Discussion.

The President. The PRESIDENT moved a vote of thanks to the Author for his interesting communication, which was accorded unanimously.

Mr. Bell. Mr. HORACE BELL, Consulting Engineer to the line, having exhibited some photographic views of the railway, remarked that in the absence of the Author, who was in India, he had agreed to say a few words in opening the discussion. The Author's claim to write on the subject was not confined to his having been the engineer of the Nilgiri Railway; he had been also one of the engineers on an important hill line joining the north-west frontier of India and Afghanistan, and he had in addition visited, on behalf of the Government of India, nearly every rack-railway in Europe and America, and every important mountain line; so that the opinions expressed in the Paper might be said to embody not only the Author's experience of the Nilgiri Railway, but also his knowledge of what had been done elsewhere. It would be remembered that in 1895 two Papers on the subject of rack-railways had been discussed at the Institution,[1] and, excellent as those Papers had been, the discussion upon them had been even more instructive. He did not know that the Author had been able to add much to the general lines which that discussion followed. The Paper laid stress, and not unduly, on the great importance, in the case of a rack-line, of accurate laying out, and, more especially, accurate laying of the road. According to the frequent letters he had received from the Author, it seemed difficult to exaggerate the importance of this point. The fact was that a rack-road, as had been often said before, was a piece of machinery, and the rack had to be laid with as much truth and care as a rack had to be laid for a planing-machine. Another point about the line was the use of timber sleepers. Hitherto all rack-railways, except one, had been laid with stamped steel sleepers. He agreed with the Author in thinking that these sleepers were not suited for the purpose, however well or ill they might be suited for ordinary railways, and he might claim perhaps to have a rather wide knowledge of them. He could not regard the steel sleepers as being as good as the timber sleepers used on the Nilgiri Railway, which had given complete satisfaction; whereas if metal sleepers

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

had been used, trouble would have been caused in several ways, Mr. Bell. and he felt certain from his own experience that steel sleepers would be found to give a great deal of trouble in the future. A point in connection with the Nilgiri line—and indeed with many rack-lines hitherto—was that the performance of the engines had not fulfilled anticipations. In the case of the Nilgiri Railway it had been stated in an outline specification that the engines should haul 60 tons gross up the incline, whereas the performance had scarcely exceeded, save in very exceptional cases, 50 tons; and, as the Author had remarked, the same trouble had occurred on the Usui line. The engines on the Nilgiri line had a rigid wheel-base of 10 feet, and he feared in allowing that he had gone a little too far, and that it would have been better to decrease the wheel-base, though it was not an unusual one, as it had been used before on a rack-line with similar curves and gradients. What he wished to discover—and he hoped it would be elicited in the discussion—was the reason why, when the engines had been properly designed to haul up a load of 60 tons, they would only take 50 tons. The Author's view was that the value of the adhesion had been over-estimated. It had been thought that a coefficient of $\frac{1}{4 \cdot 58}$ might be taken, but the Author considered, and probably he was quite right, that $\frac{1}{7}$ should have been adopted. That, however, would not account for the non-performance of the calculated duty. With regard to the adhesion, with the rails in the most favourable condition it had been found that the engines with difficulty would haul 60 tons, and his own idea was that the frictional resistances which were to be found in every rack-railway had been under-estimated. As such railways must have sharp curves and bogie rolling-stock, and be worked with the engine behind the load, he believed that, large as had been the allowance made for those factors, it was not large enough. Another point, to which the Author had not referred, was the difficulty of getting a suitable coupling for vehicles pushed round sharp curves. The Jones coupling used was one which had been largely adopted on railways of the same gauge in India (metre-gauge), and was very good for ordinary purposes; but when used on bogie stock, with carriages 30 feet long, pushed up round sharp reverse curves, it was scarcely better than any old coupling to be found on a contractor's truck. The fact was that no satisfactory central-buffer coupling was to be obtained which would really do good work when the load had to be dealt with in that way. He would have been glad if the Author had given some information as to

Mr. Bell. the working-cost of the line. It had now been open about 18 months, and for 12 months there were fairly reliable figures, very much complicated, however, by stoppages on account of slips. As far as he could make out at present the cost for haulage alone had come to 3*s.* 2*d.* per train-mile, which was largely in excess of any figure of the sort on any ordinary railway in India, and, he need hardly say, on any railway in England. If any member could furnish information on that point he would feel greatly obliged.

