the pressure at AP and PB, if indeed any existed, would be much less than that under the wheel. This would diminish, or nullify, the influence of the contraction and expansion of the foot of the lath between these points in urging the rail forward. He would be disposed to say that the forward creep observed on a flat base was due partly to the rolling-out effect of the weight, and partly to the force used in urging it forward. Dough is elongated by a permanent thinning of the material, which did not take place in wood, iron, or rubber under so comparatively light a load. What did happen, he thought, was that the bar was locally and temporarily elongated by compression under the wheel, and this elongation was translated into forward travel by the forward pressure on the wheel.

Fig. 5.



The conditions when sleepers were inserted between rail and base were essentially different. Here the rail was "upset" only over the sleepers, that was to say, for but a small fraction of its length; and it was not likely that this accounted for any but a minute portion of the creep. Here again the reverse bend of the rail would take place not directly over the sleepers next the wheel, but a little beyond, thus (*Fig. 5*), so that the contraction of the rail foot in this reverse bend could have no driving effect. A simple experiment would, he thought, show to what the major part of the creep of a rail on sleepers was due. If a bar of rubber were placed on two supports, as shown in *Fig. 6*, one, A, being fixed and the other, B, not fixed; and if the bar was then slightly bent downwards, it would be found that support B was urged forward, by the elongation of the tension side of the bar. If both supports were fixed, and

Fig. 6.



Mr. La Touche. if the pressure were applied at the centre, the foot of the bar would tend to slip in the direction away from the centre over both supports. But if the pressure were applied by a weight rolling from A to B, while it was running from A to the halfway point, the pressure on A was greater than that on B, and the end over B would slip forwards. While the weight ran on from the centre to B, the pressure on B was the greater, and slipping would take place, again forwards, over A. This took place under every wheel of a train, and must in the aggregate exert a considerable forward effort.

It was evident that this effect would be least in the stiffest material; hence the difference noted in the creep of rubber, wood, and metal bars. When the sleepers were laid on a rubber base, the slipping would be partly taken up in compressing the rubber in a forward direction, and this movement would be returned when the pressure was relieved; this, he thought, accounted for the difference between the creep of 13·77 milimetres on a wooden base, and 5·26 milimetres on one of rubber. It would probably reduce creep on a railway if the road-bed could be made resilient; but this could not be done. If the ballast was tightly packed, the rails travelled on the sleepers; if loosely, sleepers and rails travelled together.

He had had in India to deal with the creep of girders on a single line; this was so great in some cases as to bring the end of the girder against the ballast wall. It was prevented by riveting cleats of angle-bar under the girders, so as to bear against the edge of the bedblocks, or in some cases by pinning the girders at one end. The girders of every bridge did not creep in the same direction; this was particularly noticeable on the Pennair Bridge, of (about) fifteen 80-foot spans. Some of these crept southwards, and some northwards. In this case, the girder bearing-plate rested on a steel plate bolted to the top of each pier. The only way in which he had been able to account for this difference in direction of travel was by assuming that there was a "nap" on the faces of bearing plate and shoe, lying in one direction or the other according to the way in which the plate had passed through the rolls in process of manufacture. If the nap on the bearing-plate opposed that on the shoe, it would offer more resistance to motion in one direction than in the other; some effect of this kind might account for the difference of travel of the two rails on single line. He had heard it stated that the travel of one rail was generally double that of the other. A writer in *Indian Engineering* (not, he believed, an engineer) had tried to account for this by attributing it to the revolution of the earth, which he said would induce a greater side pressure on the westward rail. He hardly felt disposed to agree with this.

Sir Bradford Leslie.

Sir **Bradford Leslie**, K.C.I.E., observed that the Papers were of great practical value in directing attention to an interesting phenomenon in railway transport, hitherto imperfectly understood, and in investigating its causes and remedies. Creep was generally left to the maintenance staff to rectify by hard manual labour; but, as explained by the Authors, it was a source of danger if neglected.

The theory advanced by Mr. Reeves in explanation of creep (*Figs. 3*, p. 234) did not appear to Sir Bradford Leslie to be satisfactory. The weight of the train tending to fix the track resisted movement in either direction. In front and rear of the train the track held by its own weight only opposes inconsiderable resistance to creep of rails. At a point in front of the wheel the head of the rail was in tension and the base in compression; no positive movement could be deduced from these opposite stresses, which were necessarily within the elastic limit.

The weight of a wheel driven forward by the motive power of the engine at a certain speed was constantly being arrested by friction at the point of contact of the wheel with the rail, which portion of the wheel, whatever the speed of the train, was always stationary; thus the horizontal momentum of the wheels of a train was constantly being stopped by the friction at their point of contact with the rails; such friction must tend to drive the rails forward and probably was the chief cause of creep. This theory of creep was not inconsistent with Mr. Reeves's experiments, from which it appeared that creep depended on the weight of the wheel; that creep was also affected by rigidity of the lath, and continuous versus intermittent supports was not inconsistent with the explanation here put forward, namely, that the chief cause of creep was the friction required to bring the bottom of the wheel to a state of rest.

As to remedies for creep, with the long rails now in use, each rail could and should be securely anchored as to, say, one-sixth of its length on each side of the centre, by the adoption of suitable grip-fast supports, the keying of the outer portions of the rails being adjusted, so as not to arrest changes of length due to variations of temperature.

War conditions had to a large extent led to postponement of maintenance, and had thus emphasized the importance of adopting the most permanent types of railway-track to secure the maximum efficiency and economy in the future. Experience has established the fact that this could only be attained by the adoption of practically imperishable cast-iron sleepers, or pressed-steel

Sir Bradford Leslie. sleepers; both of these types of rail supports facilitated the tight-grip keying required to prevent creep, and, moreover, rendered the United Kingdom as well as India independent of imported sleepers.

