

Discussion.

Sir DOUGLAS FOX, President, regretted that neither of the Authors ^{Sir Douglas Fox.} was present that evening, Mr. Deane being in Australia, and Mr. Stirling in America; and therefore all that could be done was to pass them a vote of thanks, which would convey to them the appreciation by the Institution of the information communicated to it. He considered that the Papers were very practical essays on an important subject, and one needing to be frequently brought before the Institution. If English engineers were to hold their own in the world it was very important for them to study as far as possible economical railway construction. To his mind there was something refreshing about the Papers. The Institution nearly always had brought before it economical construction and break of gauge combined; but he was glad to see that the Authors showed how economy could be attained, without at the same time introducing what he thought was often a serious drawback, viz., break of gauge. Mr. Deane showed that without departing from the standard gauge of the country it had been possible to reduce greatly the cost of the railway by making certain detailed alterations. Not only was it proved that the gauge need not be broken in order to effect considerable economy, but both Papers pointed practically to the same methods for reduction of cost. The proper adjustment of the minimum radius of curves to the country traversed, the question of the ruling gradient, which was often neglected, and the concentration of the steep gradients as much as possible on certain sections of the railway, had been very carefully studied. An important point, which had been casually referred to in a discussion at the Institution recently, was the shortness of the tangents. Mr. Stirling mentioned that in some cases the length of the tangent was only 24 feet, which was very short. He had found in dealing with railways in difficult countries that nothing helped so much to get round sharp spurs of hills as reduction, as far as it could safely be made, of the length of the tangent. That was a matter about which English engineers and their foreign brethren often disagreed. Some foreign engineers would not even hear of a tangent of what English engineers considered a reasonable length; but it was clear that the introduction of any considerable length of tangent when dealing with sharp reverse curves very much did away with

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Fox.

the effect of the curves themselves. Both the Authors had referred to the subject of ballast. In his experience he had found that, in dealing with moderate speeds—say 25 miles an hour, as, for instance, was the practice on the Rhodesian and other railways in South Africa—a very small quantity of ballast was often sufficient. Over considerable portions of some of the railways no ballast at all had been used at first, but it had been added afterwards as the traffic justified it and the call for increased speed necessitated it. Thus a very small average quantity of ballast had served at first, and it had been found that this did not produce any very serious increase in the cost of the maintenance. He observed in one of the Papers that cuttings were avoided as much as possible, and that appeared to have been copied from American practice. He did not quite understand why it was introduced into Australia. It was done in Canada and the United States on account of the heavy snowstorms, and there care was taken to lay out the line—not so as to balance cuttings and banks, as was done in this country—but without cuttings if possible, and to get over the ravines with trestles of timber, afterwards gradually filling in with earth. He did not quite understand how the economy was effected in Australia where heavy snowstorms were unheard of.

Mr. Robertson.

Mr. F. E. ROBERTSON said the Papers were certainly most practical and interesting, for, after all, the main object of engineering should be to afford the maximum of accommodation for the minimum of cost, and not necessarily to build monumental and consequently expensive structures. The problem of local communication seemed to have been well solved in Australia, because the cost of the lines, which appeared to be fully equal to the wants of the districts, was rather less than the average cost of the metre-gauge lines in India, although it would be seen from the rates given that the cost of earthwork on the Australian lines varied between four and eight times the Indian cost, labour, of course, being exceedingly dear in Australia. But it appeared that the rate given for the iron part of the permanent way was rather low for an average estimate. There would be about 100 tons of iron per mile in that permanent way which would give a rate of only £6 6s. per ton; and if that was really the price including the freight to site, it was extremely low when it was considered that the spikes, fishplates, and bolts were averaged with the rails. There was one item of extravagance he regretted to see, viz., the high platforms. Considering that the whole of the Continent could do without them, he thought local lines which required economical construction could very well do without them also. With regard