Mr. Carruthers. Mr. J. CARRUTHERS considered there was little in the Paper which was open to anything but the most favourable criticism, in regard either to the line or to the manner in which it had been described; but on some points he ventured to differ from the Author. It was stated in the Paper that the interpolation of a length of rack in an important main line of railway would be worse than a break of gauge, and that, under such circumstances, an adhesion-line would almost always be the better of the two. He could not help thinking that the Author was here falling into the very common error of attributing to the mechanical appliances which were used in getting up a mountain the inconveniences which were really due to the mountain itself. The Madras Railway, fortunately, was not obliged to go over the Nilgiris, because it could get round them, but if it had been obliged to go over them, and to pass up the Coonoor Ghat—thus making the Author's rack-railway a part of the main line—then undoubtedly the inconvenience would have been greater than a break of gauge. The question was, would it have been removed or even lessened by substituting an adhesion-line? Supposing that the gradient had been reduced from 1 in 12½ to 1 in 25, the length of the incline being consequently increased from about 12½ miles to 25 miles, would there have been no inconveniences attending the interpolation in the main line of a railway of a section 25 miles long with a gradient of 1 in 25? All engineers would agree that the inconvenience would have been very serious indeed, and he thought that most of those who had also had experience of steep gradients with special means of mounting them, rack, rope, or other, would agree that a line of half the length and double the gradient, with special appliances, would be a much safer line to work, and would entail on the whole fewer inconveniences than the longer line. If the gradient were increased to 1 in 50, there would be 50 miles of incline; and an incline of 1 in 50, 50 miles long, was much more serious than one 12½ miles long, with a gradient of 1 in 12½. A runaway was never heard of on gradients of 1 in 12½, or even on the 1 in 2 incline built in Switzerland; whereas runaways were heard of on 1 in 50 and 1 in 25, and unless his experience had been exceptional he would say they were not uncommon. Mechanically, the short line was the better of the two, because the total train-resistance in getting from the bottom to the top of the incline was less on the shorter line on account of the less distance travelled, and the less resistance due to the lower speed. That became an important matter where the curves were severe, because a curve that was only a nuisance at a speed of 10 miles an hour was something more than a nuisance at 20 miles an hour. In short, wherever there was a serious range of mountains which had to be surmounted by a line with a uniform gradient between two points, the shortest line was mechanically the best, and the argument for adopting it was the more cogent the longer the railway and the heavier the traffic; the more work to be done, the more important was it to do it in the most mechanical manner. This argument assumed that the shortest line had a gradient for which the mechanical engineer could design an engine to work with perfect safety, and with a speed corresponding to say 30 miles or 40 miles per hour up an incline of 1 in 50, which the engineer could do with gradients even steeper than 1 in 12½. It implied also that the range of mountains to be attacked was high enough and abrupt enough to make the line passing over it, whether by adhesion, rack, or other means, a distinct section. It would be absurd to introduce a separate section for a short rise of one or two hundred feet; the mountain must be so high as to make the line over it a special locomotive section. When the train was brought up to the foot of the incline and the engine had to be changed for a more suitable one, it was just as easy to change to a Fell central rail or an Abt rack as it was to change to a different class of adhesion-engine; or if a bank engine had to be used to help the train up, there was no reason why the Fell system should not be used. The Author stated that the Abt rack had been selected on the Nilgiri Railway after a very careful comparison of the relative merits of the Fell and Abt systems. Mr. Carruthers thought that was a subject on which opinions might differ. One of the most important examples of the Fell system was the line over the Rimutaka in New Zealand, which had been opened for public traffic in 1878, and had been running ever since without breakdown, stoppage, or trouble of any kind. It had been carrying a large volume of traffic as part of the main line of railway. Another line proposed in New Zealand was to have been carried through the Otira Gorge. The line would have been similar to the Nilgiri

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Mr. Carruthers. line, the gradient being 1 in 12½, and the radius of the curves, of which there were to be many, 5 chains. The New Zealand Government, after careful comparison of the relative merits of the Fell and Abt systems, had come to the conclusion that the Fell system was the better of the two. Of course the Government had been guided by their engineers; but when able and experienced men who had been working the Fell system for twenty years said it was better than the Abt for a line of 1 in 12½ and 5-chain reversing curves, he thought it showed there was not such a decided superiority of the Abt system as was claimed in the Paper. He had himself used both systems, the Fell for the Rimutaka incline in New Zealand, with a gradient of 1 in 15 and a succession of 5-chain reversing curves; and the Abt for the Trincheras incline in Venezuela with a gradient of 1 in 12½ and a tolerably straight line, the minimum radius of curves being 500 feet, and such curves being few in number. If he had to do that work over again, after having heard what other engineers had said and done in the matter, he did not think he would make any change; but if he were inclined to make a change, it certainly would not be in the direction of substituting the Abt for the Fell system on the Rimutaka incline. Where the gradients were as flat as 1 in 15, he preferred the Fell system as the simpler mechanism. With a gradient of 1 in 12½ he would still prefer the Fell, unless the line were particularly straight, as it was on the Trincheras incline, because the drawbacks of the Abt system increased very rapidly with the curvature. With steeper gradients (he would not pretend to say where the line was to be drawn) the Abt was undoubtedly superior to the Fell system, but there its competitor was not the Fell, but the rope system. A case had occurred lately in which very experienced engineers had preferred the rope to either the Abt or Fell systems or an adhesion-line on an important main line of railway, and he hoped a description of that line would be given by the engineers who had carried it out. It was on that admirably designed line, the São Paulo, in Brazil, where lately it had been desired to lay a second line, and, if possible, to get an adhesion-line instead of the 1 in 10 incline with a rope, hitherto used. The engineers had had extensive surveys made, with the result that they had given up the idea of an adhesion-line and had come back to the rope; which showed that the Author was not supported by all engineers in saying that an adhesion-line was nearly always the best for a main line of railway. Of course the Abt, the Fell, and the rope systems each had their special uses. Where a line was

