Discussion.

Mr. Wilson.

Mr. ROBERT WILSON considered the Paper by Mr. Carruthers very interesting as showing the differences of location of two lines, one upon a more or less uniform gradient, and the other on low levels up to a certain point, rising with sharp gradients to the summit. It was pointed out that there was a considerable saving in engine-mileage, that the speed was increased and also the carrying capacity. At first it was rather difficult to realize that such a thing was possible; and with a view of trying to make it more clear, he had taken the hypothetical case of an engine working for 100 miles over four lines at different gradients. The result of putting in an incline worked by specially designed machinery, such as the Abt or Fell engines, would be to double the load on 1 in 12½, slightly to increase the efficiency over the whole in 100 miles, and materially to reduce the train-mileage, namely to 167·5. There would be a saving of 73·35 miles on the working without special arrangements on the incline, and a saving of 18½ miles on the continuous-gradient route. It might be said that those were theoretical conditions under which a perfect incline would be obtained. Of course, as the approach-gradients became broken, or more severe, the effect would be diminished in proportion. That seemed to point to a very important consideration when locating such a line, namely, to keep the approach-gradients as low as possible until the point was reached where the final rise had to be made. Mr. Maxwell had referred to limiting the capacity of an incline. It appeared to Mr. Wilson that limiting the capacity of an incline, worked by the Fell or the Abt system, was merely a question of rolling-stock, because it was possible to have passing places on the incline, and when the traffic was beyond the capacity of such passing places to have a double road. Of course, with a rope-incline there was distinctly a limit of capacity. The great point in a line laid out as described was, no doubt, the first saving in cost of construction. He had known a somewhat similar case where, in the first instance, a section of line was surveyed with a more or less uniform gradient throughout, and estimates were made for the line carried along the lower flats as far as possible. The required rise was obtained by an incline, and the estimated cost was much in favour of the incline line. In this case the most important saving was effected by substituting the incline for the long summit tunnel, and avoiding a

Mr. Wilson. line of 15 miles, with a gradient of 1 in 50, through a country where the conditions were unfavourable to maintenance, having a rainfall amounting to 105 inches in a year, in conjunction with rocks of clay-slates of the Jurassic period. The hill-sides in places formed great shingle slides; maintenance on such ground would be exceedingly heavy owing to the slips, which it would be impossible to avoid without exceedingly heavy expenditure. He had investigated as far as possible the cost of working the Hartz line, the particulars of which were given in his Paper. His experience was very satisfactory. He had found that when the engines were entering the rack sections they did so without difficulty, without any blow or any indication that they were entering the tongue; they seemed to go over the tongue without trouble at 5 or 6 miles an hour. Upon the curves he found that there was a slight wear, but that was only the bedding of the pinion-teeth on the rack-teeth; the former being slightly at an angle, they, of course, bore heavily on the inside points of the rack-teeth; after the bearing was formed there appeared to be little or no further wear. Mr. Carruthers had stated that he considered the Fell system to be the superior with small curves, and that it would probably be more suitable for sharp curves than the Abt system; but Mr. Wilson questioned if there would be the advantage claimed. He thought the limit of curvature on the Abt system would be found to be the clearance in the tooth of the pinion with the tooth of the rack, and that it would possibly be a radius far below that mentioned in the Paper. The compression-brakes with which the engines on the Hartz line were fitted worked most effectively, giving the driver perfect control of the train, so complete that the trains could be stopped on an incline of 1 in 16 without difficulty. In bringing a heavy train-load down the long incline there were three brakes on the train besides that on the engine. He had recently received some further information from the Directors of the Hartz Railway for 1888, from which it appeared that the working in the year was satisfactory compared with the working of 1887.

Traffic on Hartz Line, 1888.

Number of passengers . .	58,550	Increase on 1887 .	5,050
Weight of goods	146,250 tons	,, ,, .	26,250 tons
Total train-mileage . . .	57,256	Decrease ,, .	1,652
Average weight of train run	105 tons	Increase ,, .	8 tons
Maximum ,, ,, ,,	135 ,,	,, ,, .	15 ,,

Maximum load consisted of nine loaded wagons, gross load of 15 tons each; three were fitted with friction brakes.

Mr. Wilson.

Working Expenses, 1888.

	£	s.	d.
Salaries Wages	4,372	10	0
General expenses	6,665	15	10
Maintenance	728	15	0
Fuel	1,506	1	8
Repairs (engine and wagons)	874	6	10
Hire of wagons	437	3	5
	£8,584	12	9
Cost per train-mile		2	10·9
Coal	51·2 lbs.		
Lubrication	2·2 ,,		

The increase of coal per train-mile was due to the trains having been on the average heavier.

Cost of Transportation.

	£	s.	d.	Per cent.
Wages	815	13	8	27·8
Fuel	1,179	5	3	40·2
Stores	244	7	8	8·3
Water	17	1	3	0·6
Repairs (locomotive)	677	12	6	23·1
	£2,934	0	4	100 per cent.

Cost per train-mile . . . . 1·019*s*.

Mr. Maxwell had mentioned the improvements in the new Fell engine sent out from England. As one of the government engineers Mr. Wilson had supervised building the engines mentioned. The coupling-rods and the connecting-rods of the inside engines were made with a ball-and-socket joint, with an increased heating surface. The cab was so constructed that it could be entirely closed in; because on the sharp incline in the tunnels the foul air was very objectionable. When he went over the line there was an engine at the tail-end of the train, and he found very great inconvenience from the bad air, the sulphurous acid being very strong and disagreeable. Indeed, it was so bad that it had been expedient to fit pipes, one on each side of the foot-plate, 3 inches in diameter, and to carry them down to about 2 feet 6 inches from the road, and 3 feet 6 inches up in the cab. By means of those pipes the men on the engine were able to get fresh air, and he was himself thankful to monoplise one of them while going through the tunnels.

Captain C. Fairholme.

Captain C. Fairholme, R.N., said he was not qualified to speak on the technical part of the question, but as representing Messrs. Rinecker, Abt and Co., he desired to express his regret that no

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Captain C. Fairholme. member of that firm was able to be present, and to submit some information supplied to him by them on the subject under discussion. Mr. Carruthers had referred to there being only one type of locomotive for the Abt system, and Captain Fairholme had also been asked to explain that there were three, namely, the combination type for adhesion and rack combined, the coupled type, where the pinion was coupled to the driving-wheel (as used on the Oertelsbruch slate-quarry railway), and the pure rack type, of which the Puerto Cabello and Valencia engine was an example. The Abt system was already in use on the following railways:—The Hartz Mountain line, gradient 1 in 16·67; Oertelsbruch Lehesten, 1 in 12½; Oertelsbruch quarry line (2 feet 3⅛ inches gauge), 1 in 7·3; Puerto Cabello and Valencia, 1 in 12½. In Austria the Eisenerz-Vordernberg, and in Bosnia the Mostar Serajevo, lines, were now to be built, and the system was also in use on the following rope-railways, as a special means of security for the descent:—Lugano station, gradient 1 in 4; Kehrsiten-Bürgenstock, 1 in 1·73; Limmatquai-Polytechnicum, 1 in 3·84; Chiaia-Vomero, Naples, 1 in 3·35, and Montesanto-Vomero, Naples, 1 in 4·31. In 1887 the Indian Government ordered, for experimental purposes, 7 miles of triple-rack rails with the necessary switches and entrance tongues, and two locomotives of 5 feet 6 inches gauge. The locomotives, with 50 tons average service weight, were each able, by means of the rack, to haul 135 tons up 1 in 20, and round curves of 600 feet radius, at 7 miles an hour, the same engine being able to move the same load up 1 in 40 at 11 miles an hour without the rack. The first trials having been made on a gradient of only 1 in 25, the train load was fixed at 170 tons, and 1 in 50 as the corresponding gradient without the rack. The experimental line was only 1 mile long, and at the trials in March and April, 1888, the engine-drivers and firemen had not got accustomed to their engine, and consequently the Indian authorities wrote:—"No practical conclusions can be drawn from the performance of new engines on a short experimental line. Further experiments are contemplated with the Abt engines, and it is proposed to conduct these at suitable speeds, after the 5 feet 6 inches gauge line has been laid through from Hirokh to the Khotal." The experiment having been conducted on the Bolan State Railway, a report had been circulated that the Abt system was "in service upon the Bolan Railway"; but this was not correct, as the Indian Government had not arrived at any decision on the matter. In order to work trains on steep gradients by pure adhesion with ordinary locomotives, the weight upon the driving-

