Mr. Collett. and certainly not to be compared to the present rack appliances in any respect, and Mr. Collett did not think that adhesion was the most convenient or the most economical method of working that incline of $2\frac{1}{3}$ miles of 1 in 17 between Madison and Indianapolis; in many cases of this nature a strong rack-engine used as a bank-engine would seem more economical. Unless the advantages were striking, Mr. Findlay would not place a special system in the middle of a trunk line. Now one of Mr. Collett's objects in collecting materials for his Paper was that he had found that there were many railways abroad on which a rack or other special system could have been used with advantage and economy if the Governments and engineers had allowed it. Moreover, railways might have been built, which on account of their cost in tunnels and other special works were now only projects. Another point was that there was naturally more mileage in branch lines than in main trunk lines, and on these branch lines, especially when they were being built to develop a country, there was generally great advantage in economy in the work. Mr. Collett would therefore recommend in the above cases that the difficulty be faced and steep inclines made.

In answer to the enquiries as to the cost of the works on the Montserrat line, Mr. Collett would estimate that a rack railway with similar works could be constructed and equipped for £12,000 per mile.

⁂ Mr. Pownall's reply to the Discussion will be found at the end of the article.

Correspondence.

Mr. Becker. Mr. M. J. Becker, of Pittsburgh, submitted information with regard to the rack railway mentioned by Mr. Collett at p. 25 of his Paper, between Madison and Indianapolis, which had been the first ever built.[1] The same incline, it appeared, was now worked by adhesion with perfect safety and with greater economy, speed, and convenience than with the rack formerly used. The incline was 7,040 feet long, averaging 1 in 17; but for about half the distance the gradient was 1 in 16·5, and in two places was, owing to settlement, even steeper; also, owing to slipping of an embankment, a curve had been introduced on the alignment originally straight. The rack was used from 1847 to 1868, but since that adhesion had been used. The locomotives now in use were two in

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[1] See Appendix to Correspondence, p. 148.

number, with eight coupled driving-wheels and no other wheels. Mr. Becker. A trial trip with one of these engines (which had been originally built as a ten-wheel-coupled engine, and was reduced to eight wheels, 5 feet in length being taken off the frame) was made about eight years ago. The engine weighed 47 tons, and was able to haul a train weighing 219 tons (including the engine itself), but stopped after 500 yards. A trial was then made with four cars, weighing, together with the engine, 175 tons, when an average speed of 4·7 miles per hour was obtained. The tank, which was over the boiler, carried about 1,520 gallons of water, and the wood carried for fuel amounted to about three-fourths of a cord, or 96 cubic feet (dry beechwood). In tests made in 1875, before the above-mentioned alteration of the locomotive, the following results had been obtained:—Weight of engine, 50 tons; weight of train (eight coal cars), 137½ tons; total weight, 187½ tons; speed at foot of incline, 2 miles per hour; average speed of ascent, 6 miles per hour; steam-pressure, 130 lbs.; fuel used, 0·6 of one cord of dry beechwood. Another trip had been made with two passenger cars, weighing 39 tons. Total weight of train, 89 tons; speed on entering incline, 6 miles per hour; average speed, 14·5 miles per hour; steam-pressure, 132 lbs.; fuel consumed, 0·3 of one cord of dry beechwood. No want of adhesion had ever been experienced in any weather, nor had sand been used in the tests above described.

A patent had been granted in 1831 for a rack railway to one Ewer Rimber, in America, the original papers and drawings of which had come into Mr. Becker's hands when making inquiries on the subject.

Mr. Bell. Mr. H. P. Bell, of Victoria, B.C., offered information as to the practice adopted in the higher latitudes of North America in regard to the construction and working of mountain railways. One of the most important aids to the working of such railways in winter was the snow-plough. Leaving out of consideration the rotary plough, a type that had been much used might be described as an inclined plane below, surmounted by a ploughshare, or spreader, above. The toe of the plough was made of malleable iron or steel, and was hinged so as to be capable of being raised and lowered by a lever-handle from within. The toe dropped over the rails and removed the snow to a depth of about 2 inches below their heads, and two flangers attached to the fore-part of the cow-catcher (upon the locomotives making regular trips) completed the operation by removing the snow below the shoulder of the rail for some few inches in width, this last operation being necessary to prevent the effects of frost in a place where accumulation might

Mr. Bell. be a cause of danger. The toe was raised by the lever-handle at all planked road-crossings, and these were often marked by a signal-post to apprise the plough-conductor of their proximity.