to the question of ballast, the rainfall had a great deal to do with Mr. Robertson. that; the less the rainfall the better could ballast be dispensed with. The State Railways in Egypt were practically not ballasted at all, and yet between Cairo and Alexandria there was quite a respectable express service; so that it was possible to use unballasted lines for other than slow traffic. If the service was at all fast the dust was a great nuisance, and therefore a little ballast might be very desirable. He supposed that in Australia brick ballast would be too dear in places where no stone was to be had. With regard to the remark in Mr. Deane's Paper respecting the mode of carrying out the works, experience in India favoured task-work or petty contract, that was, letting items of the work to gangs, rather than using day labour pure and simple. It was certainly more economical, and gave a good deal less trouble. With respect to Mr. Stirling's Paper, for such heavy service the rails appeared to be somewhat light. Opinion in India favoured a 50-lb. rail for the metre gauge, with 8 tons as the axle-load. The statement in the Paper that the 48-lb. rail had given no better service than the 40-lb. rail gave rise to some reflection. There seemed to be an impression abroad that the rails obtained now, from differences in manufacture, were softer than they used to be; but even if that was the case, was the difference in date between the laying of the 40-lb. and the 48-lb. rails sufficient to account for the difference in wear, or was it possible that the 48-lb. rails were laid on the same centres as the 40-lb. rails, and consequently were a little tighter to gauge, as the tables were wider? That might possibly account for the wear up to the limit being as rapid in one case as in the other. He would like to ask the Author whether the curves were spirals, because with such very sharp curves every refinement in laying out seemed to be desirable; also whether check-rails were used, as there was no mention of them in the Paper. He would like to know, too, more about the coupler and how it had behaved on the very sharp curves on the line. From the brief description given it seemed to be a variety of what was known as the Norwegian coupler. That coupler in certain cases had given trouble on lines with less sharp curves and heavy gradients than the line in question.

Mr. ELLIOTT COOPER thought the two Papers would be of even Mr. Cooper. more value than they were, if they could be taken as representing in any degree what could be adopted as a general practice; but he need scarcely point out that the first Paper spoke of railways in a particular country, and special stress was laid on the fact of its having a very arid climate. He happened to be associated

Mr. Cooper. with two countries, one of which—Cape Colony—might be described as having a somewhat similar character to New South Wales, whilst the other was an exceedingly humid country, quite the opposite of the first in climate. He was quite sure that methods adopted in the one would be altogether unsatisfactory if applied to the other. He would refer briefly to the various items of construction, to see how the very low expenditure set forth in the Table could be accounted for. In the first place, the railway in question was simply laid on the surface; and of course, in a country where there was very little rain, the question of ballast was really a matter of small consideration, because with a sandy soil or a perfectly dry soil, and no streams, or very little water, the line was quite as good without ballast, especially with steel sleepers, as a ballasted road in England. Steel sleepers, however, were not used on the New South Wales lines. The method of carrying out the earthwork was the method commonly adopted at the Cape also. It did not pay in those countries to use ordinary contractors' plant, which, in fact, was quite unknown. The embankments were made from side cutting, the natives simply shovelling up the material from the side and throwing it on to the track. Cuttings were made by casting out the material to the side. The banks and cuttings were made quite independently, but that could only be done where, as described in the Paper, both were shallow. That was a very general practice, and was much cheaper than any attempt at using tip-wagons or any other mode of carrying the earth from the excavation to the embankment. The land was of practically no value, and therefore the fact that side cuttings occupied a certain area of land did not entail any material addition to the cost of the railway; in that respect, therefore, it was a comparatively simple operation. The item which struck him as being the lowest—and it applied equally to all railways, whether light or heavy—was the permanent way, to which the previous speaker had referred. The freight to Australia must be very low if rails, a little over 100 tons of which were required per mile, were delivered at £6 per ton, including the fastenings and fish-plates. Culverts and bridges constituted also a very small item, evidently because there were practically no water-courses. The mode of crossing the waterways described in the Paper might be very suitable in a dry country, but in Jamaica, for instance, the bridge would hardly last more than 3 years or 4 years, so that it would be a very expensive method of dealing with works of any magnitude to build them of timber. Again, if such a structure were built at the Cape,