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particularly straight, he would be inclined, nowadays, with the improvements made in the Abt system, to consider it a very strong competitor with the rope system. As he had already remarked he thought that in attacking an incline with a uniform gradient between two fixed points, the shortest line was the best. The Nilgiri had not been built as the shortest line; there had been a good deal of development made in order to obtain the gradient of 1 in 12½. The strange thing was that that gradient had been fixed not by the Author or by any of the engineers concerned, but by the Government, and apparently without any reference whatever to the general form of the valley, or to the in-

Mr. Carruthers. system used on the Nilgiri line, fixed the curves to be adopted. The Author stated that if his hands had not been tied by the use of the Abt system he would have used much sharper curves and greatly reduced the cost of the works. He could not help thinking that under those circumstances the Abt was not the correct system to adopt. Where very sharp curves were permissible it was better to use the Fell system. If the Nilgiri line had cost more than it need have done on account of the Abt system being used, he felt very doubtful as to whether the Fell system would not, under the circumstances, have been preferable. The gradient on the first Fell railway built had been about 1 in 12, the radius of the curves being about 120 feet. He thought it was possible to use any curves with the Fell system.

Colonel Pennycuick. Colonel J. PENNYCUICK, R.E., did not propose to enter into any criticism of technical details, but he considered that the Author was to be congratulated on having carried out, in a very satisfactory manner, an exceedingly difficult piece of work. He did not think the Paper gave any idea of the actual physical difficulties involved in the laying out of the line, apart from the construction. He had a vivid recollection of going over a certain portion of it at the end of 1895, and it had been the hardest day's work he had ever done in his life, although it was what the engineers of the line had done every day for years. One great advantage of the line was rather of a moral nature, and that was the service to humanity which the construction of the railway would render. The passenger traffic had been very considerable, in fact, two or three times in the year it had been extremely heavy; and the result had been that the unfortunate ponies which drew the tongas taking the passengers up had been treated in a manner that would raise the indignation of every member who saw it. It was no small matter to get rid of that altogether. He thought that when Lord Wenlock had been Governor of Madras, the Government had endeavoured to introduce a measure bringing the Prevention of Cruelty to Animals Act to bear on the subject—with what success he was not quite sure. He was very anxious to learn what prospect there was of the line being extended to Ootacamund, which was necessarily its objective. He believed the site of the station at Ootacamund had been settled before he had left India, but he had never heard whether the actual nature of the line between the two points had been decided upon. Speaking from memory, he believed that from Coonoor, where the present line terminated, to the crest of the ridge which divided the water-shed of the east side of India from the west side the rise was about 1,000 feet, and there was a fall of about 200 feet into Ootacamund itself. It would be quite possible to make an adhesion-line the whole way, with a gradient of 1 in 40, which would not be longer than the 11 miles of the existing road. It would be interesting to know what system was to be adopted and what chance there was of the line being finished. As long as the railway terminated at Coonoor, it could hardly be said to be completed, but he presumed it would be extended sooner or later by another special line down the west side of the plateau to join the Mysore Railway somewhere on the west coast. Colonel Pennycuick.

Lord Wenlock.

LORD WENLOCK, G.C.S.I., observed that he had had the honour, while Governor of Madras, ten years ago, of cutting the first sod of the railway; and it had given him the greatest satisfaction to be present that evening to listen to a description of the completed line. The work had been undoubtedly one of very great difficulty, and the Government of Madras had been placed in a state of great hesitation, in consequence of the indecision of the engineers as to the best line to adopt and the best system to use. One of the speakers had been rather hard on the Government in saying that it had interfered and had prevented the adoption of what was now perhaps thought to be a better system. That had occurred before he went out to Madras; but he could say very positively that the Government of Madras would not have ventured to alter or to decide upon any particular alignment or any particular system, unless it had received the most careful advice from its professional advisers. The Government of Madras, or any other Indian Government, did not take upon itself to settle matters of engineering difficulties, without having the fullest possible advice from those whom it considered most competent to advise; and in that respect it might be that the Government had been led astray by the advice it had received at the time. When he had been in Madras many different engineers had come to take up the work on the railway, and as far as he could remember, every one of them had pronounced himself able to devise a better system and a better scheme than that which he had been called upon to finish. It was quite possible that they had been right, but it might be taken that the decision of the Government had been arrived at only after careful consideration and deliberation on its part. He congratulated the Author, whom he had last seen on the railway, on having completed his work, and sincerely trusted it would be the means of extending the system of that particular railway and of opening up a very