He called attention to the necessity of subordinating hard and fast limits of gradients and curves to the natural conditions of the locality, in laying out mountain railways. In many years' work upon mountain railway survey he had never met with an instance where nature, if well studied, did not indicate the proper solution of any difficulty that arose. He could remember many cases where a long succession of sharp curves, with heavy work, would be required to establish a maximum gradient of 1 per cent., while a gradient of 2 per cent. afforded a direct line, with light work, upon the bottom flats of a valley sufficiently wide, but flanked in by precipitous mountains with tortuous base and occasional broken banks.

The switchback seemed to him a simple and economical resource, where the ground was favourable, even for a short distance. If laid out with an ascent at the lower end of each gradient, and operated with a locomotive at each end of the train, it offered an automatic protection to runaway trains, and might reasonably be considered safer than any continuous steep gradient involving sharp curvature to change direction. It would generally give easier curvature, and afforded a means of avoiding a bluff of rock or a steep ravine that might otherwise be an expensive obstacle.

He considered that there was much to be said for operating all mountain railways with two locomotives, placing one at each end of the train. Communication between the two drivers had been successfully maintained by means of the whistle, and, when the road was familiar to both, little signalling was required. A great advantage of this system lay in the fact that a smaller tractive force had to be transmitted through the couplings of the cars, and this led to a corresponding reduction of the flange friction in passing round curves. He mentioned a case of a serious accident in the United States, with a long train having two engines ahead, in which one or more of the cars left the rails on a curve of small radius, pulling the rest after them. The accident was ascribed to excessive tension. When a large portion of a long line had gradients that could be economically worked by a certain class of engine, it was an advantage to adopt on the steeper sections a gradient on which the same train could be moved by two similar engines. Where a maximum gradient of 1 in 40 occurred at intervals over the whole route, and, at one point only, a steeper gradient was required, it would seem good policy to introduce the switchback to secure uniformity, if the natural conditions allowed of it.

Mr. Bell. He agreed generally with the opinion that 1 in 40 was the steepest gradient that should be adopted for pure adhesion, but would remark that climate might modify the available adhesion very largely. He remembered having travelled on a gradient of 1 in 22, with an engine weighing in all about 40 tons attached to four empty flat cars. The engine came to a standstill four times in 3 miles of ascent, and only made a maximum speed of 3 miles per hour. This had been during the early hours of a foggy morning, when the rails were greasy.

Mr. Crowell. Mr. Foster Crowell, of New York, observed that, among the methods of working mountain railways described in the Papers, there was no allusion to the use of geared engines,[1] of which a number were employed for that purpose in the United States. He therefore forwarded particulars of the Tiadaghton and Fahnastalk Railway, in Pennsylvania, for many of which he was indebted to Mr. C. B. Farr, General Manager of the Railway.[2] He also forwarded a map of the steep portion of the line, showing the switchbacks, a drawing of the Shay engine in side-elevation, and a photograph of one of them in service. The peculiarity of the Shay engine was that it had vertical cylinders, three in number, driving a horizontal fore and aft crank-shaft, gearing, by means of bevelled pinions, into the face of each of the wheels of the engine and tender. The crank-shaft had flexible telescopic couplings, so as to confine the rigid wheel-base to the length of one truck. The boiler was set to one side of the centre-line, so as to balance the machinery. Steam- or air-brakes were applied to all wheels. These engines had familiarly acquired the name of "stem-winders."

The railway above mentioned was a logging railway worked with the rolling stock of the main line, but separately owned. The Shay engine could run, if desired, on the main line, and do the shunting at the junction. On the level this engine could haul its limiting high-gradient load at a speed of 15 miles an hour. He had ascended gradients of 10 and 12 per cent. with engines of this type, but considered 6 per cent. the limit for economical working of main line traffic, though 8 per cent. might be used on branches to loading points. The speed in ascending, attained on this line, was upwards of 5 miles per hour.