it would cost very nearly as much as if it were of steel, because Mr. Cooper. in that country timber was exceedingly dear. It happened that in New South Wales timber was available and local conditions existed which made that form of construction suitable; and the members should not go away with the idea that a railway could be built, at the cost mentioned in the Paper, where such exceptional conditions did not exist. With regard to the practice of doing without fencing, the Author had referred to it as being applicable only in countries where the traffic was worked by daylight alone, which was of course quite an ordinary thing. For many years there had not been a yard of fencing in Cape Colony, except through cultivated lands, although there were 1,500 miles of railway working. The railways he had made there had never been fenced to begin with, but as the land became cultivated, the law of the country required the cultivated portions to be fenced, the owner of the land and the railway company each paying half the cost. If the railway was not fenced, gates were not required, and that expense was avoided. But it was not at all necessary to work a railway only in the daytime in order to avoid the provision of fencing. On the American lines a very large part of the route of the State express, which ran between New York and Buffalo, was entirely unfenced, even through the towns, where it ran across streets without any gates; and as that train ran at an average speed of 65 miles per hour, he thought it could scarcely be said that there was difficulty in working an unfenced railway unless it was worked in the daytime only. The lines at the Cape were worked day and night. With regard to stations, whether £213 per mile was exceptionally low or not depended entirely on their number; but the Condobolin station, he presumed, must have cost a large part of the total amount put down for stations on the line, because there were fairly good station-buildings, a goods-shed, an engine-shed, a turntable, a tank, and a 10-ton weigh-bridge, to say nothing of the cattle-yards and the fencing which all that necessitated, as well as the sidings. So that even with the low cost of permanent way, that station must have cost a substantial amount. The only other point he specially wished to refer to was the American system that had evidently been adopted in dealing with the sleepers. In America, where timber was exceedingly cheap, and the sleepers were simply got from the surrounding country and laid in the road, they were spaced in some cases not more than 18 inches apart. That was anything but economical from the point of view of maintenance, especially when

Mr. Cooper. it was borne in mind that maintenance ought properly to cover renewals. If the number of sleepers was doubled, and those sleepers only lasted a few years, this mode of construction was manifestly a somewhat extravagant one, as he knew from personal experience in another country. In the second Paper, stress was laid on the economy of sharp curves. A 5-chain curve was really a very reasonable curve, and one that could be worked without any serious inconvenience or danger. He had often run over such curves at a speed of 35 miles per hour. At the present time there were a large number of excellent locomotives running round 5-chain curves on the Cape lines, locomotives having eight wheels coupled, weighing, with the tender, something like 90 tons, and having about 9 tons on an axle. He had just had four of those engines built, and they were doing very satisfactory work. There were stretches of 10 miles or 15 miles of line, consisting largely of 5-chain curves with short lengths of straight line between them, and there was no difficulty at all in working those sections. The curves were combined with inclines of 1 in 40, and the engines could take a load of 200 tons up such curved inclines, so that he did not think special locomotives were really required to deal with curves, provided they were not of shorter radius than 5 chains. With regard to the diagrams showing the wearing of the rail, he knew of a case in which that had occurred, and to a large extent it had been caused by the rails being laid vertically, instead of with a cant, so that the flange of the wheel had been always wearing against the side, instead of the surface of the cone being perpendicular to the axis of the rail. He thought that might be in some degree the cause of the curious form in which the rails had worn. The question of economy in any case of railway construction must necessarily be largely governed by the particular circumstances of that case; for what was an economical railway in one place might be an inefficient and uneconomical railway in another. The Papers were valuable as giving an idea of what might be done where the circumstances were undoubtedly very favourable to economy.

Prof. Warren. Professor W. H. WARREN remarked that Mr. Deane had stated in a clear and concise manner the practice which had been found generally most suitable for New South Wales, where the conditions were naturally different from those existing in a settled country. From his knowledge of the United States, the conditions in New South Wales appeared to be very similar to those in America, especially in the Western States, and pro-

bably they were similar to those which existed in South Africa. Prof. Warren. That might be an interesting matter in the future when the railways of the Transvaal were developed by British engineers. In a country which was only partially settled by a small and scattered population, it was necessary to construct a railway economically, otherwise there could be no railway at all. Consequently, every means had to be adopted to reduce the cost of construction to a minimum, consistently, of course, with economical working. He thought the tendency in New South Wales was to avoid earthwork, as far as possible, in such railways as Mr. Deane had described, on the ground of its expense, the idea being to keep the line at the surface. With regard to the various sections showing the permanent way, perhaps the most interesting was that which showed an unballasted road; and although such a road would not be suitable where the rainfall was at all similar to the rainfall of this country, yet in the dry districts of New South Wales it had been found advantageous, or, at any rate, possible to use it, just as it had been in the Western States of America. The construction of such a road was not as easy as would appear at first sight. Great attention had to be given to drainage, water not being allowed to rest upon the surface at all. It would be noticed that the road was considerably arched in the centre and that it sloped down on either side to the level of the bottom point of the sleeper. That was an important point, because it meant that between each pair of sleepers there was a clear way for the water. If that was attended to, it was possible to make such a road work very well with the small traffic carried and the low speeds used on such pioneer railways. With regard to rails, a flat-bottomed rail was universally adopted in Australia because of the use of sleepers of ironbark or other hardwood timber. The hardwood timbers of Australia were very heavy and durable, the average life in New South Wales of ordinary red-gum sleepers being 25 years; and ironbark sleepers would last longer, though ironbark was a valuable timber, and rather too good for sleepers. That was a much longer life than could be obtained with pine timbers even after creosoting them on most approved plans. With a heavy sleeper, therefore, a flat-bottomed rail, and ordinary ballast, a good stable permanent way was obtained. He was speaking entirely from memory and had in mind the results of calculations made in the past, but he thought if the weights per mile of the rails and sleepers in the permanent way of the New South Wales railways were