Lord Wenlock. much larger district both on the Mysore side and on the Madras side. There was undoubtedly a very large traffic to be served, and a great deal of advantage to be gained in doing away with the pony traffic alluded to by Colonel Pennycuick, which was a disgrace to civilization. The way in which the ponies were treated in carrying goods up both sides of the ghat was shameful, and the continuation of the railway would be an enormous advantage to civilization, would bring the greatest kudos to the engineer who was able to devise a feasible scheme, and when carried out would be to the benefit of the country at large. When he had been in Madras the plans and sections for the extension to Ootacamund had been laid before the Government, and he was very much disappointed to find that they had as yet gone no farther. However, 2 years or 3 years was a short time in the life of a country, and he hoped that very soon the Institution would have, from those who had carried out the work, a description of the finished line, and would hear that the work had been executed as successfully as that under discussion.

Mr. Passmore. Mr. F. B. PASSMORE thought the Author had dealt with the subject in a very clear and judicious manner. Whilst it was desirable to have as easy gradients as possible on all railways carrying a considerable amount of traffic, requiring trains made up of several vehicles, there was nothing in the Abt system which prevented the use of sharp curves. It was not the rack, but other factors, which determined the minimum radius. Mr. Abt had built railways of metre gauge, where 50-metre and 30-metre curves had been adopted, and even a radius of 8 metres had been used with a gauge of 0·635 metre, which clearly showed that the rack did not prohibit the use of sharp curves. Of course, the longer the radius the better, as in every other railway. Mr. Passmore considered the use of timber sleepers, which the Author appeared to favour, to be very doubtful economy. Since 1885, several rack-lines had been laid with wooden sleepers; for instance, the Rigi Railway had been laid with them originally, but they had been abandoned and replaced by steel sleepers, and the same had been the case elsewhere. Although wooden sleepers were cheaper in the first instance, they did not last as long, and actual experience on a section of rack some 5 miles in length, where wooden sleepers had been adopted, had shown that the engineer found it necessary to keep two men constantly employed in tightening up for sleeper-shrinkage. If the cost of that labour were capitalised it would show wooden sleepers in a very unfavourable light. Steel sleepers possessed all the advantages which were erroneously claimed for wooden sleepers, and no difficulty had ever been experienced in their spacing. In building a rack-railway, or most other railways, the fact was often lost sight of that the question of maintenance was quite as important as that of first cost, if not more so; and if that was taken into consideration there could be no doubt that the use of steel sleepers, although more expensive in the first instance, would commend itself as the more economical course. Fig. 8, Plate 1, showed the lugs at the bottom of the rack-chairs let into the sleepers. That was exceedingly bad practice, as moisture would inevitably collect in the cavity and cause the wood to rot, which fact would probably only be found out when the rack-chairs gave way. He did not consider the progress made in laying the road—500 feet per day—a bad performance, seeing that only native Indian labour could be depended upon. When Europeans became used to the work there was no difficulty in laying 700 feet in a day. With regard to the allowance at the joints of the rack-bars on curves, the differences were accentuated by the use of long bars, and it was generally accepted that for a double rack the best results were obtained by using bars extending over two sleepers only, so that there was a joint on each sleeper; in which case the difficulty mentioned by the Author was practically obviated. With regard to the Author's statement that expansion and contraction did not take place parallel to the line, but that the force was expended in slightly bulging or flattening the curves, in Mr. Passmore's opinion, that bulging and flattening was due in a great measure to the fact, admitted by the Author, that no precautions had been taken to prevent creep. On a gradient of 1 in 12½ laid with wooden sleepers, such action was bound to occur, and showed itself in the manner described. It was stated in the Paper that on a falling gradient it was not necessary to commence the rack in advance of the beginning of the incline, but that in such cases the rack began slightly below where the incline commenced. That was a very serious mistake, and one liable to lead to accident. It was absolutely essential that the engine should have a good hold of the rack and absolute control of the train before entering on a falling gradient. In like manner, in going up-hill the engine should retain firm hold of the rack until the train was on such an incline that the engine could deal with it by adhesion only. It was needless to point out that the entering-tongue, which was fixed on springs and had its teeth sloped off at one end, could not be expected to serve as a portion of the rack for raising the load, and any attempt to make

Mr. Passmore.