The day's work of the engine was given as 70 miles, hauling,

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[1] Minutes of Proceedings Inst. C.E., vol. cii. p. 386.

[2] Appendix to Mr. Collett's Paper, p. 37, col. 14.

Mr. Crowell. on the average (of up and down), 125 tons gross, with a coal-consumption of 5,500 lbs. He thought it obvious that, between the gradients suitable for simple adhesion engines and those suitable for the rack, there was a distinct field for this type. Other things being equal, a line built for this type of locomotive need only be one-third the length of a line of the ordinary type (taking 6 per cent. and 2 per cent. as the gradients for comparison on an ideal section). The cost would be less than one-third, owing to the smaller radius permissible on curves, and the facility thereby given for avoiding heavy earthwork, and owing, also, to the lighter rail that might be used.

In regard to the switchbacks, it might be interesting to note that, following a conspicuous authority, the tails were originally constructed on the same gradient (1 in 16·6) as the rest of the line, as a continuation of the line below the points, so that a descending train, after crossing the points, would lose its velocity in running into the tail. It was found, however, that the velocity with which a descending train had to enter in order to carry its whole length clear of the points was too great for safe working with this arrangement, and the gradient of the tails had been reduced to 3 per cent., that being about the gradient at which the engine could hold a loaded train by its own brakes or pull it up-hill. On this road the engine descended at the head of the train, by which means all the cars received the benefit of the sand used in slippery weather. On some logging roads it was thought better to have the engine behind the train, so that if control was lost, the engineman could uncouple and save his engine, the cars only being wrecked.

Mr. Fellmann. Mr. J. FELLMANN, of Lucerne, forwarded particulars of the Rigi railway.[1] Trial trips on this line were made on the 21st May, 1870, and it was opened for traffic the following year. The permanent way had originally been laid with timber cross-sleepers having longitudinal timbers notched into them. Iron sleepers had since been substituted, 7 feet 6½ inches long by 9 inches wide and 2·4 inches deep, with which the longitudinals were unnecessary. The track rails originally weighed 28·2 lbs. per yard, but had been replaced by heavier ones. The original rack, 4¾ inches in height, was still in use and showed little sign of wear.

Mr. Ferrar. Mr. W. G. FERRAR observed that Mexico furnished many examples of mountain railways. The Mexican Railway (4 feet

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[1] *Ante*, pp. 20, 44, col. 32.

Mr. Ferrar.

8½ inches gauge) had a continuous gradient of 1 in 25 (uncompensated) for 16 miles, and reached a height of 8,400 feet above the sea. It was maintained in a high state of perfection, and the Fairlie engines used on it took their load of 120 tons round curves of 330 feet radius up the incline with the greatest ease and steadiness. Various single engines had been built for this work, but up to 1890, when he had left Mexico, none of them had proved successful, as they ran short of water. Rails of 85 lbs. per yard with steel sleepers were now used on the incline with economical results. The Mexican National Railway (3 feet gauge) from Mexico City to Laredo (Texas, U.S.A.) had 3 inclines on its 837 miles of main line. No. 1, about 17 miles long, reached a level of nearly 10,000 feet above the sea, with an average gradient of 3½ per cent. and curves of 260 and 300 feet radius. No. 2, in the opposite direction, had 10 miles of 4 per cent., compensated. No. 3 averaged 2 per cent. for 56 miles. Up to 1891, inclines Nos. 1 and 2 were worked by Baldwin Consolidation engines and No. 3 by Baldwin Mogul engines, both having cylinders 16 inches × 20 inches, and the driving-wheels being 32 inches in the former case and 42 inches in the latter. It was found that greater power was required, and Baldwin compound engines had been obtained with cylinders 10 inches × 20 inches and 17 inches × 20 inches.