Captain C. Fairholme.

wheels should be as great as possible; but as this weight was limited by the strength of the permanent way, it had been necessary to increase the number of coupled-axles. It was found, however, that, owing to the unequal wear of the tires, and their rolling through curves upon varying diameters, considerable losses of power by friction, &c., ensued; the coupling of more than three axles had consequently, in most cases, been abandoned, and the system introduced of having two distinct sets, of three coupled-axles each, under either one common boiler, or twin boilers, or else as twin engines. The Fairlie locomotive might be taken as perhaps the best type of such a principle. The Abt combination locomotive had, in a similar manner, two sets of machinery, but simplified, as compared with the Fairlie, by having only one boiler and one firebox, and by keeping one set of its machinery at rest when not required. Upon easy gradients, where one set of machinery should suffice, the other set, in the case of the Fairlie engine, must also be in motion—whether steam was admitted or not—thus producing wear-and-tear and a loss of power, to say nothing of the whole weight of the second half of the engine having to be carried uselessly. With the Abt system, on the contrary, an adhesion engine was taken, just sufficiently heavy for the pure adhesion sections of the line, and the pinion machinery was then added, without materially increasing the weight. The speed of such an engine upon the steeper gradients would, of course, be less, because a greater portion of the steam would be utilized as motive power in proportion to the increase in steepness of the gradient. This loss of speed was, however, of less consequence than would appear, and, indeed, owing to the smaller number of trains required to do the same amount of work, there was practically a gain in time on the average in working the traffic, the principal advantage of the system being the proportionately smaller aggregate dead-weight moved over the incline. That this was the case would be obvious from the following considerations: A pure adhesion engine could move over a given incline, owing to its tractive force and adhesion weight, a certain train-load at a certain velocity. Let the train-load be assumed to be about the same as the weight of the engine (which would be the case, according to the coefficient of adhesion, with gradients of from 1 in 25 to 1 in 20), and assume the weight of the engine to be 50 tons; its tractive force would thus be equal to 100 tons. The addition of the pinion machinery to this adhesion engine would not materially increase its weight, but it would double its tractive force. This meant that 200 tons could be moved up the very same incline by the same engine thus

Captain C Fairholme. altered, and that the train-load could be increased from 50 to nearly 150 tons. To move 150 tons of train-load, the pure adhesion locomotive would, however, have to make the trip three times, or, in other words, the dead-load would be three times as much as with the combined engine. It was true that this treble load was only moved by the combined engine at half the speed at which the pure adhesion engine would move each of its three single ones; but the total load was anyhow moved quicker to the top of the incline. Fewer locomotives were consequently required, with fewer drivers and firemen, and smaller engine sheds, besides the other advantages, in fuel, &c., of working a smaller dead-load. These remarks only hold good, of course, to their full extent, for the comparison between the Abt and the ordinary engine; because, in the case of any duplex engine, whether Fell or Fairlie, the difference would not be so large. To return to the comparison with the Fairlie system; let it be supposed that a heavy engine be taken, and that one of its sets of six adhesion wheels be left coupled, the other set being converted into three uncoupled axles, the Abt coupled pinions being then added. There was now at one end a rack-engine, at the other end an adhesion engine, nothing else being altered except that the total weight had been perhaps slightly increased, the tractive force and velocity remaining the same. A great improvement had, however, been effected, since, on the easy gradients, where the adhesion set was sufficient by itself, the losses of power, due to the friction of the other set, had been done away with; whereas, on the steeper grades, where the driving force of the pinions was added, less frictional loss resulted than with a second set of six-coupled adhesion wheels. All slipping of wheels was also done away with, and variations of adhesion, due to climatic changes, did not come into account, whilst the gradients could even, if necessary, be increased; besides which, perfect safety in descending the inclines was guaranteed by the rack. This, however, was not all, as the construction of the engine might be still further improved. The rack-rail upon which the pinions worked being a central one, space was gained for the two sets of machinery; whilst, instead of two fireboxes, two boilers and two chimneys, only one of each was required, the aggregate heating surface being the same as before, but the total weight being diminished. No flexible steam-pipes were necessary, and the front end of the boiler could be fixed to the frame, the rear end resting on slides, and being borne by the three uncoupled axles which had been gained by doing away with the second set of adhesion machinery. The improvement, however, Captain C. Fairholme.

extended also to increasing the steaming quality in addition to simplifying the arrangement. As was well known, the steam-generating power of a locomotive increased with the speed, owing to the greater number of beats in the exhaust. The combination locomotive obtained by improving (as above described) on the original idea of the Fairlie engine, had still the same heating surface and speed, but had the exhaust of four cylinders beating jointly at very short intervals into one and the same chimney, and a far better draught must consequently be the result than with the former two separate sets. The experience of several years on the Hartz and Oertelsbruch railways had fully established the reality and value of this last improvement. The type here described of a six-coupled tank engine was only given as an instance, as of course the system could be equally well employed with any other type of engine. For the Abt system, tank engines were preferable for steep gradients, on account of their smaller weight; whilst the disadvantage of the varying weight for adhesion due to the weight of coal and water carried becoming less, was of scarcely any consequence with the rack.

Mr. Grover.

Mr. J. W. Grover said that the gradient of 3½ per cent. for the La Guaira line had been adopted entirely in consequence of the conformation of the country. The line from La Guaira to Carácas, which was the parent of all the lines in the country, was originally laid out in 1873, when he had made some of the surveys, and reported upon it, and his report was ultimately adopted. In the centre of the line there was a great pass called the Boqueron, which rendered this gradient inevitable. The pass had very steep, precipitous sides, and it was impossible to make a railway except with a succession of sharp curves going round the summit of the pass. It appeared from the Paper that the engines constructed for the Puerto Cabello and Valencia Railway, on the Abt system, were not to work by adhesion at all; but according to the views of the Engineer of the Hartz Mountain system, the Abt engine should be able to work through, whether there was a rack or not. Perhaps it would be explained why the engines were not made to work on the adhesion principle like those on the Hartz incline. The La Guaira and Carácas Railway had been most expensive to maintain, in consequence of its being constructed on the side of very steep hills. The soil on the side of the mountain would sometimes come down in the night, and trees would be found standing in the middle of the road. Any method which would enable an engineer to construct a line away from the side of such a slipping mountain would be desirable.