Mr. Passmore. it serve that purpose would probably lead to the result that the teeth would slip out of gear, and the rack-engine would slip and damage both the rack-pinion and the entrance-tongue. He must state that the engines used on the Nilgiri Railway did not in any sense represent the Abt practice. The attachment of the rack-frame direct to the main axle-box, to which attention was called as a novelty or improvement, was really an old device. It had been used by Mr. Abt in 1887, but he had discarded it in favour of the system now adopted, which he considered a great improvement. Another improvement claimed was that the rack-pinion was not driven directly, but by spur-gearing. Mr. Abt had tried that system 10 years ago, but, not finding it satisfactory, had given it up. If the matter were studied it would be seen that in such a design it was necessary to deal not only with the wear on the pinions due to contact with the rack, but also with the wear due to the intermediate pinion; so that with that arrangement it was absolutely impossible for the pitch to be maintained as accurately as with direct driving. The Author was quite in error in saying that that arrangement increased the safety, and made the pressure on the rack-teeth half what it was with the ordinary Abt engine, in which, according to the Author, all the power was transmitted by one pair of pinions only, the second pair being used merely to give additional brake-power. No Abt engine had ever been built in that manner. In the Abt engine the power was transmitted directly in the ordinary way to the rear rack-pinion, which was in turn coupled with the leading pinion, so that both the pinions were driving under the same conditions. He was surprised to hear that the working train-load taken up a gradient of 1 in 12½ on the Nilgiri Railway was not greater than 45 tons to 50 tons with a 33-ton engine. The Author stated that a coefficient of adhesion of one-fifth was too high for the conditions prevailing on mountain railways, and that in his opinion it should not be taken for the purpose of calculation at more than one-seventh. The combination rack-locomotive worked, as regarded the adhesion portion, exactly under the same conditions as an ordinary locomotive, and the weight on the drivers had to be distributed similarly, in accordance with the work to be done. From the statement in the Paper, Mr. Passmore was tempted to conclude that the trials during which the engine had taken up 60 tons had been made when the rails were in such a condition that the coefficient of adhesion reached the value of one-fifth, or even higher. On the Beyrout-Damascus Railway the rise began about 5 kilometres from the port, being chiefly 1 in 14·3, with short adhesion-lengths of 1 in 40 to the watershed at an elevation of 4,879 feet. The gauge was 3 feet $5\frac{3}{8}$ inches, the minimum radius of curves 394 feet, and the ruling gradient 1 in 14·3 on the west side, and 1 in 16·6 on the east side. The problem was to take train-loads of 100 tons up gradients of 1 in 40 by adhesion traction, and up 1 in 16·6 by combined adhesion-and-rack, and 80-ton loads up 1 in 14·3, at a speed of at least 5·6 miles per hour. The engine weighed 33 tons empty and 44 tons in full working-order, the weight on the drivers being taken as 34 tons. The resistance on the 1-in-40 gradient equalled 1·6 ton for the locomotive and 3·05 tons for the wagons, or a total of 4·65 tons. On the 1-in-16·6 gradient the resistances were:—locomotive, 3·12 tons; wagons, 6·5 tons; the total being 9·62 tons. With 34 tons on the drivers that allowed a co-efficient of adhesion of one-seventh. The engines would have been of much lighter build under other circumstances, but they had to take the trains 146 kilometres, over two ranges of Lebanon, so that storage of a large amount of coal and water had to be provided for. The result of the increased strength and weight was that the engines were doing a far greater duty than had been prescribed originally; but even in December, 1894, although the men had then been imperfectly trained, it had been possible to take a somewhat heavier load up the incline at a speed of $7\frac{1}{2}$ miles per hour. Applying the method of calculation to the Nilgiri engine with a 60-ton train-load on a gradient of 1 in $12\frac{1}{2}$, the resistances would be: locomotive, 3·0 tons; wagons, 5·08 tons; total 8·08 tons. Probably the weight on the driving-wheels would not exceed 22 tons or 23 tons, so that, with a coefficient of adhesion of one-seventh, practically the whole of the adhesion would be required to lift the engine itself, leaving the rest of the load to be taken by the rack-engines. Messrs. Dubs & Co. of Glasgow had built some Abt engines for the Mount Lyell Railway in Tasmania, and the work they were specified to do was to take a train-load of 49 tons up a gradient of 1 in 16. The result of experience with those combination engines showed that a train-load of about 60 tons could be actually taken up by one locomotive, and by putting on more engine-power gross loads of 140 tons to 150 tons were taken without difficulty over the line. The resistances had been calculated for various conditions, and worked out at 4·92 tons and 5·15 tons respectively. The weight of the engine was about 24 tons, in full working-order; and taking the resistances as for the Damascus and Nilgiri engines, they worked out at 1·76 tons for the locomotive, and 4·05 tons

Mr. Passmore.