He considered that the advantage of a narrow gauge in regard to curves was greatly overrated. In Ceylon (5 feet 6 inches gauge) there were many curves of from 330 to 400 feet radius on 1 in 44, compensated. On the Mexican Railway (4 feet 8½ inches gauge) in 1881 and 1882 for many months the trains passed round a curve of 150 feet radius on 1 in 25 while a tunnel was being completed. On the Mexican National Railway a semicircular curve of 128 feet radius had been in use since 1882, thus giving the 3 feet gauge an advantage of 22 feet in radius only over the standard gauge. There were on the National several curves of 200 feet, but by gradual improvements the minimum radius was being raised to 280 feet. He thought that, if possible, a gradient of 1 in 40 should not be exceeded in mountain railways, and that when this could not be obtained, it would generally be advisable to pass at once to a gradient of 1 in 12 or steeper, using the rack.

By the courtesy of Mr. W. G. Raoul, he was enabled to append the following Table showing particulars of the tractive-power of the compound locomotives in use on the Mexican National Railway:—

Mr. Ferrar.

Gradient.		Tractive-Power in Tons.	
		CLASS Q. Baldwin Ten-Wheeled, Outside-Frame. Cylinders {10 inches × 20 inches. 17 „ × 20 „ Driving-Wheel Centres, 40 „ Weight of Engine 76,000 lbs. „ „ „ with Tender ready for Service . . } 138,000 „	CLASS R. Baldwin Consolidation, Outside-Frame. Cylinders {10 inches × 20 inches. 17 „ × 20 „ Driving-Wheel Centres, 32 „ Weight of Engine 83,000 lbs. „ „ „ with Tender ready for Service . . } 145,000 „
Feet per Mile.	Per cent.		
Level	Level	1,380	1,875
26·4	½	555	750
52·8	1	335	455
79 2	1½	235	315
105·2	2	175	235
132·0	2½	140	185
158·4	3	110	150
184·8	3½	95	125
211·2	4	85	115

NOTE.—The tenders when loaded weighed 62,000 lbs., or about 28 tons, which must be added in each case to obtain the actual tractive power of the engine.

Mr. Fraser.

Mr. P. A. FRASER thought the Papers demonstrated the necessity of some general classification of all railways being adopted by engineers, based upon their carrying capacity and irrespective of gauge or traction system. Such terms as "light railways" and "mountain railways" would then obtain a distinct definition. In the case of the two lines described by Mr. Berg it was obvious they had nothing in common beyond the fact of ascending a mountain, and could no more be compared than the elevator of an hotel with the winding engines of a coal pit, except upon the basis of work done. The class to which a railway should belong might be determined by the number of tons which it was capable of transporting to a given distance or raising to a given height in a unit of time, and the term "speed-tons," made use of by Mr. Pownall, would aptly express this. To go a step further the efficiency of a railway might be arrived at by introducing a unit of cost, and such a formula as $E = \frac{S \times T}{C}$, where E was the efficiency, or amount of work done per unit of time and cost, S the speed in miles per hour, T the weight of net or paying load in tons, and C the cost of haulage per ton of net load, would afford a means of comparing all such lines and systems as those given in the Appendix to Mr. Berg's Paper. Where the system of traction used was similar, the degree of efficiency expressed would be absolute; where dissimilar, the efficiency attained would be relative, a coefficient applicable to the system being found, just as in the case of girder-bridges or prime motors. Mr. Fraser

It appeared from these and other Papers that engineers had abandoned adhesion-railways for gradients exceeding 1 in 30—and his own experience entirely agreed with this. Having had charge of the traffic of the Guaira Railway on a continuous gradient of 1 in 27, and of the Oroya Railway with its long stretches of 1 in 25, the danger, cost, and inconvenience of such gradients for ordinary locomotives were fully brought home to him. Apart from the loss of time through slipping in the ascent, and the liability to runaways from careless driving or deficient brakes in the descent, such lines presented their whole length to such dangers as landslips and washouts, against which a dense tropical vegetation was the only protection. In the Peruvian Andes the mountains were bare, and but for the fact that rain fell only at intervals of many years on the western slope of the Cordillera, the Oroya Railway could not have resisted the weather as it had hitherto done. From the fact of being in the tropics, avalanches were unknown, the snow line being above the height of the summit tunnel (15,648 feet). It had always been the regulation, however, for a pilot trolly to start down the mountain ahead of each train to inspect the track. The speed of trains, taken from the time tables, was 8·7 miles up and 11·3 miles down, per hour, but a trolly could cover the distance of 80 miles from Chicla to Lima in four hours. Accidents frequently happened to the trolly-men, and only the most rigorous discipline, and report by block-telegraph, could keep some of the more reckless engine-drivers under control. That no passengers had been killed in runaway trains upon the Oroya Railway since the line was opened in 1876 was due more to those who worked the line than to those who designed it. He had several times been in runaway trains that were pulled up by encountering sharp curves, and the feeling was not a pleasant one. Nothing but a sharp curve would stop such a train with all the wheels skidding on the rails.[1]