In connection with the foregoing observations it might not be irrelevant to invite attention to his lecture of 21st April, 1914, to the Permanent Way Institution, on "Track for Trunk Line Traffic."

Mr. Lloyd-Jones. Mr. C. W. Lloyd-Jones remarked that trouble from creep was by no means confined to double-line tracks. The Nizam's Guaranteed State Railway was entirely single line, and on certain sections rail-creep caused considerable trouble and expense. On the broad-gauge section the traffic was much heavier in one direction than in the other. West of mile 260 traffic was heaviest in the up direction, and creep occurred in that direction. East of mile 260 traffic was heaviest in the down direction, and creep occurred in that direction. On a broad-gauge branch line having a preponderance of traffic in one direction, creep occurred, but to a much less extent, and this was probably the effect of much lower speeds on the branch. On the metre-gauge section traffic was also unevenly divided between up and down lines, but there was little trouble from creep. This was probably due to the track being heavier in relation to the axle-loads and speeds. Where creep occurred grading and alignment seemed to have little effect on its amount. Renewal of broad-gauge track with heavier material had been found to reduce creep.

His experience was that if the connection between the rail and sleeper was such as to prevent relative movement, the track as a whole did not creep. In the case of a bull-headed rail he had found steel keys effective in stopping creep. Creep was greatest with wood sleepers and spikes, and on a short experimental section with screw spikes he had been unable to detect any reduction in the amount of creep. The Indian type of steel sleeper had transverse lugs punched out of the seat, between which the foot of a Vignoles rail was secured by a steel key. This type of fastening had a greater resistance to creep than a rail spiked to a wood sleeper, but on the N.G.S. railway the amount of creep was still considerable with steel sleepers when one key was used for each rail. Within the last few years a similar sleeper had been introduced but with a steel key on both sides of each rail, the keys being driven in opposite directions. He had found this type of sleeper effective in stopping creep.

Mr. Lloyd-Jones.

The injurious effects of creep were greatly aggravated by unequal creep of the two rails. It had been frequently reported that the rails crept in opposite directions, but in every case in which he had tried to verify this statement by fixing reference posts he had found the creep to be of varying amounts but in the same direction. The unequal creep of the two rails could not be accounted for on the N.G.S. railway either by the alignment or the cross drainage of the track. It was undoubtedly affected to some extent by the fastenings. Spikes were placed diagonally, and in a direction to cause them to bind when the leading rail crept. Keys were driven where possible in the same direction as the creep. In the case of some patterns of pot sleepers and steel sleepers the design is such that the keys must be driven in opposite directions against each rail, and therefore the resistance to creep would be greater in the case of one rail than the other. On the N.G.S. railway when creep was in the up direction the right-hand rail led, corresponding to a counter clockwise turning of the sleeper. In this case most of the road had symmetrical fastenings. When creep was in the down direction the rails crept fairly evenly, but the fastenings were mostly keys driven to resist counter-clockwise turning of the sleeper. The engines in use on this line had the right crank leading, so that the advance of the right rail on this line did not support the suggestion that had been made[1] that the advance of one rail was due to the oscillation of the engine caused by one crank leading.

The experiments described by Mr. Reeves were very interesting, and the regularity of the slight movement caused by quite a light wheel was striking. The results of the experiments did not appear to be consistent with the theory put forward on p. 234. Mr. Lloyd-Jones thought that from the theory proposed it followed that the creep should be proportional to the load on the wheel per unit sectional area of the lath divided by the fourth root of the depth of the lath. The measurements given on p. 232 were not consistent with that conclusion.

Mr. Neachell.

Mr. E. J. Neachell remarked that the Liverpool Overhead Railway, an iron structure elevated about 16 feet above the ground and supported on columns at 50 feet intervals, was naturally somewhat elastic. The track was laid with 60-lb. flat-bottom rails resting on longitudinal timbers and thus supported throughout their whole length. The timbers, on the straight road, were 10 inches wide and

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[1] Bulletin of the International Railway Congress, 1901, p. 975.

Mr. Neachell. 4½ inches thick, and on curves the high side timber was thicker, to give the requisite superelevation. The track was double and the trains were worked electrically, motors being carried under the first and last coaches only. It was found that creep rarely occurred on the curves, but in places on the straight track it had been necessary to pull the rails back as much as 8 inches in a length of 400 yards. All the creep was in the direction of traffic, and both rails were equally affected. The tendency to creep was greater in warm weather than in cold, and appeared to increase the longer the rails were in use. This was probably due to the wheels striking the irregularities formed on the head of the rails, and corresponded with the action of the wheels striking the ends of rails mentioned by Mr. Miles on p. 244. To prevent the creeping a wrought-iron lug was fastened by one bolt through the web of the rail and by two bolts through the timber. On the under side of the timber large washers were used between it and the nuts. This method of anchoring was found to be quite effective, but when the creeping action was bad the bolts through the timber were sometimes drawn well into the timber and at an angle in the direction in which the creep took place. He had come to the conclusion that creep was largely due to difference in temperature, as, on one ½-mile of the railway which was in a tunnel, and in which extremes of heat and cold were not experienced, where similar 60-lb. rails were laid on cross sleepers, practically no creep had been noticed. This, again, might be partly due to the fact that the track was here laid on a solid foundation, free from the elastic effects which were inevitable in a structure of this nature.