Prof. Warren. taken out and compared with the weights of the permanent way of other railways it would be found that the permanent way of the New South Wales railways weighed more, so that they were at least a little more stable than ordinary railways carrying the same weight of rails, simply in consequence of the extra weight of the sleepers. The design of structures, also, was governed by the materials at hand. The Australian timbers he had referred to were also very valuable for beam-bridges or truss-bridges. Ironbark was almost universally adopted in New South Wales for the construction of timber trusses, or the various spans of beam-bridges. In the diagram, Fig. 4, Plate 5, for instance, there was an opening of about 14 feet, and in a 14-foot opening of a beam-bridge it was possible to do very well with three ironbark beams, 12 inches by 12 inches, spaced so that the load would be equally divided over each beam. That was the most convenient and marketable size which the growth of the trees allowed to be cut; and it was hardly possible to get timber deeper than 12 inches in large quantities, a fact which in itself had caused the methods of construction to differ widely from those adopted in America for timber trestle beam-bridges. There two or three timbers were placed in a group under each rail, each beam being about 4 inches wide and 16 inches or 18 inches deep. That method had been adopted with pine timber simply because it could be most conveniently obtained in those proportions. The only danger was that the beam might be made too deep, and might fail by longitudinal shearing along the neutral axis towards the end. That was not likely to occur with Australian timbers, because they were very strong in horizontal shear, and, in fact, strong altogether. Ironbark was at least one-third stronger than the strongest oak, the modulus of rupture being about 13,000 lbs. to the square inch in beams 12 inches by 12 inches. It was, therefore, quite possible to design a timber bridge that would carry the heaviest engines on the New South Wales Railway; or, in the case of the light railways described in Mr. Deane's Paper, where the weight on an axle would not exceed 12 tons, two ironbark beams, 12 inches by 12 inches, would probably be used. In designing a bridge for a span of say 20 feet, 12-inch by 12-inch beams could not be very well put side by side, as the weight would not be equally distributed over them. In that case one beam was placed under the other, and the two were united by wedges and bolts. Various attempts had been made to construct a compound beam which would be as stiff as a simple one of like depth, and it had been found

that by placing the wedges diagonally, and slicing pieces with a saw out of the bottom and top of the upper and lower beams respectively, wedges could be put in, the beams could be bolted together, and a compound beam was made which had about 90 per cent. of the strength of the simple beam but was not quite as stiff. For longer spans, the diagram showed a 60-foot truss-bridge with timber top and bottom chords and, apparently, vertical steel bolts, which could be screwed up to adjust the timbers. The timber tended to shrink, and when it shrank it was necessary to bring the wood together again. By keeping the angle of the diagonal members the same, there was no difficulty in adjusting shrinkage by merely screwing up the bolts. A still better plan appeared to be to place the steel bolts diagonally, and to arrange the timber compression-members vertically. If models made on the two styles were examined, it would be seen at once that there was greater stiffness in the bridge made with vertical timbers and with diagonal steel or iron bolts. That form of bridge had given great satisfaction, not merely for railways but also for roads. It would be noticed that the bridges had what was called the American deck, consisting of timbers spaced 6 inches apart, on which the rails were laid. That formed a very good way of constructing permanent way over bridges. Mr. Deane said that the sleepers on the unballasted road were spaced about 2 feet 2 inches between centres; and, of course, by spacing the sleepers so closely a good deal of the difficulty caused by not having sufficient ballast was got over.