Mr. Martineau. Mr. W. Martineau remarked that in studying the subject of the Papers, the members ought not to overlook what had been done in Brazil, a country where several large and important steep inclines had been constructed. There was first the incline, or rather a series of inclines, on the São Paulo Railway, constructed by Sir James Brunlees, but as a Paper had been read on the subject by Mr. D. M. Fox in 1870,[1] he need not further remark upon it, except to say that if the additional experience of twenty years' working had elicited any further information, the members would be glad to hear it. He might also refer to the Cantagallo line, the gauge of which was 3 feet 8 inches, and where the Fell system had been adopted for a distance of 8¼ miles; in fact the material and the engines had been brought there from the Mont Cenis Railway. The incline on which the Fell system was laid varied from 4 to 8 per cent., the total height attained being about 3,300 feet. But the Fell system did not seem to have met with the same success as on the Rimutaka line, in New Zealand. After the Fell system, which he believed was no longer working, the Fairlie engine had been tried. He himself inspected a Fairlie engine made by the Yorkshire Engine Company for the line some years ago. It did not seem to have afforded entire satisfaction, and he had been informed that the line was now being worked with American engines made at the Baldwin Locomotive Works. They had three pairs of wheels coupled, 3 feet 3 inches in diameter, 18-inch cylinders, and a stroke of 20 inches; the weight of the engines was about 40 tons, and they took another 40 tons up an incline of 8½ per cent. It did not seem very economical for an engine to take only its own weight up an incline. The incline to which he wished specially to refer was on the Petropolis Railway. This was not a mere pleasure line like the Rigi, but was a regular means of communication. It gave communication between the City of Rio de Janeiro and Petropolis, which was the summer residence of a large portion of the population, and where the Emperor and Court then resided, so that the line carried a considerable amount of passenger and goods traffic. It was a rack-railway, the rack portion being 3¾ miles in length, and the incline was 15 per cent., or 1 in 6⅔. It started from the terminus of a railway known as the Mauá Railway, originally constructed by Viscount Mauá, which claimed to be the oldest railway in South America; but he believed that honour belonged to the Lima Railway. Starting from the Bay of Rio de Janeiro, it went a distance of 10 miles over a level country to the

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[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 29.

Mr. Martineau.

foot of the hills. The remainder of the journey to Petropolis used to be performed by coaches over the road; but was now performed by the rack-railway, the same carriages being taken through. The train started from Port Mauá with these carriages, and went to the station at the foot of the hills. The engine then left the head of the train, passed through the points, and went to the tail of the train; it then pushed the two leading carriages on to the rack-railway; the rack-engine followed pushing these two carriages. Then two more carriages were pushed on to the rack, and a second rack-engine came behind them, and the remaining two were taken by a third rack-engine. There were three rack-engines, each pushing two carriages in procession. When they arrived at the level line at the top, the reverse operation took place. The carriages were detached from the rack-engines, and the train was made up again, and taken on with an ordinary engine to Petropolis. The total height gained on the incline was about 2,800 feet in a length of $3\frac{3}{4}$ miles. The gauge of the line was 1 metre; the weight of rail, 40 lbs. per yard; the weight of rack, 100 lbs. per yard; the sharpest curve, 491 feet radius; the sleepers were of native timber, 6 feet by 8 inches by 6 inches. The engines were of the Riggenbach type. The coal consumed per kilometre was 28·570 kilograms, equal to 100 lbs. per mile; coal consumed per ton per kilometre 0·085; the cost of the line, from the foot of the incline to Petropolis, had been about £140,000, which was equal to about £25,000 per mile. The total capital of the Company was about £350,000, which included the purchase of the Mauá Railway, steamers, &c. The profit was stated to be about £24,000 per annum, which was a very good return on the capital. If it were possible in that country to lay out a line that should develop the length necessary to attain that height with a gradient, say, of 1 in 40, instead of being $3\frac{3}{4}$ miles long, it would have to be $22\frac{1}{2}$ miles, and it would necessarily be a line of a much more expensive character. He had mentioned the Petropolis line in particular, on account of the great success that had attended its working, and the way in which heavy traffic of passengers and goods was regularly carried between Rio de Janeiro and Petropolis. There was one other incline in Brazil which might be worth mentioning: that on the rack-railway recently made up the Corcovado mountain, in the neighbourhood of Rio. It was purely a pleasure line; the steepest incline was 30 per cent., or 1 in $3\frac{1}{3}$, which he thought was about the steepest ever attempted.

Sir George Bruce.

Sir GEORGE B. BRUCE, President, said, a letter had been received from Mr. Livesey, in reference to a reason for adopting the Abt

Sir George Bruce. system referred to by Mr. Carruthers. "One reason," he said, "for adopting the Abt in preference to the Fell system was, that at times locusts abounded in Venezuela, and we felt assured that their presence on the rails would be fatal to any system relying solely on adhesive action." That reason had not been mentioned by Mr. Carruthers.

Mr. Woods. Mr. EDWARD WOODS, Past President, observed in the Appendix mention of a rack-railway and cog-wheel locomotive in 1811, so that the rack system was not quite new. The improvements, however, by Mr. Abt, and the invention by Mr. Fell, applied in the first instance on the Mont Cenis Railway, had been so effective that the old rack system was now out of date, although it was at one time suggested that it might be applicable to the working of the traffic of the Liverpool and Manchester Railway. Of the systems which had been brought before the notice of the members in the Papers just read, he thought the Abt system the most effective, although the Fell system had also worked well. The systems described appeared to him to be most applicable where the gradients exceeded 1 in 20, or 1 in 25. Railways with gradients not steeper than 1 in 25 were worked effectively simply by locomotive power. Some locomotives were specially designed for working such heavy gradients, but others were of the type in ordinary use. On the West Coast of South America, in Chili, there were many railways from the coast to the lower ranges of the Andes, with gradients of 1 in 20, 25, and 33, running, perhaps, for 20, 30, and 40 miles at a stretch, all worked by locomotive engines. No doubt on the western side of the Andes the climate was so dry that the disadvantages of slipping were not felt so much as they were on European railways. He had been afforded the opportunity, by Messrs. Beyer, Peacock and Co., of examining one of the engines made for a railway in Venezuela, and he was much pleased with its construction, and thought it admirably adapted to the work which it had been effectively doing. The combination system was, he thought, specially applicable to those cases in which the line, so to speak, undulated in the vertical sense, and where the steep gradients occurred during the course of the line, rather than being concentrated at the end. In the case described by Mr. Martineau, and in that mentioned in the first Paper read, he thought it was a prudent course to concentrate the gradient at one end, and to apply the simple rack system, not adopting the combination system. But where steep gradients intervened over different portions of the line, as he believed they did on the line opened last summer over the Brunig Pass, connecting

Lucerne with Brienz, the combination system was especially applicable. Mr. Woods.