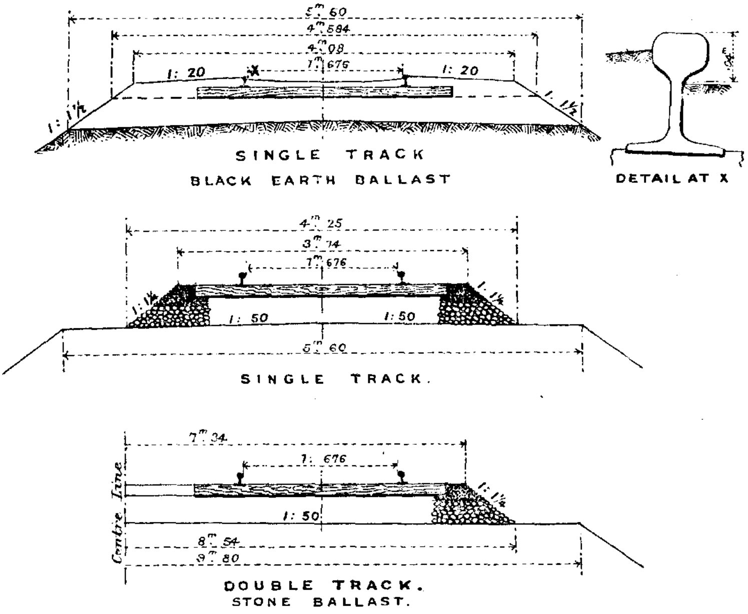
Mr. Renton. Mr. A. C. **Renton** considered the Papers on prevention of creep were of great practical interest, particularly to engineers in warm countries where the flat-bottomed rail was used. On the Buenos Ayres Great Southern Railway also, the question of creep had received great attention, as the evil was a very real one. At first it had been deemed sufficient to connect the joint sleepers by means of old tie-bars taken from pot-sleepers, but this was obviously a wrong method of treatment, and a better result had been obtained by the use of lugs or creeper plates in the centre of the rails, which, by anchoring rails to sleepers, permitted the free expansion and contraction of the rails within their own length. Even this had not given entire satisfaction, and other means had been sought to deal effectively with the evil. This railway system had single, double and quadruple track, and the rails, of various lengths and weights, were in general spiked to hardwood sleepers. The ballast consisted

Mr. Renton.

of three kinds, earth, shell ballast from old sea beaches now underground, and stone. In the case of the two former the ballast reached nearly to the top of the rail, but the stone stopped at the level of the top of the sleeper (*Figs. 7*).

The worst cases of creep were found to occur on the stone-ballasted section, on the quadruple and double tracks, but it was noticed that no creep took place on earth or shell-ballasted track, except on certain lengths where the ballast was scant or had been blown away leaving the rails exposed to the heat of the sun.

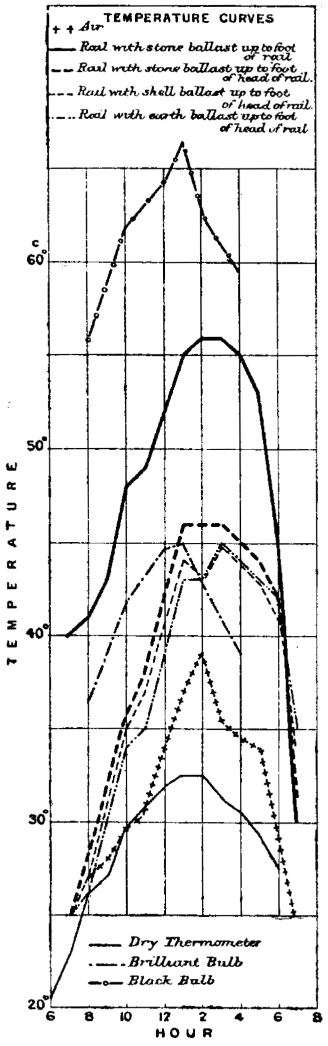
Figs. 7.



An exception on the stone-ballasted section was found in the case of rails laid on steel sleepers (fourteen sleepers per 40-foot rail) and attached thereto by means of twin bolts and clips, as these fastenings proved sufficient to hold the rails against expansion and creep, but a certain amount of twisting had been observed to take place in the rails during the heat of summer, and the remedy proposed was to slacken the nuts of the twin bolts holding the clips, of all

Mr. Renton. sleepers except five or six in the centre of the rail, and thus leave the ends free to expand. As no creep occurred on sections where the ballast was heaped high, certain experiments had been undertaken with the object of ascertaining if stone ballast heaped to rail-level would give the same satisfactory result as that obtained from earth and shell ballast. These experiments had been carried out chiefly on the local section which was laid with 100-lb. rails, 40 feet long, spiked to hardwood sleepers resting on stone ballast. First of all it was thought desirable to ascertain the difference of temperature between uncovered rails and rails with stone ballast heaped against them, and with this object loose rails were taken and a hole was bored vertically nearly to the full depth of the rail and filled with water; paraffin wax or mercury would serve as well. The temperatures under these conditions were observed (*Fig. 8*). The results showed that there was a marked difference (about 10° C.) between the covered and uncovered rails, and the same result might be assumed in the lower limit of temperature. The temperature of the covered rails would seem to follow closely the curve of the clear-bulb thermometer, as registered in the Meteorological Office. Next a length of track was treated to an increase of stone ballast to the level of the rail-head, carefully packed up and watched. After due lapse of time no creep could be detected, and it was then decided to adopt the high-ballast arrangement (*Figs. 9*) over

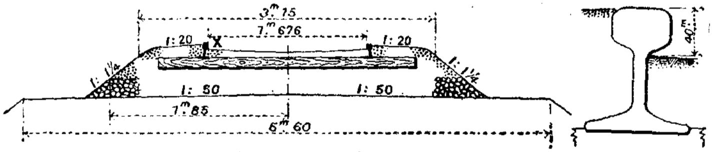
Fig. 8.



Mr. Renton.

the whole of the local section; since this was carried out no further trouble with creep had been experienced, which seemed to indicate that rail-creep was started by the excessive expansion of rails under a hot sun. It should be added that this method had proved also to be the most economical way of dealing with the matter, and, incidentally, had further improved the running condition of the tracks by enabling the expansion spaces to be correspondingly reduced.

Figs. 9.