Mr. HORACE BELL said there was only one point he would like to accentuate in the discussion, and that was the question of ballast, which weighed on the minds of many members in connection with the construction of light railways. In the case of a great many lines a very good shift could always be made by using ordinary river-sand, which could generally be obtained very cheaply; or, in many cases, the soil itself might be found to be sufficiently sandy to stand a heavy traffic without any addition whatever, as his own experience had shown him. The drainage of such sandy soil was comparatively immaterial. When the sand from rivers and streams was used, a sufficient thickness could be obtained very often for but little more than the mere cost of digging, and it required no special cross section in the embankment. The whole tenour of Mr. Deane's Paper would lead the members to see that the construction of a cheap railway was largely due to exceptional circumstances, and certainly in the case of the particular line referred to it was due very largely to the

Mr. Bell. existence of ironbark trees in the vicinity. Such wood as that was invaluable to the engineer for constructing cheap railways. But it should be remembered that the construction of timber bridges was not a question of the mere materials of the bridge; it was more a question of the working up, or the joints in the timber, which were the first places to fail. However cheap timber might be, or however durable it might be, the joints would give, and from that point of view the class of line that Mr. Deane had described, although cheap, was more or less a temporary line, and that view, he thought, would be accepted by the members.

Mr. Robertson. Mr. F. E. ROBERTSON thought that, apropos of what Mr. Bell had said about the use of sand for ballast, it might interest the members to know that on the East Indian Railway there was a section of about 25 miles of the old loop line constructed before the Mutiny, which was laid with sand-ballast and pot sleepers, and a light boxing of brick to keep down the dust. He did not know how many pots had been changed since the line was made, but during the time he had been chief engineer that section had kept in excellent order. It was fairly light in maintenance, and breakage of the pots was exceptional. It would thus be seen that sand in certain cases made excellent ballast.

Mr. Rigby. Mr. J. RIGBY remarked that the form of permanent way referred to in Mr. Deane's Paper appeared to have been adopted because the ballast was of earth. The Author alluded to cutting it away from the end of the sleeper to prevent the traffic splashing it up on to the working parts of the locomotive. He had had a good deal of experience in a country where there was practically nothing for ballast but black vegetable earth, and he had found that on the whole it formed a very good ballast. It was necessary in that case to keep the boxing somewhat in the style of Fig. 9, Plate 5. That was in the Argentine Republic, and roads there were ballasted almost to the shoulder of the rail. They were kept a little low between the rails to prevent the flange catching up the mud. In that way a surface was formed from which the rain ran off, and water did not lodge under the sleeper. Occasionally, when the road had been freshly packed and heavy rains came on, the water soaked through and caused a little trouble by lodging under the sleeper, but, on the whole, earth formed a very good ballast. One thing struck him with regard to the peculiar manner of cutting away the ballast, viz., that whilst on the American lines it was carried out on comparatively straight roads, on the New South Wales lines there were very sharp curves; and it seemed to him that such an unballasted road would be very difficult to keep in

line. On railways in Brazil, where there were equally sharp Mr. Rigby. curves, he had seen the road shifted over 10 inches under a passing train, although there had been a shoulder of ballast of decomposed granite outside the sleeper. In New South Wales, where there was no ballast at all, and the road was simply held in position by friction under the sleeper, he would have thought that heavy engines travelling at even a moderate speed would throw the road considerably out of line. He thought Mr. Deane might give some information on that point.

Mr. DEANE, in reply to the Discussion, remarked, with reference Mr. Deane. to the President's observations on the insertion of tangents of sufficient length between reversed curves in hilly country, that it was now the general practice in New South Wales to have all curves laid out in the first instance with straights at least 4 chains long between them. This admitted of the use of transition curves about 4 chains in length, or twice the half length to each curve, *Fig. 1*. All curves of a radius of 20 chains and under, whether single or reversed, had transition curves at their ends. These