Mr. J. B. Fell wished to make a few remarks on Mr. Maxwell's Paper. It appeared that some new engines had been made subsequent to the original engines sent out to New Zealand several years ago; and that improvements had been introduced into them which had resulted in efficiency and economy in the working. The improvements consisting in grooving the centre-rail wheels so as to bite upon the rail, thus avoiding the use of sand, and getting additional adhesion, and the plan had been successful. He had thought of it before the Mont Cenis Railway was made, and he had discussed the question with Mr. Ramsbottom, who believed that the tendency would be to draw up the centre-rail, or throw too heavy a load upon the spring-plates of the engine; but that did not appear to be the case. So far as the engines had worked on the line in New Zealand, they had proved that the centre-rail system had been certainly a success to the extent of doing its work. The question was whether it was doing the work economically. Mr. Wilson had contended that the rack-and-pinion system was more economical and better adapted under some circumstances; and he had stated that whereas the cost per train-mile for locomotive power in New Zealand was 3*s.* 8*d.* it was only 1*s.* 0½*d.* on the Hartz Mountain line. But, as he had observed, the circumstances were totally different. In the first place the cost of labour was double in New Zealand what it was in Germany. Then again, on the Hartz line the engines ran through, and were worked by adhesion and also by the rack-and-pinion; whereas on the Rimutaka, the engines worked on the incline alone, and were therefore more than half their time under steam without doing work. He saw no reason why the engines, which were able to run on flat as well as on steep gradients, were not made to run on to the Wellington station and back. On the Mont Cenis, parts of the line were flat, and there were gradients of 1 in 12, but the same engine was run over the entire line. If that had been done in New Zealand, the cost per train-mile would have compared more favourably with the cost on the Hartz line. It appeared to him that the engines, though doing their work fairly satisfactorily in New Zealand, were not the best class of engines if they were only worked on the incline. It would be quite possible to work them with two cylinders instead of four, and then they would be more efficient, and the adhesion would be better, because when the carrying rails were slippery the centre-rail might be dry. On the Mont Cenis line two cylinders were first used, and they Mr. Fell.

Mr. Fell. were more powerful, getting up steam better, the exhaust being more regular; but there was the difficulty that the outside wheels were worked by rocking-shafts and by oblique connecting-rods; and, although the diameter of the inside and outside wheels was exactly the same, they did not travel at the same rate at the same time. For instance, each quarter of a revolution was made in less time by one set of wheels than by the other, and there was a scrub, which caused a great deal of friction, wear and tear, and sometimes breakages. The four-cylinder system was therefore reverted to on account of that difficulty; but this was simply a retrograde movement because, in the first experiments, the four-cylinder arrangement was used, and afterwards that of two cylinders had been adopted as an improvement, which, however, had not been quite satisfactory on account of the mechanical defect he had mentioned. In the designs prepared by the Italian Government for working over the pass of the Mont Genévre, at an elevation of 6,000 feet above the sea—a much higher level than the Hartz Mountain railway—weigh-beams had been adopted in place of rocking-shafts for driving the carrying-wheels; and by this new arrangement the movements of the two sets of wheels would be coincident and mathematically correct. This class of engine would be best adapted for the Rimutaka incline, if the engines were required to work on the incline only. The present engines, it appeared to him, might work for any distance on either side of the incline, because the vertical wheels were of much larger diameter than the others. He had prepared drawings of the improvements which had been proposed to, and adopted by, the Italian Government for working over the inclines of the Mont Genévre, of which there were two of 5 miles each, upon gradients of 1 in 15. It was expected that these engines would shortly be running over the mountain, and he hoped then to be allowed to bring before the Institution a report upon the working of the engines, and of the cost of locomotive power, which, if all the elements of cost were taken into account in both cases, he believed would be quite as favourable, and in some respects more favourable, than the results which had been obtained by the rack-and-pinion system. No doubt, in some respects, more could be done with the rack-and-pinion than with the centre-rail system, as it could be worked on gradients of 1 in 5, but the centre-rail system had the advantage of permitting the use of sharper curves. The principal element, however, in the cost of working mountain railways was the elevation to be overcome, and the cost of traction would be very much in proportion to that elevation. Mr. Wilson had stated that there was more axle-friction (and there certainly was a little more) with the centre-rail system as compared with the rack-and-pinion; but, taking the pressure on the horizontal wheels at 40 tons, and the axle friction at 20 lbs. to the ton, the total resistance would only be $\frac{1}{30}$ of the tractive power of the engine. Upon the inclines of the Mont Genévre the engines would have a tractive force of about 10 tons, after allowing for the friction due to the axles of the horizontal wheels; but this being about $\frac{1}{30}$ part of the total resistances, all that could possibly be saved by the rack-and-pinion system would be a fraction of this thirtieth part, which was a matter of small consideration, the cost of traction being in fact almost in exact proportion to the vertical height to be overcome. He should be glad to be informed why the centre-rail engines in New Zealand had only been working on the incline, and not also upon the level portion of the line, as had been the case on the Mont Cenis Summit Railway, where out of a distance of 48 miles there had been about 20 miles of line with gradients of 1 in 12 to 1 in 15, all the rest being comparatively level. Mr. Fell.

Mr. Ernest E. Sawyer remarked that now that railways were being extended into parts of the world sparsely inhabited, and often very mountainous, it became more and more a question of importance how to deal with steep inclines. Mr. Carruthers had illustrated the advantage of steep inclines. Mr. Wilson had given the working of one of the best systems of getting over steep inclines, and Mr. Maxwell the result of about ten years' working of steep gradients. He had suggested to Mr. Maxwell that, having had the working of the only Fell railway that he knew of for the last ten years, he should give the Institution the benefit of what he had learned. In the first Paper, although Mr. Carruthers advocated a special system for going up a steep incline, the "key of the line" was not that incline at all, but was the section between Cambur and Trincheras. He thought a little more might have been said about that section. The steep incline was only $2\frac{1}{4}$ miles of about 1 in $12\frac{1}{2}$, whilst the part from Cambur to Trincheras was $6\frac{3}{4}$ miles of 1 in 29, which was sufficient to give ample advantage to the special system. If it had been 1 in 40 a second engine would have been able to take up the train entire without its being broken up; but in this case the engine could only take one-third of the train, so that it had to be broken up, or three engines would have to be put on. Mr. Mosse, who had had a great deal of experience in the Mauritius, where the gradients were continuous of 1 in 27, had expressed an opinion that no gradient for a long rise should exceed 1 in 40. Mr. Sawyer.

Mr. Sawyer. Having had the advantage of working a line for some time where there was an almost continuous rise of 1 in 40 for 8 miles, Mr. Sawyer quite agreed that that was as steep as any line ought to be worked by ordinary means. The trains on the Bolan Railway in India started from the plains with one engine up ruling gradients of 1 in 100; on coming to a grade of 1 in 40 a second engine was put on; and then, coming to grades of 1 in 22, a third engine was put on; the train being maintained intact all through. Every traffic manager knew this to be a matter of the utmost importance. In the same way, on the Canadian Pacific Railway, the Selkirks and the Gold ranges were surmounted by simply adding an engine to the train; on arriving at gradients of 1 in 40, one engine was added, and on reaching gradients of 1 in 22, a third. In that way the difficulty was overcome without any trouble, every train being kept intact. In the case described by Mr. Carruthers there was a special road and a special engine, and yet that was not the key to the line. There was only one suggestion that he could make why this was so, viz., that the curves on the line from Cambur to Trincheras were of 300 feet radius, whilst those on the piece from Trincheras to La Entrada were 500 feet. Was that the reason why the Abt system had not been employed on the Cambur and Trincheras section? Mr. Carruthers had fathered the Rimutaka incline; he was really the Author of it, and had very good reason to be proud of it. From what Mr. Sawyer had seen, it worked splendidly. Mr. Carruthers had said that he intended to use the Fell system in this case also, but as he was there on the part of the Contractors, he had to give way to the Company's Engineer. He should be glad to know whether, if he had had his own way, he would not, having adopted the Fell system, have started it at Cambur, and worked it all the way through to La Entrada? If he could have got the train with one special engine up to Trincheras, he had only to put on two engines to get the whole train to La Entrada, which, from a railway manager's point of view, was of the utmost importance. He had been told by Sir Guilford Molesworth that the Oertelsbruch Railway, built by Mr. Abt, had curves of 325 feet, and that one was contemplated with a curve of 197 feet. Any information as to those two lines would be very valuable to the Institution. Mr. Carruthers had stated that although the Trincheras gorge was very rough and steep, it was unusually straight, and his impression was that the time-honoured system of rope-traction would prove the best. Mr. Sawyer agreed in this, and held that rope-traction was one of the systems of overcoming steep gradients that engineers had somewhat neglected.