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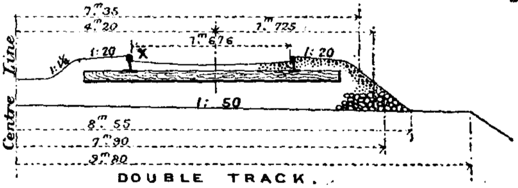

DOUBLE TRACK.
STONE BALLAST.

Mr. Rowlandson.

Mr. J. Rowlandson observed that his experience tallied generally with the chief factors mentioned on pp. 247 and 248. He did not find that gradients made any marked difference in the amount of creep, except on portions of the road where brakes were constantly being applied; but the creep was certainly increased according to the speed of trains. He had had no experience of a road creeping in an opposite direction to the moving train, but he had one case under his charge where the rails of a particular road moved one with the train and the other in the opposite direction. The portion of road referred to was in tunnel, near London, down main line on a rising gradient of 1 in 100, and on a 20 to 22 chains radius, left-hand curve. Whilst the outer rail of the curve, with an elevation of 3⅞ inches, crept forward, the lower or cess rail crept consistently in the opposite direction to the trains. The speed of a train at this place (which extends for about ½ mile) was about 30 miles per hour. He was of the opinion that in this case the movement might be due to the friction of the flanges of the wheels being

Mr. Rowlandson. mainly on the outer rail of the fairly sharp curve, causing a "throw-back" action on the part of the wheels on the other rail. Practically no flange-friction being on the lower rail, Mr. Miles's Factor No. 1 probably came into play. The formation of the tunnel, the invert of which rendered it necessary for more ballast under the outer rail than under the inner, might contribute also to the cause of this creeping. He did not think steel keys, though they required very little attention after being placed in the road, would satisfactorily stop creep, the best method of minimizing which was, he thought, by keeping the roads well lined, topped, keyed and ballasted. In view of the foregoing he could not agree with Mr. Reeves's statement as to creeping always being with the traffic.

Mr. Sexton. Mr. R. E. SEXTON communicated the following notes on the practice of the Queensland railways. The gauge was 3 feet 6 inches. The rails were of the Vignoles pattern, ranging from 41¼ lbs. to 75 lbs. per lineal yard, and were held to timber sleepers by square dog-spikes, and to steel sleepers by clips and bolts. The length of steel-sleeper road, however, was only a very small portion of the total length of line in the State, which was 5,275 miles: of this only 107 miles were double-track road. The timber sleepers were cut from the best Australian hardwoods, which were heavy and durable. They measured 7 feet long, 9 to 10 inches wide on base, and 4½ inches deep below adzing for rail-bed. For a period the practice had been to hew them square, but latterly half-round ("hog-backed") sleepers cut from logs 10 inches in diameter, clear of sapwood, and "edged," had been chiefly used, both forms giving a firm grip and resistance against being dragged by rail-creep in well-ballasted roads.

The greatest trouble from creep of rails had occurred in the western part of the State, where there were long tangents and flat curves, and where the range of shade temperature varied between about 25° F. in the winter and about 118° in the summer, although extreme shade temperatures of 13° and 128° had been experienced. The shade temperature in the coastal districts usually ranged from about 30° to 95°. Trouble, however, had been experienced in the coastal districts as well, one case occurring on the Northern Railway at 31 miles 50 chains from Townsville, where on the night of the 9th August, 1897 (the weather being cold), the rails jumped apart, leaving a gap of 10½ inches; another case occurred on the 8th December of the same year (the weather being very hot), at 9 miles 25 chains on the Mackay Railway, where the road was noticed to be about 3 inches out of line, and while under observation the divergence suddenly increased to 20 inches. A length of 5 inches had to be cut off the rails before the road could be brought to its proper alignment. Mr. Sexton.

On the Western line a good deal of trouble had been experienced in former days on account of rail-creep, the rail joints, which were originally laid square, became separated in places as much as 17 feet 8 inches. In those days no action was taken specially with regard to creep, but for some time attention had been given to creep as described below. The causes which had tended to assist creep on these railways in the past appeared to be:—(1) Steep gradients; (2) Brake action; (3) Weak permanent way, consisting of light rails with sleepers spaced widely apart; (4) Weak joints and excessive screwing-up of fish-bolts.

It had been observed that in the main trunk lines going west from the coast the southern rail usually crept west, and instances had been noted of guard-rails upon curves also creeping in this direction. On straights the various causes of creep would be expected to act equally on each rail, but in some instances, on both hard and soft formations, both rails had moved in the same direction on "up" as well as on "down" gradients, while in others the movement had been in opposite directions. In one instance one rail was noted as travelling 7 feet 6 inches west, and the opposite rail 6 feet 6 inches east, on straights as well as on curves.

Rail-creep had been checked where there were stations, on account of the stock-rails and crossings being securely fastened to the crossing timbers, and checks to creep had also been noted where on portions of the road the rails had been notched and spiked. Formerly the strap type of fish-plate was in general use, but some Ibbotson shoe plates were also used, and where the latter, on account of rail-creep, had been brought hard up against sleepers or bridge transoms the creep had been effectually checked. On the Normanton-Croydon Railway where steel sleepers were in use there had been no creep. These sleepers were trough-shaped, open at the ends, and made by bending $\frac{1}{8}$-inch steel plate, the sleepers being sunk into the formation by the weight of the engine and wagons.

Latterly, roads had been improved by increasing the number of sleepers (now usually placed 2 feet apart from centre to centre) and extra quantity of ballast, and in some cases by the substitution of heavier rails, with stronger joints by means of long angle fish-plates. These fish-plates had holes punched in the bottom flange through which the dog-spikes were driven. Since this has been done the trouble caused by creep had been greatly reduced

Mr. Sexton. On a well-ballasted road with new sleepers creep caused little trouble.