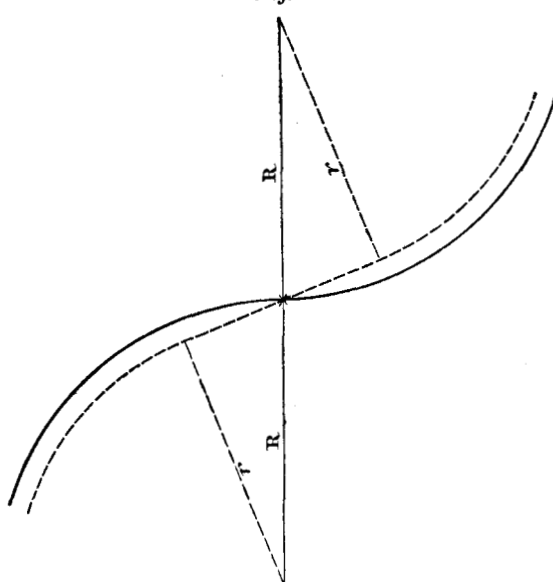
Fig. 1.



were set out on the cubic-parabola principle by means of Tables applicable to each particular case. The length of straight line left between the ends of reversed curves after absorption by the transition curve might be very short, even nil, but no difficulty was experienced by the rolling stock, as the change from the radius of the middle part of one curve to one of infinite radius, and then over the transitional part of the reversed curve to the other proper curve, was very gradual. The radius of the sharpest curves now laid out for new lines was 10 chains. There was much less difficulty in finding room for transition curves, even in rough country, than would at first sight be supposed. If R were the radius of two reversed curves between which it was desired to place a tangent of 4 chains length, the curves must be set in the centre, *Fig. 2*, the new radius r being given by $r^2 = R^2 - 2^2$ and if $R = 10$ chains, then $r = 9.795$ nearly, or only 20.2 links shorter than the original curve. If 10 chains was the limiting radius, as in New South Wales, then all that was necessary was to use a slightly longer radius for the curves of the preliminary survey, calculated from the same equation, $R^2 = r^2 + 2^2$,

Mr. Deane. and $R = 10 \cdot 198$, where r was 10, the difference thus being less than 20 links. Cuttings were avoided where possible because the drainage was so much more effective on banks and the cost of maintenance was less. The water falling on an embankment ran off at once; the weathering on the slopes of cuttings caused an accumulation in the water-tables which reduced the drainage of the formation, and the latter tended to become sodden under the sleepers if the water-tables were not kept very clean, which of course involved expense. This was the only reason for avoiding cuttings. The American method of erecting timber trestles over

Fig. 2.



ravines, with a view to economise time and earthworks in the first instance, would not pay in Australia, where the hard woods used were so much more costly than pine in America. As had been remarked by Mr. Robertson, the prices of rails and fastenings, when the estimates for the Parkes-Condobolin Railway had been made, had certainly been low. The average price of steel rails and fastenings delivered in Sydney, up to 18 months ago, had been about £5 per ton. The last rails and fastenings ordered would cost about £7 10s. 0d. per ton delivered in Sydney. The steamer-freight for rails from England had been as low as 5s. per ton, but the price paid for many years had been 7s. 9d. per ton. The

railway carriage charged from the stores to the works was at the Mr. Deane. rate of 1*d.* per ton per mile. The weights of 60-lb. rails (in lengths of 30 feet) and of fastenings per mile were the following:—

	Tons.	Cwt.	Qrs.	Lbs.
Rails	9½	5	2	24
Fish-plates	6	18	1	14
Fish-bolts and nuts	1	0	2	27
Spikes	3	6	2	13

By brick ballast Mr. Robertson presumably meant burnt ballast. This would be too expensive, as suitable material was rare in the interior, and fuel was difficult to obtain. With regard to piecework, this principle was frequently made use of in excavating, where there were too many stumps in the ground to use the plough and scoop, and where it was therefore necessary to use pick, shovel and barrow. Small contracts for taking out cuttings, for bridge-tops, etc., were let; but, generally speaking, day-work had been found to be quite satisfactory in its results, and it could of course easily be seen that, for plough- and scoop-work, piecework would be of no advantage; all that was required was an efficient ganger to see that men and horses were kept steadily at their work. The cost of waterways was naturally low where rainfall was small; at the same time he thought the economy was due quite as much to design as to the small amount of waterways required. The rainfall in the interior of Australia, although generally sparse, was liable to great fluctuation. It occasionally happened that a district might have as much rain in 1 month as usually fell in a year; and 5 inches or 6 inches in 24 hours was by no means an uncommon occurrence over a particular patch of country. It did not appear desirable, however, to provide for very exceptional conditions which occurred at intervals of perhaps 20 years or 30 years, because if a low bank were washed away the damage was quickly and cheaply repaired.