It used to be far more common than at present, and probably it Mr. Sawyer. had given way before prejudice; but the development of traction by wire ropes had been so great in America with tramways, and so improved, that he thought very little more was required to make it exceedingly useful in connection with railways. At San Francisco a speed of 10 miles an hour was attained on gradients of 1 in 4½ with curves of 20 or 30 feet radius. The cables were over 5 miles long, and they worked even up to 10 miles economically. He was not able to ascertain exactly what weight they could haul, but he had seen cars with two hundred and fifty passengers following each other within sight on the same cable, and going at 10 miles an hour with far more safety than a London omnibus. There was an example in London of a cable tramway up Highgate Hill, but it was not at all like what might be seen in San Francisco. It had fared badly between the Vestry and the Board of Trade, and was now figuring in the Bankruptcy Court. It was a remarkable example of public prejudice. The charge for going down hill had been reduced to 1*d.*, the fare up hill being 2*d.*, but even at 1*d.* the people were afraid to go down hill, because they thought it was more dangerous than going up hill. The statement of Mr. Carruthers as to the gorge being straight, so that rope-traction would be applicable to it, was hardly worthy of attention, since it was now possible to go round curves of 20 or 30 feet radius with the greatest ease. The present system had been so developed that there could be no danger of breaking the rope. He was himself on a car going down a gradient of 1 in 4½ at the usual speed. Another car was coming up hill, and it stopped a little before the other came up to it, and some of the passengers got out. A high wind was blowing, and the hat of one of the passengers was blown off and fell on the tram-line on which he was. The man not seeing the other car ran on to the track for his hat, when the approaching car was only about four lengths from him. The grip-man instantly took off the grip and put on the double-brakes, one working the wheels and the other on to the rail. The car was stopped easily within a length of the man. Of course, the passengers were slightly heaped up at the lower end, but the man was safe. That was a good example of what could be done in stopping the cars at any moment. So long as the man was watchful there could not be an accident. The advantage of rope-traction over any system requiring a locomotive to go up an incline was self-evident. On the Hartz line there was a maximum train-load of 120 tons, the average load being 97 tons. The weight of the locomotive was 52 tons, or from 44 to 53 per cent. On

Mr. Sawyer. the Puerto Cabello line, on the piece from Cambur to Trincheras, the maximum load was 68 tons. Taking off 20 per cent. for the average load that would be 55 tons; the locomotive was 37½ tons on that portion, or from 58 to 68 per cent. of the load it took up. On the next piece, from Trincheras to La Entrada, there was a maximum load of 68 tons and an average load of 55 tons; the locomotive was 40 tons, the percentage of the locomotive to the train-load being from 57 to 74 per cent. On the Rimutaka incline the load was from 70 to 60 tons; and the weight of the locomotive was 39 tons, or from 55 to 65 per cent. So that in every case the weight of the engine was from 50 to 60 per cent. of the load of the train it took up. Of course, with any system of rope-traction, only the loaded cars, and nothing more, had to be drawn up. The next point to be considered was how the special arrangement, of whatever kind, compared with ordinary traction. Sir Juland Danvers had kindly placed at his disposal a report of some experiments made in 1887 on the Mexican Railway. It was a very important report, and it drew attention to the fact that the best ordinary locomotives were expected to go up a gradient of 1 in 25 with a load twice their own weight, and to ascend a grade of 1 in 13 and haul up their own weight, at 7 miles an hour. It was also stated that on the Cantagallo Railway in Brazil, the locomotives of the Baldwin Locomotive Company in Philadelphia, of 40 tons, drew a load of 38 tons at 8 miles an hour up a gradient of 1 in 12 with curves of 83 feet radius. Those locomotives had generally eight wheels coupled, the four inner wheels having no flanges, and the tires being often as much as 7½ inches wide, so as always to be on the curve. The experiments made on the Mexican line were between an engine of the Baldwin type, and a Fairlie; which on this line alone had been used on a very large scale, and had proved, as far as its power was concerned, very superior to any other. The Fairlie engine, with a load of 70 tons on twelve driving-wheels, 8 feet 3 inches coupled wheel-base, took up an incline of 14 miles of 1 in 25 with continuous 325 feet curves, more than 153 tons, or about one-fifth more than double its own weight. The Baldwin engine, with 45 tons, on eight driving-wheels with 7½-inch flanges, the flanges being removed from the two pairs of inner drivers, with a coupled wheel-base of 14 feet 10 inches, took 50 tons gross. The area of the four Fairlie cylinders was as 5 to 4 of the two Baldwin cylinders. But an important point was that the expenditure of fuel for the Fairlie engine was as 3 to 2 for the Baldwin. The Fairlie engine in 29 miles, rising 4,014 feet, and returning, used 6,000 lbs. of coal. Thus the ordinary

Mr. Sawyer. locomotive ascending gradients of 1 in 25, and traversing 350 feet curves, did not take up twice its own weight, while the Fairlie locomotive on the same road took up from $2\frac{1}{5}$ to $2\frac{7}{10}$ its own weight. The Baldwin locomotive in Brazil, on the small line, took its own weight up an incline of 1 in 12, with 83 feet curves. On the Hartz line, the locomotive took up inclines of 1 in $16\frac{1}{2}$, with 590 feet curves, from 2 to $2\frac{1}{3}$ times its own weight. On the Puerto Cabello line, by adhesion, the locomotive took up inclines of 1 in 29, with curves of 300 feet, $1\frac{1}{2}$ to $1\frac{4}{5}$ time its own weight; by rack, it took up an incline of 1 in $12\frac{1}{2}$, with curves of 500 feet, from $1\frac{3}{8}$ to $1\frac{5}{8}$ its own weight. On the Rimutaka line, the Fell locomotive took up inclines of 1 in 15, with 330 feet curves, from $1\frac{1}{2}$ to $1\frac{4}{5}$ its own weight. Of course, the greatest advantage with the centre-rail system, whether the Fell or the rack, was experienced in times of frost, or when the rail was greasy. The report on the Mexican Railway, to which he had referred, appeared to have originated in a divergence of opinion, which resulted in valuable information being obtained. The Simla authorities had recommended the Abt system for the Bolan Railway, and the home authorities had recommended the Fairlie system. Sir Guilford Molesworth had compared the Abt and the Fairlie engines, and the results obtained by him were as given in the Table on the next page.