The following means had been tried for checking creep:—

(1) Notching the foot of the rail to take the dog-spikes (done over the sleepers on each side of the middle of the rail). (2) Boring holes in the foot of the rail for driving round spikes in the sleepers, as in No. 1. (3) Fixing flat-bar rail-anchors to the web of the rail, and to two sleepers near the middle of the rail. (4) Spiking flat bar iron diagonally to several sleepers. (5) Making a square hole over each joint sleeper in the angle fish-plates to take the dog-spike, thus anchoring the fish-plate to two sleepers. (6) Fixing malleable cast-iron anchors to the foot of the rail so as to bear against sleeper or bridge-transom.

Of these Nos. 1, 2, 5 and 6 had been more or less successful, the best results having been obtained by adopting 5 and 6. No. 4 had been abandoned as it tended to throw the road out of line.

Mr. Sherlock. Mr. H. Sherlock remarked that, although his experience on the 350 miles of railway that constituted his division tended to show that rail-creep had a distinctly erratic tendency, he had nevertheless arrived at the general conclusions that—

1. Creep was invariably in the direction in which the traffic was running.
2. On the straight the "6-foot" rail (the right-hand rail in the direction of the traffic) crept more than the cess or left-hand rail generally in a ratio of about 1 to 3.
3. On curves the creep was very variable; generally speaking, when the 6-foot rail was the low rail the creep of the two rails tended to become more even as the radius of the curves decreased, owing to the greater creep of the high or cess rail in this case. On the other hand, when the 6-foot rail was the high rail, the ratio of uneven creep was increased on curves of sharp radius, owing to the augmented creep of this rail over the lower or cess rail, but this difference tended to diminish as the radius of the curves increased.
4. Usually one sleeper only was moved out of position, and that one at the leading ends of the rails.
5. Ordinary gradients do not affect creep to any remarkable extent.
6. Heavy rails did not creep as much as lighter sections on the same length of line.

7. A cross-jointed road crept less than a square-jointed one; Mr. Sherlock. it was also more easily adjusted.
8. Rails crept more on a soft formation than on a solid formation, and more on smooth ballast, such as ordinary sandy gravel, than on angular, broken ballast.
9. Near stations, where the creep was due to brake-action, the creep of both rails was practically the same.
10. On single lines the right-hand rail in either direction crept to the same extent, providing the line was straight and horizontal, and the traffic was equal in the two directions.

As to the causes of creep he was in general agreement with Mr. Miles. He considered him to be in error, however, in confusing the expansion and contraction of rails with creep; the former were solely due to differences in temperature, whilst the latter depends entirely on traffic; this was clearly proved by the fact that a line lying unused would not creep, although the rails would expand and contract, and the reason why a greater creep was more observable in hot weather than in cold was simply that the keys were apt to become loose under the former condition, thereby allowing the rails greater freedom of movement. His experience also was that junctions and cross-over roads did not afford sufficient anchorage to prevent creep, and in default of periodical counter measures the crossings and switches would be forced out of position. Large paved level road-crossings usually form an effective stop-block.

The reason that had been advanced for uneven creep, namely, that locomotives were not symmetrical on a centre line, he believed to be the correct one. On the Great Eastern Railway the right-hand crank of the locomotives led, and it was remarkable that the right-hand rail almost invariably crept more than the left-hand on the straight when the traffic was in one direction. This fact also, taken in conjunction with cant, went far to explain the creep on curves, and it would be interesting to know whether, on the railway referred to by Mr. Reeves, it was the left-hand crank which led—similarly it would be interesting to hear from Mr. Miles which crank of the locomotive led on his line, and which of the two rails crept the more.

With regard to the prevention of creep he attached importance to the following points:—

1. Tight keying, and anything that contributed to it, was beneficial.

Mr. Sherlock. 2. Keeping the expansions even: this could be effected in some measure by the method, recommended by Mr. Miles, of slackening the fish-bolts in hot weather where the expansion was excessive, and tightening them again when the rails closed up, as they usually would. Also, as chair marks were to some extent a preventative against creep, particular attention should be directed to keeping the rails of a new road in their right relative position.

Mr. Stoney. Mr. E. W. STONEY had investigated the subject more than 30 years ago, and had embodied his results and conclusions, from careful measurements on the lines of the Madras Railway, in an article in the *Indian and Eastern Engineer.*[1]

The lines between Madras and Arkonam on which these observations were made were laid with double-headed 75-lb. rails in grades bowl pot sleepers, six pairs to the 20-foot rail, keyed with taper teak keys to fit the jaws of these sleepers, which were connected in pairs by wrought-iron tee-bars. Two pegs were driven opposite each milestone outside the rails of the "Up" and "Down" lines, nails being driven in their heads, so that a string stretched across these would be square to the rails; and chisel marks were made on the sides of the rails as zero points. The distance these marks had moved was measured each month. Observations on the "Down line" extended over 26 months, divided into periods by pulling back and squaring the joints; while those on the "Up line" were for 14 months from mile 18 to mile 29, and for 9 months from mile 30 to mile 42.

The tapered keys in the pot-jaws on the outside rails of each line were driven in the direction of the arrows, while on the inner rails next the 6-foot way the keys were driven in the opposite direction. It followed that any movements of the rails in the direction of the arrows would tighten the lines of keys of the outside rails, and loosen those of the inner rails, and in consequence the inner rails would creep much faster than the outside rails, as the former could slip through their pots, while the latter in moving had to drag their pots with them. The teak keys used were long, with considerable taper, to allow for the large shrinkage during the many hot months, and they were not compressed. At each station the outside points and crossings formed fixed anchorages, from which creep began or ended, which took place in the following manner:—The rails on each line crept from the outside points at

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[1] 29th October, 1887

Mr. Stoney.

each station in the same direction as the trains ran, the joints being gradually drawn out from $\frac{5}{8}$ inch to $\frac{3}{4}$ inch, i.e., as far as the oval fish-plate holes allowed, and this continued till it amounted to about 5 inches, when the fish-plates came against the pot-jaws, when the creep was much retarded, as the joint pot-sleepers had then to be forced through the sand ballast as the rails crept forward. The force was so great that the pots were pushed on, tie-bars bent, and in some cases the jaws of chairs spiked to girder-bridge sleepers were broken; $\frac{3}{4}$-inch fish-bolts were also often sheared or broken. Each girder bridge formed a fixed point from which creep began or ended, but as these occurred at very irregular distances, the creep varied very much. The rails on each line crept out from the departure end of each station, while the joints closed and jammed at the arrival ends, where further creep was stopped by crossings. On these double lines the gradients were very flat and the curves of large radius, so that they did not affect the creep.