Mr. Passmore. for wagons, or a total resistance of 5·81 tons successfully overcome. The Author quoted in support of his contentions the cases of the Usui Toge, Transandine, and Snowdon railways, but a reference to the discussion which followed Mr. Pownall's Paper[1] would explain the reason of the failure. In reference to the load taken up by the Nilgiri engine Mr. Abt had written to him:—

> "If a locomotive of 33 tons weight only draws 45 tons on 8 per cent. or 9 per cent., the failure is due either to faulty construction or to very inferior fuel or to improper handling. On the Visp-Zermatt I take, with a locomotive of 29 tons service weight, 42 tons to 45 tons up 12 per cent. At Lehesten, with 23 tons service weight, 50 tons up 8 per cent., &c."

With regard to the Snowdon engines, he was not aware that any trouble had been found in raising the required load, but in any case the engines had not been designed by Messrs. Rinecker, Abt & Co., for the particular case, and there were several points in the design to which that firm took exception. If, however, any defect existed, it was only another instance which went to prove the correctness of the Author's statement that it was a mistake to suppose that because a special system had proved a success in one place it would necessarily be so in another where the circumstances might be dissimilar. The Author was also right in saying that every mountain railway was a problem in itself which must be solved independently. The Author seemed to have taken very great pains and to have solved for himself the question of the danger supposed to be found in the rising of the pinion on the rack; and he had come to the conclusion that the only way in which that was conceivable was by the pinions becoming locked, which only occurred with a very powerful brake, and that in no case should a brake of such power be used as to render locking of pinions possible. That had been clearly shown in the Snowdon accident, and no safety appliances attached to the rack would obviate the danger due to any disregard of this rule. He thought the Author was rather severe in his criticism of the rack-system when he said that, while a rack-line was most suitable for the Nilgiri Railway, the disadvantages of the system should not be lost sight of. If a boulder fell on a rack-bar and bent it to any appreciable extent, the traffic might be stopped until the bar had been replaced; but if the damage were not very serious it would be set right temporarily by the platelayer, and in any case this was an accident which might, with equal justice, be cited as a drawback to railways in general. He quite agreed that if a rack-

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[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 136.

railway was to be successful it must be carefully and substantially built and be maintained in absolutely perfect order; but he contended that this applied also to ordinary adhesion-railways. He did not agree with the Author's opinion that the interpolation of a length of rack on a main line would be as objectionable as a break of gauge, and that in most cases the alternative adhesion line would be entirely preferable. With reference to the opinion expressed by the Author on this subject, Mr. Abt had written to him:— Mr. Passmore.

"Concerning the adoption of the combined adhesion-and-rack system for main lines or for heavy traffic, one forms to-day quite a different opinion from that set out in the otherwise very interesting Paper. The rack-railway at Harz, at Erzberg in Bosnia and Herzogovinia, in the Carpathians from Zolyombrezo to Tiszolez show that even State Governments have learnt to appreciate the advantages of this construction. On the Erzberg, the goods traffic alone amounts to 450,000 tons of goods per annum. On the Zolyombrezo the normal train weight is 175 tons ex loco. Just at present I am building a long rack-railway for Austria from Tannwald to the Prussian frontier, which will have to deal with an enormous traffic; and a rack-railway of equal capacity is now being built, on my system, by the Prussian State Railways from Scheusingen to Ilmenau."

This clearly showed that Continental engineers, who were not generally credited with spending money without being satisfied as to the advantages to be derived, were not in accord with the views expressed in the Paper.

Mr. J. C. Larminie had seen a good deal of the railway while it was under construction, and could fully endorse what Colonel Pennycuick had said about the difficulties of carrying out the work there, and the cost. Labour was very scarce, and very difficult to get, and each day the labourers had had to be carried up from the plains. He had carried out work himself on the same hills, so that he could speak from experience in regard to it, and he thought the Author deserved every credit for the successful way in which he had carried out the enterprise, and for the substantial and excellent character of the work. Mr. Larminie.

Dr. A. B. W. Kennedy remarked that there was a point connected with such railways as that under discussion upon which he had made some experiments; and probably they would be interesting to some members of the Institution. The question had been whether there was any difference in the amount of power taken by a train being pushed up a line and a train being pulled up. It had seemed to him that possibly some of the local wear on the Waterloo and City Railway might be due to the partial pushing of the train round the rather sharp curves. The trains consisted of four coaches, with motors in front and at Dr. Kennedy.

Dr. Kennedy. the back, and of course the work was done half by pushing and half by pulling. He had divided a train into two parts, one consisting of two long coaches with the motors at the front, and the other of two long coaches with the motors at the back. He had run those trains alternately pushing through the up line and pulling through the down line, and pulling through the up line and pushing through the down, and as the motors were electrical it had been possible to measure fairly accurately the power given out by the motors in each case. Each experiment had been repeated several times, so as to get the figures as accurately as possible. In the end it had been found that there was practically no more difference between them than would naturally be expected in any such measurements. The difference had not been more than $1\frac{1}{2}$ per cent., and a small matter of that kind really meant that, as far as it was possible to measure, the power was the same in the two cases. Perhaps he ought to have known that beforehand, but somehow it was not quite what he had expected. The experiments had been made because it had been suggested that some difficulties occurring at that time would be overcome by the use of an ordinary locomotive. It was found that the difficulties disappeared, and the use of the locomotive had not been found necessary. In case such experiments were not familiar to the members he was glad to be able to put these on record.