It appeared to him from the Papers, and from other information received, that any special system, whether the Fell or the Abt, for gradients steeper than 1 in 40, was preferable to ordinary adhesion, giving better results and greater economy. That was proved amongst other things by the statement of Mr. Maxwell, that the engine worked by adhesion only would take up 30 tons, and by centre rail only it would take up 40 tons, so that a great deal more was done by the centre rail on the same incline than by the ordinary rails. Mr. Wilson had stated that comparisons were fallacious when they were not on the same basis, and he certainly thought no comparison could be made between the Abt and Fairlie systems from the working on the Rimutaka incline. A glance at the figures would show this at once. The whole incline was 3 miles, including the station-yards. The train-mileage was given at 10,859, or 3,620 trains over the 3 miles. The net load carried was 50,000 tons, or only 14 tons net load per train, the maximum gross load being 70 tons. Taking the gross load carried at double the net, the Rimutaka average would amount to 40 per cent. of its maximum train-load; that of the Hartz amounted to 87 per cent. That the former figures were abnormal was also shown by the engine-mileage, which was 50 per cent. more than

Mr. Sawyer.

COMPARATIVE PERFORMANCE of ENGINES of the ABT and the MEXICAN TYPES at LOW SPEEDS.

——			Abt.	Mexican.
Weight of engines		tons	53	72
Weight available for adhesion		,,	41·34	72
Diameter of cylinder		inches	18·896	16
Stroke		,,	23·622	22
Effective mean pressure		lbs. per sq. inch	90	90
Diameter of coupled wheels		inches	51·182	42
Tractive force adhesion		lbs.	14,882	24,179
,, ,, pinion		,,	14,062	..
Total tractive force		,,	28,944	24,179
Adhesion in frost		tons	3·69	6·43
Traction for pinions		,,	6·28	..
Total traction		,,	12·92	10·79
Gradient 1 in 40, summer	Total load[1]	,,	486	407
	Net ,,	,,	433	335
	Relative haulage		1·29	to 1·00
	,, efficiency		1·75	to 1·00
,, 1 in 25, summer	Total load	tons	300	251
	Net ,,	,,	247	179
	Relative haulage		1·38	to 1·00
	,, efficiency		1·87	to 1·00
,, 1 in 40, winter	Total load	tons	375	242
	Net ,,	,,	322	170
	Relative haulage		1·89	to 1·00
	,, efficiency		2·57	to 1·00
,, 1 in 25, winter	Total load	tons	232	149
	Net ,,	,,	179	77
	Relative haulage		2·32	to 1·00
	,, efficiency		3·16	to 1·00
,, 1 in 20, winter	Total load	tons	188	121
	Net ,,	,,	135	49
	Relative haulage		2·76	to 1·00
	,, efficiency		3·74	to 1·00
,, 1 in 15, winter	Total load	tons	143	92
	Net ,,	,,	90	20
	Relative haulage		4·5	to 1·0
	,, efficiency		6·11	to 1·0

the train-mileage. It was a pity Mr. Maxwell had not explained the cause of this. Though either the Fell or the Abt systems might be good for steep grades, yet the time-honoured system of rope-traction, as now developed and improved with endless steel ropes and modern brakes, was better than any, and should receive far more attention than railway engineers had yet given it.

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[1] The "total load" includes the weight of engine. The "net load" includes the weight of the wagons hauled, with their contents.

Mr. Fox.

Mr. D. M. Fox said he was sure that in a discussion on steep Railway Inclines the omission of any reference to the inclined planes of 1 in 9·75, worked by fixed engines and ropes, on the São Paulo Railway, Brazil, would be regretted. These inclines, surmounting a height of 2,650 feet in 5 miles, were originally laid out by himself for Sir James Brunlees, so long ago as 1857, and in a Paper which Mr. Fox had written "Description of the Line and Works of the São Paulo Railway, in the Empire of Brazil,"[1] in 1870, a full description was given of their construction and of the mode of working. The line was completed and opened for traffic in 1867, and in a communication in November 1880,[2] he had given the results after ten years' working, as he was now in a position to do for over twenty years. It was satisfactory to be able to record that, during this long period, no less than 2,600,000 passengers, and about 4,000,000 tons of goods, had been carried without the loss of a single life, and, indeed, without any accident of importance, attributable to the system of traction; whilst he ventured to assert that the figures he had compiled, from official returns, would show that this large traffic had been transported over the inclined planes at a less cost per unit of work done than could have been accomplished by any other system of working steep inclines. But before showing how those results justified Sir James Brunlees in adopting the old-fashioned rope system, he wished to make a brief reference to the Papers that had been read. The first, by Mr. Carruthers, related to the location of railways, and raised the question whether it was best to have a uniform gradient over the whole distance, or follow the valley with locomotive gradients as far as possible, and then rush up with a short steep incline requiring special tractive power. Of course that could only be decided on local reasons. It might have been thought that, where there was an almost exact coincidence of length (within 100 feet), Mr. Carruthers would have preferred a line of uniform gradient; but there were no doubt good reasons—such as the expensive works, the danger of land-slips, and the curves—that led him to follow the valley with locomotive gradients, and then climb the mountain with a steep incline. Still, as Mr. Sawyer had said, the whole had been spoiled by the Cambur piece, where the gradient was 1 in 29. If the line could have been made with a maximum gradient of say 1 in 75, or 1 in 50, going into the gorge to the foot of the mountain, then straight up it with a steep incline, that would have been the

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[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 29.

[2] *Ibid.*, vol. lxiii. p. 128.

Mr. Fox. most economical way of working it. The São Paulo Railway was an entirely different case. It started from a sea-port, traversed a marshy plain for about 12 miles, and was then confronted with a gigantic sea cliff—it could be called nothing else—known there as the Serra do Mar—at right-angles. There was no valley running from the interior to the sea; there was a plateau at the top, and nothing could be gained by tunnelling. Every mile, therefore, of development on the ascent lengthened the line directly in proportion to the gradient adopted. There was a limited capital, and the concessionary said that not a penny more must be asked for, and the distance must not be increased. Sir James Brunlees accordingly adopted, at Mr. Fox's suggestion, the 1 in 10 inclines. If there had been a valley running into the interior, or if the range had been oblique to the direction of the line, so that the line could have been carried sideways up the Serra, Mr. Fox should have recommended a locomotive line; but, under the circumstances, he thought it would be admitted that Sir James Brunlees was decidedly right in shortening the ascent by the inclines of 1 in 10, to be worked by fixed engines and ropes. In 1857 the rack-and-pinion, central rail, and other contrivances were not known. The disadvantage of such systems of traction was that, first of all, the necessarily ponderous engine had to drag itself up the incline, and this involved the raising of 50 per cent. additional dead-weight. All that was saved by the rope system, where the motive power was housed, except the weight of the special brake to which the rope was attached, and the weight and friction of the rope itself. In reading the account of the Hartz (Abt) system in the second Paper, he at first thought there must be something extraordinary in it, as the cost of working per train-mile, 1*s.* 0½*d.*, was so very low. But the section of the line (Fig. 4) showed that the Hartz Railway was an undulating line, and it was worked partly by adhesion, and partly by the rack-and-pinion system. Of course, by mixing the abnormal incline work with ordinary locomotive work, the cost was brought down very much; but a comparison could not be fairly made with a fixed steep incline like the São Paulo, without taking the same proportion of locomotive line added to it, so as to average the expenses. Allusion had been made to the extraordinary prejudice against the rope. It was not confined to England. When the inclines were first opened in São Paulo, the Brazilians dreaded to go on them, not liking, as they said, to be hung on a rope. That reminded him that, in a comic paper, published in São Paulo, there was, shortly ofter the opening of the railway, a clever picture of a man with a rope round his

Mr. Fox.

neck on the gallows, and another of a train going up the incline with a passenger in evident fear looking out. The question was asked: "What is the difference between a man going to be hanged, and a man going to travel on the São Paulo Railway?" and the reply was: "One prays that the rope will break, and the other prays that it will not!" Nor was this fear confined to the Brazilians. Even the celebrated traveller, Sir Richard Burton, in his book on the Highlands of Brazil, thus referred to the inclines: "The four terrible inclined planes—those glissades of death which make the stranger 'squirm'—on the Santos and São Paulo Railway." "Glissades of death," indeed! when, as had

São Paulo Brazilian Railway.—Cost of working the Serra Inclines (fixed Engines and Ropes).