The creep in the hot months was very much greater than in the cold ones, as in the former the keys shrunk and became loose, while in the cool and wet months they swelled and held tight. It was also found that the creep was much greater after the rails had been pulled back and squared, until the fish-plates again came in contact with the pot-sleepers' jaws. The circular pot-sleepers laid in sand did not offer nearly as much resistance to motion as similar cross sleepers in stone ballast would have done.

The conclusions then arrived at by him, which he still considered correct for India, were that on double lines:—

1. The creep was in the direction in which the trains ran.
2. The rail which tightened the taper keys as it moved crept much less than the one which loosened its keys.
3. The creep was much greater in the hot than in the cold months.
4. The only practical remedy was anchoring and using keys which held tight.

A single steel key which had proved very effective in stopping creep had been invented by Mr. A. R. Stuart while a district engineer on the Madras Railway.

The measurements made on many miles of the Madras Railway's single line showed that:—

1. The creep was in the direction of the greatest traffic.
2. The creep was down heavy gradients, such as 1 in 66, 1 in 70, etc.

Mr. Stoney

3. The creep was greater in hot than in cold months.
4. The creep was much less than on double lines where the traffic was all in one direction.

Mr. Sullivan.

Mr. J. G. SULLIVAN, of Winnipeg, thought Mr. Reeves's conclusions were warranted. It was known from experience that on a yielding road-bed the creep of rail was especially intensified. The incident cited by Mr. Reeves of a rail creeping 13 feet in one week was no doubt absolutely correct. The late Sir William White (then General Manager of the Canadian Pacific western lines) told Mr. Sullivan that, standing some years ago beside the track on the Julius muskeg (swamp) (situated east of Winnipeg, and about 4 miles long), he marked a point on a rail opposite a point on a pile of ties that was lying beside the track, and after a train had passed the rail had moved 21 or 22 inches in the direction of the moving train. That, of course, was in the days of 56 lb. steel rails with fish-plates. There was a notch at the end of the rail which allowed a spike in the joint tie to help hold the rail, but in yielding, ground-like swamps, this was practically of no use. The rail would pull out of the slot and was practically free to move under every train. The track at that time was single and, of course, the next train in the opposite direction would shift the rail back. All Mr. Sullivan's experience has been—like Mr. Reeves's and Mr. Miles's—that on double-track lines the rail moved in the direction of the traffic at nearly all points.

Of Mr. Miles's factors which tended to produce creeping, the third was the one which caused the greatest movement, especially where the road-bed was on a yielding substance. Mr. Sullivan could neither disprove nor agree with Mr. Miles's statement of the creeping of rails on a curve. He was inclined to believe that the outside rail was the more apt to creep for the following reason:—The wheels were so rigidly fixed that the different length of inner and outer rail (especially on sharp curves) necessitated skidding; and the pressure of the flange against the outer rail, while the necessity of skidding the outer wheel somewhat along the outer rail, and the tendency of the inner wheel to slip on the inner rail, thus pushing the rail back, would be sufficient reason for believing that the outer rail on a curve would creep more than the inner one regardless of the super-elevation.

Mr. Sumner.

Mr. C. H. SUMNER asked whether Mr. Reeves had made any experiments to determine the relative coefficient of friction between the lath and the bench or sleepers with the wheel at rest when the lath was on flat and on edge. The reduced creep with the lath on edge might be due wholly or in part to the reduced bearing area, Mr. Sumner. allowing the lath to bed itself in the bench to a greater extent than when on the flat. He would like also to point out that the lath or rail on sleepers had an analogy in the continuous-girder bridge. It would be interesting to know whether creep would be expected in a continuous-girder bridge subjected to unidirectional traffic.

He ventured to suggest that creep was chiefly due to (a) the direct impact between the oncoming wheel and the heel of the rail, should the rail-ends get slightly out of alignment due to "give" in the fish-plates; (b) the suddenly set up friction (of the nature of an impact) when the wheel rolled on to the rail. When wagons were standing in a siding, buffer to buffer, but not coupled, and a wagon was shunted hard on to one end, the effect was to cause the wagon at the other end to break away. He suggested that there was a tendency for the impact of the wheel striking the heel of the rail to be similarly transmitted to the rail ahead of the train, the force of the impact being transmitted through the fish-plates. The shock due to impact or friction might be lessened by tonguing and grooving the expansion-joint, thus permitting the weight to come more gradually on to the rail, but this appeared hardly feasible, owing to expense, and because of the very narrow bearing between wheel and rail at right angles to the direction of motion.

Mr. Todd. Mr. J. S. Todd observed that the experiments described by Mr. Reeves did not include conditions inseparable from the consideration of rail-creep problems, such as the simulation of vibratory effects set up by moving loads and the effect due to the existence of joints: without taking these into account, the results of the experiments appeared to add little to existing knowledge. Local differences in the coefficient of friction between the surfaces, due to contact inequalities and varying pressure in the application of the wheels, would probably account for the varied amounts of creep measured in the several experiments. In his theory, Mr. Reeves hardly seemed to go far enough. No doubt the sinuous action took place somewhat as he described, but creep would not ensue without the motive power imparted to the rails by the friction between wheel and rail tending as a whole to drag the rails in the direction of traffic, and the impact on the leading rail-end at the joint by a rapid succession of wheel-blows, while the rails and other components of the track were in a state of vibration. Under these conditions the rails were potentially able to force their way through the fastenings wherever the resistance provided by the latter was insufficient to stop their forward movement.