With regard to the question of dispensing with fencing, it was generally considered that when travelling by night was necessary the line should be fenced, as sheep and cattle would camp on the formation at night. Trains did run after dark, however, on portions of the unfenced lines, especially in winter when the days were shorter; and then safety was secured partly by the adoption of a low speed and partly by an efficient look-out, rendered possible by a powerful headlight on the engine. With regard to settlement bringing with it the necessity for fencing, it was to be noted that there was considerably less risk in running at night through cultivated land with farm-crops and orchards, where

Mr. Deane. there was no stock likely to stray on to the line, than through pastoral country. A little calculation would show the economy of close sleepers, and the saving in first cost compared with ballast. The new lines in New South Wales had about 580 sleepers per mile more than the previous design of permanent way. Taking the cost of these at 3s. each, the extra expenditure per mile was £87, which would be far less than that of ballast under most circumstances. As the sleepers lasted between 20 years and 25 years before they required renewing, it was clear that the annual cost of renewing the extra quantity was small. Guided by the results of his own observation, he was strongly of opinion that it paid to put in the extra sleepers even where ballast was used as well; the road obtained a better support, it was also less liable to subsidence and to lateral shifting, and consequently it was better and more cheaply maintained. The weight of the permanent way in New South Wales was, as Professor Warren thought, greater than that of most other countries, and the lines were therefore somewhat more stable. This was due to the high specific gravity of ironbark and other timber used. A cubic foot of ironbark weighed 70 lbs., and the permanent way of the unballasted lines with the 60-lb. rails weighed 343 lbs. per yard. In reply to Mr. Horace Bell, he did not understand how the class of line advocated could be called "temporary." If the traffic remained constant the line would require no improvement, and it was not easy to see why the use of a material such as ironbark, which had lasted in bridge structures at least 25 years, should earn for the line the character of "temporary." There were many examples of timber railway bridges of different designs in New South Wales, which had preserved their form in spite of age, and which had had to be renewed after a period such as that mentioned—not so much on account of deterioration, as because they had had to make way, like many of the old cast-iron and wrought-iron girder bridges in England, for a design more fitted to carry the heavier rolling-stock.

With regard to possible shifting of the roads on sharp curves, under passing trains, to which Mr. Rigby had referred, there were curves of 10 chains radius on portions of the unballasted lines already open for traffic, but with the limited speed adopted no damage seemed to be done. It must be remembered, as mentioned above, that the weight of the permanent way was very considerable, and must resist distortion. Further, the outer rail on all curves was of course elevated to suit the radius and a speed of 20 miles per hour, and the pressure on the earthwork when the

speed was 20 miles per hour or under would be normal to the Mr. Deane. inside of the curve.

Mr. STIRLING, in reply to the Discussion, observed that the short Mr. Stirling. tangent between many of the sharp curves, viz., 24 feet, had been fixed as the shortest practicable one for the eight-coupled class of locomotives. This only allowed for one bogie and the driving-wheels being on the straight line, while the other bogie was on a curve, yet the engines went smoothly from one curve to the other. It would be noted, however, that the speed did not exceed 15 miles per hour. Moreover, the full curvature was not given at the entrance to the curve, but was increased gradually in the length of the first rail (24 feet) at each end of the curve.

It had been frequently found in revising the curves that the tangent was not more than 12 feet, but in such cases the eight-coupled locomotives were felt to lurch, although the "Meyer" and "Fairlie" engines still passed smoothly. On account of the almost entire absence of rain, the ballasting was a comparatively simple matter. On the first section, ballast of excellent quality was easily obtained from the hill-sides and water-courses, and this was the only section where rain ever fell. The other sections were ballasted with the dry baked salty mud of which the ground was composed. This generally contained a good percentage of sand and packed firmly, but in some parts it had no sand, and broke into a powder so fine that it was blown from under the sleepers by the movement of air caused by passing trains. In these cases sandy soil had to be brought from the nearest watercourse.