Gradient, 1 in 9·75; length of inclines, 5 miles; number of inclines, four; height surmounted, 2,650 feet; cost of coal per ton, 35*s.* to 40*s.*

——	1870. Estimated.		1880. Actual.		1888. Actual.	
Average number of trains per day . . . . up		20		16·5		36
Average number of trains per day . . . . . down		20		16·5		36
Total average number of trains per day		40		33		72
Average number of vehicles per day		40×3=120		33×3=99		72×3=216
Average gross weight in tons raised and lowered 2,650 feet per day, say		1,040		850		1,890
Average paying load, tons per day, say		600		495		1,080
Average number of train-miles per day		200		165		360
	Coal. Tons.	£ *s.* *d.*	Coal. Tons.	£ *s.* *d.*	Coal. Tons.	£ *s.* *d.*
Average daily cost of running—coal, stores and wages .	7	29 14 0	5·75	22 18 4	10	36 10 0
Average daily cost of repairs and renewals—stores and wages		10 0 0		6 17 4		17 10 0
Average daily cost of tractive power		39 14 0		29 15 8		54 0 0
		d.		*d.*		*d.*
Cost per train-mile		47·6		44		36
" " vehicle-mile . . .		15·9		14·7		12
" " gross ton-mile . .		1·8		1·7		1·4
" " paying ton per mile .		3·17		2·9		2·4

Mr. Fox. been shown, not a single life has been lost in the twenty years since the opening of the line. But this prejudice had been overcome, and the Brazilian engineers were now coming round to the fixed-engine and rope system, having seen how successful and economical it was on the São Paulo line, and were admitting that it would have saved money if it had been adopted on their own State line—the Dom Pedro II. Railway. That was, he thought, a great triumph for Sir James Brunlees and the engineers who had carried out his plans. In the Paper on the São Paulo Railway, which had been read in 1870, he had made an estimate (based on the experience of two years) of the cost of working a given traffic up and down the inclined planes, as compared with what it would have been by means of a locomotive line of 1 in 40 His figures were criticised at the time, and said to be too favourable to the rope and fixed-engine system. But the Table on the previous page, giving the cost of working the Serra Inclines, as estimated by him in 1870, and from actual working in 1880 and in 1888, showed that in 1870 he had rather over- than under-estimated the cost of working them.

Considering that the price of coal in São Paulo was 35*s.* to 40*s.* per ton, as against 17*s.* 6*d.* in New Zealand, and probably 8*s.* to 10*s.* on the Hartz Railway, he thought these figures compared very favourably indeed with the cost of working steep inclines by the rack-and-pinion, or Abt system, and still more so by the Fell, or centre-rail system. As to the capacity of the inclines, as at present worked, they were equal to an annual goods traffic, besides passengers, of say 300,000 tons down, and 350,000 tons up, or 650,000 tons up and down, working from daybreak to sunset; and nothing could be easier than to add at least 50 per cent. to this by lighting the inclines throughout with electricity, thus making their capacity practically about 1,000,000 tons per annum.

Mr. Mosse. Mr. J. R. Mosse asked for more information about the cost of the rack and of the locomotive on the Trincheras incline. He also wished to know the gauge, and whether the pinions worked well, or were constantly breaking. With regard to the speed, the pinion-wheels were only 2 feet 2 inches in diameter, and clearly, therefore, the speed must be very low. He agreed with Mr. Carruthers that, if a gradient could be driven into a corner and then a rush made, this course was often advisable; but on account of the nature of the country, or the districts to be served, it was generally impracticable to do so. In long inclines often very difficult ground was encountered, and the roads were frequently subject to slips. On the extension of the Ceylon Government

Railways,[1] which reached a height of 5,300 feet, there were many slips, and there were continual curves of 5 or 6 chains radius. The ground generally sloped from 1 in 2 to 1 in 4; consequently the cuttings were very deep. The line rose 40 miles with a gradient chiefly of 1 in 44; and was being continued on to a summit of 6,200 feet above the sea with curves of 5 and 6 chains radius; the gauge was 5 feet 6 inches, and the line was worked very successfully by ordinary locomotives. It might be interesting to compare the results of working the Midland line of the Mauritius Railways,[2] with that of the Trincheras incline. By ordinary locomotives on the former line a gross load of 800 tons of goods a day was taken up an incline rising 1,800 feet in 16 miles, and falling the same distance on the other side. One point with reference to the rope system had not been touched upon, which he thought was of great importance. If only the engine was made powerful enough, any ordinary train could be taken up by it. With the other system, it was necessary to be constantly increasing the number of locomotives. He had been a railway manager on steep inclines, and knew how much trouble there was in having the trains limited. If two or three extra wagons were put on, it was often necessary to have an extra engine. With the rope system, and a sufficiently powerful engine, the working was not cramped in the same way as by other systems. He therefore thought that the rope system had a very great advantage over the Fell or Abt systems. Mr. Mosse.

Mr. Edward Pritchard said that his chief experience had been in connection with tramways and rope-traction. On tramways a 10-ton engine had succeeded in ascending gradients of 1 in 15, carrying 5 tons exclusive of passengers. With regard to rope-haulage, he thought it must be admitted that what would be one of the best means of travelling over severe gradients had been lost sight of. Reference had been made to ropes used both in this country and in America; but he gathered that the ropes used in this country had been tail-ropes, so that it was impossible to have the full effect or benefit of the rope-haulage. A rope must be a continuous one to work economically; in other words, the loads should be balanced, and the greatest friction to be overcome the rope itself and the machinery. Two years ago he had the satisfaction of making a professional inspection of nearly every cable tramway in America. He had seen the ropes in San Francisco, and noticed the very steep gradients there, and could confirm the statement Mr. Pritchard.

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[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 63.

[2] *Ibid.* vol. xxviii. p. 232.

Mr. Pritchard. that there was no danger of the rope breaking. He might be permitted to give one illustration. On the inspection of a cable line with which he was connected in Birmingham, the Board of Trade Inspector was anxious to know what would be the result of a rope breaking with the various cars attached to it. From information that he had obtained in the States, he remarked that the cars would simply cease running, and that the conductors or brakesmen would apply the brakes. The engines were then running at full speed with cars attached, and he so slackened the tension that the driving-wheel which operated the rope continued rotating, but in consequence of the tension being reduced, the cable immediately became stationary although at the time the experiment was made there were five or six cable cars attached by their grippers to the rope. Allusion had been made to the system of rope-haulage at Highgate, but he was astonished that the roads in Edinburgh and Birmingham had been overlooked, because he believed they were superior to the majority of the roads in America; they were certainly greatly superior to many that he saw there two or three years ago. The Birmingham line was one of the most difficult roads to work, both for its lateral and vertical variations. There was a curve subtending an angle of about 90° on a rising gradient of 1 in 15, and having a radius of 57 feet 6 inches. He had alluded to the tail-rope not giving good results, and he would now refer to the disadvantages of a continuous rope. The friction was enormous. He had frequently known, with 2½ miles of rope, something like 79 or 80 indicated HP. absorbed, and by putting on eight cars, each weighing from 5 to 5½ tons, exclusive of passengers, the indicated HP. had not been more than from 84 to 85, showing that the loss was very great in the first instance. That was upon a very difficult portion of the road, 2½ miles of single road, to be connected shortly with another 4½ miles of single road, being worked from the same machinery. Although, in one instance, 70 per cent. of the power might be absorbed in moving the idle-rope, he believed not more than 50 per cent. would be absorbed in moving the other, consequent upon the conditions of the roads and the methods of construction. When there was a tortuous road, such as the one he had referred to, the power expended was very great; but even then, with continuous or constant service of the loads at equal distances, they could be worked much more cheaply than it was possible to work with a locomotive engine. At Birmingham, the cost of working on some of the steam roads having gradients of 1 in 19, and sometimes very greasy, was 3¼*d.* per car-mile, including wages, fuel, oil, and repairs; the weight of the train, one engine and one car, being from 15 to 16 tons.