The Valley of the Rimac, up which the line forced its way by these heroic gradients and frequent switchbacks, really offered a

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[1] The dangers alluded to were illustrated by an accident which occurred on the Interoceanic Railway of Mexico. A train was descending an incline at a high speed, and when entering a sharp curve part of it was thrown from the rails over the embankment, and dashed to pieces at the bottom of a precipice.—*The Times*, March 2, 1895.

Mr. Fraser. fair opportunity for much sounder engineering, and not only would the successive steps by which the river descended enable a line on the combined rack and adhesion system to be easily found, but the power available from a boisterous mountain torrent, ever running, and parallel to the railway for 70 miles, would, in the present day, not be neglected. Reference had been made by Mr. Pownall to the smoke nuisance in long tunnels on steep gradients. Even in the earlier tunnels through the Alps the question of ventilation had not received the attention it now did, and it was noteworthy that, in traversing the St. Gothard tunnel, the windows of the carriage could remain open without discomfort. This was not possible either in the Arlberg or the Mont Cenis tunnels, and was due to the difference between a gradient of 1 in 172, and those of 1 in 72 and 1 in 43.

The summit tunnel on the Oroya Railway stood at such a height above sea-level that to breathe even pure air was a painful exertion. Its length was $\frac{3}{4}$ mile, one-half of this being on a gradient of 1 in 27, preceded by an approach of 1 in 25 on a curve. The tunnel was for a single line only, and the use of coal-burning locomotives was most distressing to passengers. Fortunately the adoption of petroleum fuel on the Peruvian railways had got over this difficulty, and upon such a line as the Usui it would be thoroughly suitable, having regard not only to its perfect combustion and freedom from smoke, but to the economy of 50 per cent. in cost per mile over coal, and in weight of fuel carried. There could be no two opinions as to the advantage of petroleum fuel, where it could be obtained. That used in Peru was found on the Coast, and the adaptation of the locomotives and tenders to it was a simple matter.

Mr. Mallet. Mr. A. Mallet desired to comment on the criticisms of Mr. Berg (p. 11), with regard to the engine compounded on the "Mallet" system working on the St. Gothard inclines. First, as to the condensation in winter, the engine was put to work in 1891, and at first the steam-pipe connecting the two groups of cylinders, and acting as a receiver, was insufficiently protected, so that condensation ensued; but all that was necessary was to treat this pipe as the boilers, cylinders, and steam pipes (which in most Swiss railways were outside) were treated. There was nothing in this matter peculiar to the system of compounding; and on the Davos railway, at greater altitudes than were found on the St. Gothard, no such defect had been noted. The system had been considered complicated by Mr. Berg, but some complexity might be said to be inherent in the object sought after. At any rate it could be claimed that the

Mr. Mallet. Mallet engine was less complicated than the Fairlie, there being but one bogie in place of two, and only one jointed steam-pipe, which carried steam at only 50 lbs. to 55 lbs. pressure. The Swiss lines employed at present four types of these engines, two on the normal gauge and two on the metre gauge.[1] He desired also to direct attention to an adhesion line recently opened (1893) from Yverdon to Ste. Croix in Switzerland, on which there were gradients of considerable length as steep as 1 in 22. This line was worked by similar engines to those above discussed. Although not of technical interest, the remarkable fact might be mentioned that, according to a stipulation made in the concession, at the express desire of the concessionnaire, no trains might travel on this line on Sundays.