Mr. Todd's experience of rail-creep, extending over 20 years, had

Mr. Todd. been entirely in connection with the type of permanent way dealt with by Mr. Miles. The following observations had been made on the 400 miles of running single-line mileage comprising the lines of the southern division of the Great Eastern Railway system, and embracing metropolitan, suburban and country conditions of track-maintenance, and traffic varying considerably in weight, intensity, and speed. These lines included four types of track:—(*a*) 80-lb. rails, 30 feet long, carried by eleven sleepers per length on gravel ballast; (*b*) 85-lb. rails, eleven sleepers to a 30-foot length on gravel ballast; (*c*) rails, as under (*b*), with thirteen sleepers to the length laid on slag ballast; and (*d*) 95-lb. British Standard rails, 45 feet long, with sixteen sleepers of usual section to the length, and two joint timbers, 12 inches by 6 inches, laid on slag ballast. With types (*a*), (*b*), and (*c*) the chair-fastenings consisted of two spikes and two trenails, and in (*d*) of two through bolts with fang-nuts on the underside of the sleepers.

To the factors which Mr. Miles gave as mainly tending to produce creep, he would add the want of sufficient inertia in the component parts of the track to counteract the disturbance caused to them by the dynamic action of traffic. This action continually tended to destroy the anchorage of the several parts of the track to each other, and to the ballast bed upon which they primarily depend for support: if this were not so, the rails and sleepers would not suffer displacement, and no problem of creep would exist.

The observed creep, with each of the four kinds of track mentioned above, went to show that creep of rails and sleepers accumulated most rapidly in type (*a*) and declined progressively with the other three kinds. With (*d*), although there was some creep, its rate of progress was only about half of that with the lighter types. Taking a long view of the matter, it would appear that if track-components continued to increase in weight, and assuming a continually improving efficiency in track-maintenance, the resistance inherent in the track as a whole would be sufficient to reduce creep of rails and sleepers to negligible limits. The objects to be aimed at were permanence and inertia in all parts forming the permanent way, and means taken to counteract the effects of traffic vibrations by providing as heavy and strong a track construction as economic considerations would permit.

With regard to peculiarities in the manifestation of rail-creep noticed on the lines under review, it had been found that, with trifling exceptions on double lines of way, the rail on the six-foot-way side, both on curved and straight sections, always crept more than that on the outside of the track, regardless of weight or speed of traffic. It was submitted that this was due to the additional

Mr. Todd.

effect of vibration spreading laterally from the traffic of the adjoining line, under which the rails and sleepers on the six-foot-way side were disturbed considerably more than on the outside, thus causing loosening and consequent loss of grip of keys and sleepers. The effect of the action was enhanced in dry weather through the shrinkage of the keys, which also accounted for the greater rapidity of creep in the summer as compared with the winter. Another seasonal influence tending to increase creep was the percolation of surface water into clay formations, which added to the disturbance of tracks laid on formations of this character.

On sharp curves situated on branch lines with low-speed and light traffic, creep took an exceptional course to the above. In such positions the high rail crept faster than the low rail as a rule. This was probably mainly accounted for by the greater radius of the rail on the high side, along which the wheels of vehicles travelled and ground faster than their companion wheels, which momentarily pivoted on the low rail. On single lines of way, while little or no creep took place in some instances, in others the right-hand rail in the direction of traffic moved faster than the left, but the differential action developed very slowly. This was probably due to the balance of creep-effect on curved sections. Gradients did not appear to have any appreciable influence on the incidence of creep-action.

With reference to remedies for creep, he concurred with Mr. Miles's general conclusions, but would add to them the need for more attention in the maintenance of the rails and sleepers on the six-foot-way side of double lines, for the reason already given. Steel rail-anchors of the wedge-and-buckle type have been tried. About two hundred were fixed on a length of track where extensive creep occurred some years ago, twelve anchors being fastened to each pair of 30-foot rails, so as to butt against the chair-seating of the central six chairs along each rail-length contrary to the direction of creep. In 7 years the rail-anchors had to be taken out as they had become too worn for further effective use. While in position they were quite effective as creep preventatives, but they were a somewhat costly device, and had the disadvantage of adding considerably to the number of separate parts to be maintained. Experiments on a limited scale had also been made with steel keys, but the trials had not been of sufficient duration to enable an opinion to be given as to their merits. They had been fixed six to a pair of rails—three to the central chairs of each rail-length—with the intention that this number should be added to in either direction until creep was reduced to a negligible amount. The keys

Mr. Todd. had been fixed central with the rail-length because the creep factor due to temperature-changes operated from the centre of gravity of the rail, causing creep in the direction of least resistance. For this reason it would appear that more effective results were likely to be got by this grouping than where such keys were fitted in conjunction with wood keys at intervals along the rail-length. Another device with which complete experiments had been carried through was the Wright fish-plate chair-joint, which consisted of a pair of angle fish-plates carried round the bottom of the rail, meeting within $\frac{1}{8}$ inch. The bottom wing of the fish-plates rested on and was fastened to the joint sleepers, thus dispensing with the chairs on those sleepers. These plates formed a rigid, rectangular frame at each joint, which entirely prevented creep of both rails and sleepers. After about 10 years, however, the joint plates had to be removed because they caused the rails to cripple at the joints, through faulty design. Further, the cost of these joints was nearly three times that of the usual joint parts. A more generally adopted device was the fixing of flat iron bars about 2 inches by $\frac{1}{2}$ inch in section, with spikes through holes, to four sleepers, two on each side of the joint and along each side of the 4-foot-way at the foot of the chairs. These bars had considerably reduced the tendency to creep where they had been used on the (*a*), (*b*) and (*c*) types of permanent way described above, while with type (*d*), where in one case they had been in use for about 9 months, there had been no creep as compared with the occurrence of creep at the rate of about 1 inch per annum before their installation. This arrangement, however, was somewhat expensive under existing conditions. A trial of another arrangement was contemplated, comprising the use of fish-plates of different lengths, the inner plate fitting between the jaws of the joint chairs and the outer one being of the usual length. This arrangement, judging from the results of other experiments, appeared to offer possibilities of meeting the requirements successfully, and had the advantage of simplicity and cheapness. He believed that some railway companies had this type of fish-plate in extensive use, and it would be interesting to know what results had been attained with it.