Referring to Mr. Robertson's question why the 48-lb. rails gave no better service than the 40-lb. rails, it would be noted that quality (*b*) of the 48-lb. rail gave really poorer service. The 40-lb. rails had been manufactured in Belgium, of a much harder quality than was produced by English makers; but although they had given so much better service there had been at first quite a number of broken rails. This had been chiefly, if not wholly, due to faulty manufacture, but the danger of a broken rail on the edge of a precipice was too great, and precluded the ordering of more rails of this make. The greater part of the line was laid with these rails, and except on the first section, where, owing to the sharp curves and heavy gradients, the service was exceptionally severe, there had been very few broken rails. English rails of ordinary quality, weighing 48-lbs. (*b*), had been obtained, and for double the loss of metal had given actually a poorer service than the 40-lb. rail.

Mr. Stirling. An attempt had been made to get a harder rail from English makers, and quality (a) was the result, but this again for double the loss of metal had given no better service than the Belgian 40-lb. rail. In the meantime the Author had been making inquiries, and had found that in the United States some of the leading railways had been specifying for harder rails, giving almost exactly the same analysis as the Belgian rails. The following Table gave the analyses of the different rails referred to:—

	No. 1. Belgian.	No. 2 (a). English.	No. 2 (b). English.	American Specification.
Carbon	0·3495	0·60	0·49	0·45 to 0·50
Silicon	0·109	0·052	0·052	0·15 to 0·20
Sulphur	0·045	0·055	0·054	0·069 maximum
Phosphorus	0·062	0·045	0·060	0·06 „
Manganese	0·662	1·09	1·06	1·05 to 1·25

This had confirmed him in his opinion that the harder rails, if properly manufactured, could be relied on, especially as with the low speeds and more elastic road-bed obtained by flanged rails laid directly on wooden sleepers, the jars or blows on the rails were much less severe than on English railways. Unfortunately, for the small quantity required, the special section could not be obtained in America, but a comparatively hard rail giving an analysis approximating to that of the 40-lb. rail and of satisfactory manufacture had been obtained from the same Belgian makers. These rails were being laid on the curves at the end of 1898, when he had left Tocopilla, but he had no advice of the results obtained. At present there was great complaint in America that makers, in the present press to turn out steel, were producing rails of a softer quality, which did not give nearly as good results as the harder rails formerly obtained. The rails had all been laid to 3 feet 6½ inches gauge on the curves, and the 48-lb. rails had had to be brought in to this gauge when half worn, so that the conditions for both classes of rails had been identical. The curves were segments of circles, one rail only at each end being opened out gradually. No further modification had been possible on the sharper curves without incurring the extra cost which would have been equivalent to a curve of greater radius. No check-rails were used because of the extra friction they would have caused. Turton central buffers and hooks were fitted on the original cars, but on all new stock a simpler buffer with one spring on the draw-bar had been adopted. The slack of the hook was taken up by a simple eccentric as in the

Turton arrangement, but without the extra spring. The jaw of the buffer had to be wide enough to prevent the hook becoming jammed on the sharpest curve. No trouble whatever had been experienced with these buffers and hooks on the curves; a case of uncoupling was of very rare occurrence, and could almost always be traced to too great difference between the heights of the cars. No ring was used over the hook. He was aware that considerable trouble had been experienced on other railways with the hook-couplings, but it had never been quite clear to him whether this had been due to the want of the eccentric to take up the slack, or to want of care in keeping the heights of the buffers to standard. The trouble on one railway had evidently been due to the four-wheeled wagons in use, which naturally would give more vertical motion to the buffers on an uneven track than would be the case with bogie cars. Mr. Stirling.

In reply to Mr. Elliott Cooper, the radius of the curves was less than 3 chains (181 feet). Rail section No. 3 (*Figs. 4*) showed that the wear of the rails on a curve approximating to 5 chains (302 feet) was not excessive. All the rails were laid with a cant, each sleeper being channelled to a template. The form to which the rails had worn was such as would be expected from the flange of the tire being thickest at the root, and not so deep as the head of the rail. Rails worn to exactly similar form, though of course after much longer service, might be seen on curves on some of the main lines in the United States to-day. There was no doubt that economy in railway construction must be very largely governed by circumstances, but English engineers had always been too prone to base their specifications on conditions ruling on English railways, and to neglect too much local conditions and requirements. Had the specifications for the first railways in New South Wales, described by Mr. Deane, been adapted to the circumstances, as was the case with railways being constructed in America at the same time, large territories would have been developed years ago, and the colony would probably now have double the mileage. The astonishingly rapid development of the Western States of America had been entirely due to the rapid extension of economically constructed railways, which had been improved as the increasing traffic warranted.