Mr. Martineau. Mr. W. MARTINEAU directed attention to the Petropolis Railway, of which he had given some account in a previous discussion at the Institution.[2] In that case the use of the rack had been a perfect success, while it would have been most costly, if not impossible, to develop an adhesion line of 1 in 40. As an instance in the other direction, he would refer to a railway in the North of Spain on which he had reported. In this case the line, which was of metre gauge, had a steep section in the middle of its length, connecting a plateau above with a valley below. This section had eight or nine tunnels, with cuttings and banks on side-lying ground, the strata in some places sloping with the surface. The embankments were gradually sliding down into the valley and the upper sides of the cuttings also moving. This state of things should be foreseen and guarded against in mountain railways. The case referred to was a good one for introducing a steep gradient of about 1 mile in length, which he believed could have been made for half the money spent on the eight or nine miles of heavy and unsafe line actually built. Generally he would say that in any case where sections of ordinary railway are separated by a great difference of level, it was better to face the hill at once and adopt a steep gradient, though he would not advocate this on main through lines.

Mr. Mosse. Mr. J. R. MOSSE, although without experience in working either the Fell or the rack system, did not think that the approaches to the St. Gothard Tunnel would, if laid out at this date, have followed one of these systems rather than the present alignment with spiral tunnels, required to protect the railway from landslips

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[1] See Appendix to Mr. Collett's Paper, p. 31 *et seq.*, cols. 4, 10 and 11.

[2] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 152.

Mr. Mosse. and avalanches, and to give a gradient of 1 in 40. In fact, he did not believe that the existing traffic on these approaches could be carried on a very steep gradient by the Fell or rack system without increasing to a very inconvenient, if not dangerous, extent the number of trains.

Where the traffic was very light, and the trains consequently few, the Fell or rack system might suffice; but it would still be the duty of the engineer to provide for the future, and experience showed that, in general, the increase of traffic greatly exceeded previous anticipations. He thought that, unless there were an ample margin of engine-power, traffic was always carried disadvantageously, additional expense in working was incurred, and the delay involved was often accompanied with serious risks. He might state, as an instance, that on the Highland Railway in August and September last, between Perth and Forres, on a gradient said to be 1 in 40 or 1 in 50, the trains were so overloaded that they generally required two locomotives in front, with sometimes one also in the rear, and, notwithstanding this, they usually reached their destination one hour late. Some unusually powerful locomotives were said to have been since ordered for this service.

His eleven years' experience in the working of the Ceylon Government Railway, with gradients of 1 in 45, confirmed the opinion he had expressed[1] as to the Midland Railway of Mauritius, viz., that for long inclines the limit for working with advantage by adhesion was 1 in 40. On this gradient the trains ran with safety and comfort, but on steeper gradients they occasionally stopped, ran backward, or gave trouble. The adoption of pieces of comparatively level gradient on long and steep inclines was found to add greatly to the safety of descending trains.

Mr. Parsons. Mr. W. B. Parsons, of New York, had constructed, a few years ago, a system of railways in a very hilly portion of north-western Pennsylvania, for the transport of timber.[2] As these lines were only intended for a few years' service the utmost economy in construction was necessary, and the gauge had to be 4 feet 8½ inches in order to save the cost of transshipment. The main stem of the system had a gradient 3·64 miles long at a rate of 1 in 30, and was a succession of curves, many of which had a radius of 319·6 feet. In other parts of the system gradients up to 1 in 26 were frequently used, some of which were against the heavy

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[1] Minutes of Proceedings Inst. C.E., vol. xxviii. p. 250.

[2] See Transactions American Soc. C.E., vol. xxv., 1891, p. 119.

Mr. Parsons.

traffic. Two classes of engines were used: one, the ordinary Mogul type with six coupled 4-feet driving wheels, a rigid wheel base of 10 feet, and a total weight of 35 tons, and the other being the Shay geared locomotive.[1] The chief advantages of the latter engine are the utilization of the whole weight of both engine and tender for adhesion, a flexible wheel-base and a high piston speed. On the railway above mentioned three Shay engines were used, varying in weight from 28 tons to 60 tons. The rails were 40 lbs. per yard, laid on soft-wood ties. Great care was taken with both alignment and level, so as to ensure uniform resistance. The value of this care had been proved when a runaway train, consisting of an engine and seven heavily loaded cars, passed safely round the sharp curves at a high speed and then left the rails, after passing on to the main line, at a point where there was no steep gradient or sharp curve, but where the same care in laying out the line had not been used. A railway in Utah, with which he was acquainted, had an incline 5 miles long with an average gradient of 1 in 12 and a maximum gradient of 1 in 9½ with curves of 50 feet radius. It was built to a gauge of about 30 inches, and was an adhesion line operated successfully by Shay engines, of which the heaviest weighed 20 tons and could haul up the incline 40 tons, besides its own weight. The line served silver mines and the bulk of the traffic was down hill.