Mr. Pritchard. With regard to the rope itself, much would depend upon its construction. He had seen ropes in San Francisco which had been in use for twenty-six months, made of British wire, while other ropes, made of American or German wire, had been destroyed in much shorter periods. The best ropes he had seen in the United States were those made by Mr. Hallidie, who had been called the father of cable-traction; but he had learned, at the Patent Office at Washington, that an Englishman, not an American, was the father of cable-haulage. He believed that the question of rope-haulage had yet to come to the front, and he hoped it would have the support of engineers in this country which it deserved.

Mr. Watson. Mr. J. W. MITTON WATSON observed that many years' experience in the construction of very steep gradients in Europe, Asia, and South America, together with his having recently had an opportunity of inspecting the Rigi, the Brunig, and the St. Gothard railways, had led him to believe that in setting out a very steep incline, the question of curves might, under some circumstances, become almost as important as that of grades. He could best show the reason he had for forming that opinion, by comparing two of the most remarkable railways that had come under his own immediate attention. One was the Oroya Railway, in Peru, which, starting from the wharves at Callao, attained by means of a gradient of 1 in 25 an altitude of 15,500 feet above the level of the sea, nearly the height of Mont Blanc. The other was the St. Gothard. Both were worked by the ordinary traction system, and were of the ordinary gauge, and in each the difficulty had been to surmount a great height within a short distance. On the Oroya Railway,[1] it was considered advisable, even with several viaducts, nearly sixty tunnels, and curves of only 120 feet radius, to use frequent reversing stations, which were always in themselves dangerous and objectionable. On the St. Gothard Railway, these were altogether avoided by the adoption of circular spiral tunnels; but their great cost would probably, in many instances, prevent a railway from ever being made. If with the steep gradients on the Oroya Railway sharp curves could be successfully worked, most of the reversing stations might have been done away with; while the spiral tunnels on the St. Gothard Railway, even if not altogether avoided, might at any rate have been materially shortened. These facts led him to believe it would be of great general utility if some reliable information could be given as to the smallest radii with which each of the systems under discussion could be advantageously

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[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 145.

Mr. Watson. worked, and he felt sure that many members of the Institution, besides himself, would be greatly obliged to any one who would furnish such information.

Mr. Wilson. Mr. ROBERT WILSON, in reply, was unable to state definitely the reasons why Mr. Carruthers had adopted the 3½ per cent. gradient from Cambur to Trincheras. He was under the impression that it was a question of first cost, combined with the topographical features of the valley. Mr. Fell had asked why the engines were not run over a longer portion of line than the mere incline, on the Rimutaka. It was pointed out in the Paper that the weight of the rails precluded the possibility of running the engines over the other portions of the line. Mr. Fox had objected to the compared cost of working on the Hartz line with that of the Fell system. The Paper was, perhaps, not very clear on this point. He had not intended to institute a comparison of the cost of working the Hartz line and the Fell incline, but rather to point out that a saving was to be obtained by adopting the adhesion and rack system combined in running over a line of that description; and he had in his mind the Rimutaka incline, knowing that if it had been possible to run the trains beyond the incline, it would have materially reduced the cost of working. With regard to the Hartz line and the incline worked on the Fell system, he had attempted to make a comparison to show, that even reducing them both to like conditions there was something in favour of the Hartz, due, no doubt, to the possibility of working the trains continuously over the line. On the Hartz Mountain Line the maximum adhesion gradients were 1 in 40, and the maximum rack gradients 1 in 16·67. The adhesion sections were 14½ miles and those with the rack 4·7 miles in length. For the round trip, that would be 28·5 miles of adhesion, and 9·4 of rack. The coal-consumption on the round trip was given at 1,845 lbs. Assuming that the consumption of fuel on the adhesion sections was 30 lbs. per mile, which was a low estimate, it would give, for the round trip of 28·5 miles, 855 lbs., leaving 990 lbs. for the rack sections; equal to 105·4 lbs. per train-mile. On the Rimutaka incline the consumption per engine-mile, according to the government returns of 1888, was 112·43 lbs. The mileage was thus made up: 10,988 train-miles, 4,233 shunting-miles, 21 ballast-miles; total 15,352. The coal consumed was 766 tons. The shunting-mileage was made by the Fell engines, not on the incline, but in the station-yards at the top and bottom; and for comparison it might be assumed that those engines would burn 30 lbs. per mile for that duty. The inside engines would not be at work at the time. That would absorb a coal-consumption

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of 126,990 lbs., leaving a balance of 1,588,850 lbs. for the incline. That divided by the train-mileage would give 144·2 lbs. But the Fell engine took 65 tons up 1 in 15; it would take 75·6 tons up 1 in 16·67, the Hartz grade. The Abt engine took 95·5 tons; therefore, if the coal consumption were taken directly as the load, the proportions would be, as 75·6 to 95·5 tons, and 144·2 to 182·1 lbs. But the coal in New Zealand had not the same evaporating power as that used on the Hartz. New Zealand coal would evaporate about 7 lbs. of water for 1 lb. of coal, and that used on the Hartz about 8 lbs., so that the consumption would be reduced on the incline itself to 159·3 lbs. for a 95-ton load against 105·4 lbs., or a difference of 53·9 lbs. per train-mile. Assuming that the two systems were equally efficient, the 53·9 lbs. represented coal burned without earning mileage. From this it might be deduced that the Fell engines on the Rimutaka incline consumed about 13 lbs. more coal per train-mile, under present conditions, than they would if kept fully employed. He thought that those figures justified him in having stated in the Paper, that if a line was laid out necessitating the use of a bank-engine, at one or several points, increase of cost of working must ensue, unless the traffic were such as to keep the bank-engine in constant use. There was thus a great advantage in the combined adhesion- and rack systems, which enabled the same engine to take the load over the entire line, notwithstanding exceptional grades on various sections. He did not wish to advocate any special system for working inclines. He took great interest in the question, and thought that probably for one line the Abt system might be more effective, and the Fell for another, or rope-traction for a third; but must in fairness state that after considering the mechanical details of each, he had come to the conclusion that the Abt system would best meet the requirements of railway-incline traffic both as regarded cost and safety. He did not think there would be a material difference in the curvature round which the Abt or Fell engines would run satisfactorily. He thought the limit of curvature for the Abt system would be governed by the clearance of the pinion teeth in the racks, and the radius at which that was arrived at would be far below the limits of practical application to railways.