The cost of pulling back rails on the lines under review amounted to an average of £65 per mile, which was a considerably higher figure than that given by Mr. Miles. The difference was probably due to the necessity of carrying out the work on Sundays at overtime rates with complete possession of the track, there being no means of diverting traffic to parallel lines while work was in progress.

Mr. Reeves. Mr. REEVES thought the statement in Mr. Miles's Paper that change of temperature causes the rails to move in the direction of the traffic, needed some explanation or proof. He believed Mr. Miles was right, as an advancing train, finding the rails in a state of either tension or compression, temporarily anchored them by friction due to its weight and prevented a backward movement, whilst there was nothing to prevent a forward movement. The matter was, however, complicated, and it seemed that more investigation was needed to substantiate the statement in question.

In reply to the Discussion and Correspondence, he wished to express his appreciation of the large amount of useful information elicited. He agreed with several of those who had taken part that stripping the ballast down to the top of the sleepers aggravated creep. He considered this, however, to be mainly due to the lessening of the resistance of the ballast ("anchorage"), though doubtless the effect was assisted by the extra expansion of the exposed rails. He had found that heaping ballast on the ends of the sleepers was very beneficial, even though the rail was fully exposed.

In answer to Mr. Sumner's question, he had not previously determined the coefficients of friction, but had since done so, with the result that the coefficient of friction, on the bare bench, of white-pine planed lath, uniformly loaded with a weight approximating to that of the heavy wheel, was:—Lath on flat, 0·527; lath on edge, 0·514. Each of these figures was the average of the results of three tests, which were practically uniform.

Mr. Miles. Mr. MILES, in reply to the Correspondence, observed from Mr. Dawson's remarks that the adjustment or pulling back of rails on the London and North Western Railway appeared to be very much less than on the portion of the railway system to which he had referred in the Paper. The explanation of this, no doubt, was in the fact that on the section of the railway system which Mr. Miles had described, the great bulk of the traffic was both fast and heavy, and if the whole system—of which the section he described formed part—were taken, the length of rails which had to be adjusted would probably be approximately the same. In making a comparison, however, it would of course be most necessary to take into account not only the total length of road where rails were adjusted, but also the actual amount which the rails were pulled back.

In the absence of explanation of the increase in the length of road on the London and North Western Railway which had to be adjusted during recent years, owing to the rail-creep, Mr. Miles

Mr. Miles. suggested that probably that was due to increased axle-loading, and possibly to the increased length of rails in use, as he had observed that other conditions being similar, the longer the rails the greater the creep. This latter however appeared inconsistent with the 5th factor producing creep which he had mentioned in his Paper, viz., the impact given to the running on end of the rails by the wheels of vehicles. It would therefore appear that although some creep was eliminated by reducing the number of joints, it was increased to a greater extent by the introduction of longer rails.

He thought Mr. Dawson had misunderstood the Paper when he said that the effect of high speeds and heavy axle-loads had little influence on the amount of creep, as the Paper stated that his opinion that the creep of the rails was due to the high speed of trains combined with heavy axle-loads, and that if the gradients were moderate and the curves of fairly large radii, the two latter elements had little influence on the production of creep. He was of opinion that he had been misunderstood by others with regard to the 6th factor, viz., change of temperature, tending to produce creep, which he had mentioned in the early part of his Paper. The contraction and expansion of the rails from this cause had no tendency to make the rails creep in one direction more than another; but, taken in conjunction with other factors mentioned, he was of opinion that it had a very marked effect on the amount of creep in the direction of the traffic.

When this was a double line on the straight, his experience was entirely in accordance with that of Mr. Frank Reeves, viz., that the left-hand or outside rail crept to a greater extent than the 6-foot or right-hand rail. The causes of this peculiarity in creep he had always attributed to those mentioned by Mr. Reeves, viz., that the ballast was looser near the end of the sleepers on the outside rail than on the 6-foot side, and the tendency of the road and ballast on the adjoining road to move in the opposite direction.

The timber keys on both sides of the roads described were on the outside of the rails, and were driven in the direction of the traffic, and not as suggested by some correspondents in opposite directions on each side of the line. There was therefore no tendency for the keys to become tighter on one side and looser on the other as the rails crept in the chairs.

He could give no definite opinion on the theories advanced as to the effect which the leading crank of the locomotive had on the uneven creep of the rails, but would point out that on the railway to which he had referred in the Paper, the position of the leading crank of the locomotive was on the right-hand side, and, as he had already stated, his observations had shown that the left-hand rail crept more than the 6-foot rail. He was of opinion that any special devices which were provided for eliminating creep should be attached near the centre of the rail, and as far from the joint as possible, as the latter was the weakest part of the road, and the fish-plates and joint sleepers had already as much work as they could do. Mr. Miles.

22 January, 1918.

HARRY EDWARD JONES, President,
in the Chair.

The discussion on the Papers by Messrs. Reeves and Miles, on Rail-Creep, occupied the evening.