Mr. Riggenbach.

Mr. RIGGENBACH stated that he had, in conjunction with the Maschinenfabrik, of Esslingen, for ten years manufactured loco motives and other special apparatus for rack railways at the works at Esslingen. About forty such railways had been constructed, of which the most important was the Padang Railway in Sumatra. All the latest rack railways in Switzerland had been made with the Riggenbach rack, as, for instance, from Interlaken to Grindelwald and Lauterbrunnen, from Lauterbrunnen, by the Wengernalp, to Grindelwald, from Lucerne to Meiringen by the Brünig, and also the line from Monaco to La Turbie. He begged to submit to the Institution particulars of some of these lines.[2] He would like to call attention to the statement by Mr. Collett on p. 25 that the Riggenbach ladder-rack "is not so durable and effective as the Abt rack." This, he considered, was incorrect, and was quite at variance with the experience of the Rigi Railway, which was built as long ago as 1870 and showed no trace of wear yet.

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[1] For description, see p. 129; also Transactions American Soc. C.E., vol. xxv. 1891, p. 119.

[2] See Appendix to Mr. Collett's Paper, p. 31 *et seq.*, cols. 21, 27 and 33.

Mr. Rinecker.

Mr. F. RINECKER, of Würzburg, commented on Mr. Collett's observation (p. 26) to the effect that the speed on rack railways was at present somewhat low, pointing out that the introduction of the rack in no way altered the principle of the time rate of work done being measured by force × velocity. The object of the rack was to enable the factor "force" in this expression to be increased without increasing the weight of the motor, by removing the limit to the "force" (*i e.*, tractive-force) imposed by adhesion. But if this object were attained and the weight of the motor not increased, then the power developed was the same as before, being mainly dependent on heating-surface. If now one of the factors of the expression force × velocity were increased, the other must be diminished to leave the product unaltered. The velocity must necessarily be reduced, therefore, as the gradient became steeper, unless either the motor was made stronger, and consequently heavier, or the train-load made lighter. Further, he considered the measurement of speed of trains by horizontal distance traversed to be fallacious when applied to mountain railways; the vertical distance traversed would be a better measurement of speed. With a velocity of 7 miles per hour on 1 in 16, the speed of vertical rising would be the same as with 17½ miles per hour on 1 in 40, being at the rate of 2,310 feet rise per hour. He thought also that the measurement of coal-consumption in lbs. per train-mile was misleading when applied to mountain railways, the mileage travelled being in these cases no measure of the work done by the locomotive. If, instead of this, a standard of 1,000 foot-tons (*i.e.*, train-weight × vertical height) or some similar standard were used, the comparison would be of some value, and the advantage of the rack in such cases would appear. The losses due to friction were less as the gradient was steeper because of the shorter length of line, and a further saving arose from the motor being lighter and thus giving a smaller total weight to be lifted in proportion to the train-load proper.

Proceeding to Mr. Pownall's Paper, he desired to call in question the statement on p. 49, that "in consequence of the small heating-surface provided, the locomotives proved unable to take up the inclines more than two-thirds of what was expected." This statement reflected seriously on the inventor and designer of the engines, and nothing was to be found in the Paper by way of justification for it. The leading dimensions of the engines had been most carefully calculated, and submitted to the consulting engineer of the railway in England. They had been sent to Japan in such time that any desired alteration could have been made before the con-

Mr. Rinecker.