Mr. Bell. Mr. HORACE BELL observed that he was not able to reply fully to the questions which had been raised during the discussion, and he would leave the Author to deal with them in writing. There were some points, however, on which he might make a few remarks in closing the discussion. In reply to Colonel Pennycuick's question, the extension to Ootacamund was being arranged, and it would be about 12 miles in length. It would not be as heavy a piece of line as the line up to Coonoor, but, as at present advised, about one-third of the distance would be rack and the remainder would have a gradient not exceeding 1 in 40. When that line to Ootacamund was completed, which would be in about 2 years time, it would have the important function of serving not only Ootacamund, but also the new cordite factory which he believed was to produce cordite for the whole of India. Therefore the line would be an important one. He thought Mr. Carruthers was unduly hard on the Government of Madras in charging them with having interfered and adopted a gradient of 1 in $12\frac{1}{2}$. He could say that the Government had done nothing of the sort. They had been asked to sanction a gradient of 1 in $12\frac{1}{2}$, and, acting no doubt upon the advice of their engineers, they had agreed to it. He had not been consulting engineer at the time. As far as his connection with the railway was concerned, nearly everything asked for had been conceded, more especially in the case of the engines. The standard axle-load on metre-gauge railways was 8 tons, but the Government, at the request of the engineers, had altered that to 13 tons. The engineers had asked for a slight increase upon the total of the engine from 30 tons to 35 tons, and that also had been conceded. In fact in every direction, except unfortunately in the direction of finance, the Government had afforded sufficient assistance. Mr. Passmore, not unnaturally perhaps from his own point of view, had drawn a distinction between the advantages of an engine built by Messrs. Rinecker, Abt & Co., and one built from the designs of an English engine-builder. There was no secret, as far as Mr. Bell was aware, in designing a locomotive to do a certain duty. Although Messrs. Rinecker, Abt & Co. had had exceptional experience in dealing with rack-railways and with rack-engines, yet he would doubt whether, with the general experience on the subject, it was not possible for an English engine-builder to produce an engine which would do as good work as one designed by that firm. He would not traverse the remarks made by Mr. Passmore with regard to metal sleepers. He only wished to say that the wooden sleepers used on the Nilgiri Railway were of an extremely hard wood, known as "Pyngadu." There was one point about a rack-railway which had not been alluded to, and that was that when a slip occurred on a rack-line the permanent way was hopelessly wrecked, or when such boulders fell on it as had come down on the Nilgiri Railway—one of them weighing over 600 tons, it was rather an unhandy thing to come on the rack-bar. It was impossible to deal promptly with a movement or slip on a rack-line, because the road was either shortened or lengthened, but in the case of an adhesion-road or a Fell road, a rail could be cut, and the line could be worked easily. As to the pulling *versus* pushing which Dr. Kennedy had alluded to, some experiments had been made on that point on the Nilgiri line, and it had been found that pulling a load up was 15 per cent. better than pushing it. It was a thing that required working out, especially with regard to the frictional resistances to be overcome in pushing a load consisting of bogie-wagons round 100-metre curves, with the rack in addition. He would be glad if Mr. Passmore could give some idea as to what he had found the resistance to be in pushing a load up a rack-railway.

Mr. Bell.

Mr. Passmore. Mr. PASSMORE said it varied according to the gradient, but from the frictional resistances and for the curves, about 13·2 lbs. per ton was calculated for the train, and about 26·4 lbs. per ton for the engine.

Mr. Hudleston. Mr. F. HUDLESTON asked if Mr. Bell could say whether the pushing experiments had been made on curves or on the straight. Mr. Bell had stated that the resistance was 15 per cent. more in pushing than pulling up a hill, and he would like to know whether that was on the straight or round sharp curves?

Mr. Bell. Mr. BELL said it was on 100-metre curves.

Mr. Hudleston. Mr. HUDLESTON believed the increased resistance was largely additional friction between wheel-flanges and rails, caused by the friction of buffer-faces when pushing through a series of curves and straights, for such friction tended to force the carriage across the road. With the centre buffer, this buffer-locking effect was far heavier than with the ordinary outside buffer. On roads such as Dr. Kennedy had referred to the curves were comparatively easy.

The Author. The AUTHOR, in reply, observed that the remarks of Mr. Carruthers, describing the results of his own experience, and showing that he had used one system in one place and a different system in another, only served to emphasize the contention in the Paper, that it was impossible to generalize in the case of mountain railways; the circumstances of no two were precisely similar; each was an independent problem, requiring independent solution. With regard to Mr. Carruthers' advocacy of the Fell system, he need only draw attention to the following facts. The Fell system had been before the engineering world for 33 years, and there was in existence at the present time but one short line 2½ miles in length; the Abt system was 16 years old, and there were nearly 500 miles of it working; it was steadily increasing in public favour, and additions to its mileage were being made every year. Mr. Carruthers had referred to the Rimutaka Railway as being one of the most important of the Fell lines; he was evidently, therefore, under the impression that there were others; this was not so. Notwithstanding Mr. Passmore's official position as agent of the Abt system, he had not been correctly informed on some important points; no metre-gauge Abt lines had been built with a radius of curvature of 30 metres or 50 metres, nor had any been laid with wooden sleepers, except the two mentioned in the Paper. Mr. Passmore had made the surprising statement that there was nothing in the Abt system to prevent the use of sharp curves, yet it was Mr. Abt's invariable custom in all combined roads built by him to flatten the curves on the rack portions, as the following instances would show:— The Author.

Name of Railway.	Minimum Radius of Curves.	
	Adhesion Portion.	Rack Portion.
	Feet.	Feet.
1. Hartz	590	919
2. Viege-Zermatt	262	328
3. Eisenerz	492	590
4. Mount Lyall	264	330
5. Beyrout-Damascus	328	394
6. Transandine	377	656

Mr. Passmore had entirely missed the point of the effect of changes of temperature in alternately bulging and flattening curves; he ascribed it to creep; as a matter of fact it was a conclusive proof that there was no creep. The remarks regarding the commencement of the rack on falling gradients were also due to a misconception. As was explained in the Paper, vertical curves of large radii were put in at all changes of gradient, and the entrance tongue was placed a short distance (25 feet) below where this vertical curve commenced, not where the maximum gradient began; so that when the engine engaged it was on a slight gradient of about 1 in 100, while the whole train was on the level. With regard to the engines, he thought Mr. Passmore was mistaken in claiming that the two improvements introduced and patented by Messrs. Beyer, Peacock and Company, were old devices of Mr. Abt, which had been discarded. Mr. Passmore expressed surprise that the Beyer-Peacock engine, weighing 33 tons only, took 45 tons to 50 tons up 1 in 12½, but he had not been very happy in his selection of instances to prove that the Abt-built engines were superior; he gave the load of the 44-ton engine on the Beyrout-Damascus Railway as 80 tons up 1 in 14·3, and that of the 24-ton engine on the Mount Lyall Railway as 49 tons up 1 in 16, neither of which performances was anything like as good as that of the Nilgiri engine. In giving the performance of any engine it was very necessary to state whether the load was that taken in some special experiment, or the ordinary daily working-load. As had been pointed out by Mr. Horace Bell, it was probable that Dr. Kennedy's experiments would have shown a very different result if they had been made on a line with numerous and sharp curves; the Author agreed with Mr. Hudleston that the difference in resistance between pushing and pulling was largely due to buffer-

The Author. locking; with long bogie-stock on sharp curves this was especially noticeable. From the latest information available the working-expenses of the railway were about 3*s*. 5*d*. per train-mile, and the expenditure of fuel was 115·17 lbs. per train-mile.

Correspondence.

Mr. Berg. Mr. S. J. Berg observed that the following system of railway location on difficult ground was frequently used in Switzerland. The ground was roughly surveyed to get a contoured map, to a scale of $\frac{1}{2000}$ or $\frac{1}{5000}$ of a fairly broad belt of ground along the probable route. When study of this in the office had resulted in the choice of a suitable line, a traverse approximately fitting the location of this line was run on the ground, cross sections were taken, and a new contoured map to a scale of $\frac{1}{1000}$ was made, steep places being mapped to a suitable larger scale. On this map the final line was carefully selected and afterwards staked out, and final cross sections were then taken. This method seemed expensive, but, as a rule, money well spent on surveys was a first-rate investment, and with difficult ground it was, as a rule, impossible to arrive in any other way at the most satisfactory solution of the different questions arising in the location of the line. Very often the valley slopes were flatter near the bottom of the valley, which indicated that the line ought to be located as low down as possible, with due regard to the other factors in the problem. With regard to retaining-walls on sidelong ground, experience had shown that these ought to be replaced by masonry viaducts when they were as much as 25 feet high, the cost of wall and viaduct being then equal. A retaining-wall 63 feet high cost more than twice or three times as much—according to circumstances—as the corresponding viaduct, and was a source of much greater danger where the ground was somewhat difficult. In many cases, however, it was possible to employ viaducts where the use of retaining-walls would entail danger of slipping. The viaduct left ample room for drainage, and did not require a continuous cut in the ground, merely needing excavation for the foundation of the piers. Where possible, the bridges ought to be of masonry and not of metal, and, judging from the prices mentioned by the Author, masonry bridges, and in particular hillside viaducts, had not received full consideration; though of course it was not easy to judge Indian matters from a European point of