struction of the engines was proceeded with. No error had been observed by any of the persons who had examined the calculations and drawings, for the simple reason that none existed. The design was made on the same principles as had been followed in other cases, where all anticipations had been realized. If it were true that the expected duty had not been obtained from the engines (and no official complaint on the subject had ever been made), he would attribute such a result to the inexperience of the Japanese drivers employed. It had been pointed out to the Japanese authorities that a combination locomotive required a special knowledge to handle it properly, and it was proposed to send out a mechanic to erect the engines and to instruct the drivers as to the working of them. The Japanese authorities would not listen to this proposal, and the result was that, as he believed, very grave mistakes had been made in handling the engines, and permanent injury had been done to them. He believed that the figures in Mr. Pownall's hands showed the heating-surface to be equal to developing 294 HP., which would be more than sufficient for taking a train of 100 tons up 1 in 15 at a speed of 5 miles per hour.

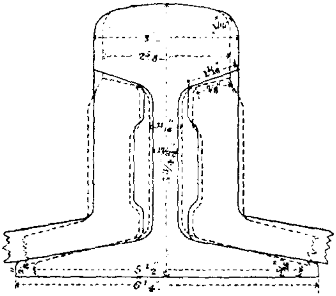
He wished also to call in question the propriety of using "speed-tons," as defined by Mr. Pownall, for comparing the merits of an adhesion with those of a rack railway. The speed was in miles of horizontal distance, and the main part of the mechanical work was done in lifting the load vertically. The vertical velocity of the train would form a much better element than the horizontal velocity in such a comparison. Taking Mr. Pownall's figures for the Hartz and Eisenerz inclines, and for the Gotemba respectively, in the former case a lift of 2,257 feet was obtained in one hour, whereas in the latter the lift was only 1,557 feet. The train-weights being 118 tons and 136 tons respectively, the figures obtained by multiplication would be 266,326 foot-tons per hour for the Hartz and Eisenerz, and 211,752 for the Gotemba.

Mr. Pownall's statement that the adhesion incline in this case would take double the traffic of the rack incline was, he thought, misleading. A true comparison would show the traffic capacity to be much the same, if the locomotives were of the same power in the two cases. The main advantage of the rack system, combined with adhesion, would always lie in the saving in cost of construction, and here the railway forming the subject of the Paper would not appear to be a favourable example of the use of the rack. If an adhesion line with no heavy works could, as Mr. Pownall said, have been built for almost the same cost as the steeper rack incline

Mr. Rinecker. it would probably have been preferable to build it as an adhesion line, with perhaps an occasional rack section of not too steep a gradient, in order to enable the heavier trains to be worked on it. The almost continuous tunnel of the line, as built, must be objectionable, and should not be credited to the Abt system.

Mr. Sandberg. Mr. C. P. SANDBERG, in reference to the remarks on the permanent-way of the St. Gothard Railway in Mr. Berg's Paper, submitted a drawing of the rail-joint used with his first 100-lbs. Goliath rail,[1] and also a drawing comparing the section of that rail with that of a new 100-lbs. rail designed by him in 1894, *Fig. 1.* The latter had not yet been tried, but a similar design of 50 lbs. weight had been made and found preferable to the old section. He had lately designed and inspected a 110-lbs. flange-rail, now being laid in place of an 87-lbs. rail, in a tunnel on an English railway, with a view to increasing the life of the rail by 50 per cent. and reducing the cost of maintenance. This rail was to be laid direct on the sleeper, and had a flange-width of 6½ inches. In tunnels, owing to the moist and sulphurous atmosphere, a rail sometimes would lose 2 lbs. per yard per year, and this rapid corrosion should always be considered in designing a rail-section for tunnels.

Fig. 1.



Rail of 1894—Full lines.
,, 1886—Dotted lines.

	1894.	1886.	
Area of head . .	46	43	per cent.
,, web . .	17	22	,,
,, flange .	37	35	,,
	100	100	

He called attention to the relative weight of the engines and the rails on the St. Gothard line. The general principle in England was to have heavier rails, as compared to the engine-weights, than were used on the Continent. This might be necessitated by the higher speeds in England; but he thought the English policy was undoubtedly the right one, from the point of view of economy in maintenance, especially with rails at their present price. The increase in weight of rails used on the St. Gothard Railway, described by Mr. Berg on p. 6 of his Paper, was small as compared with the increase that had taken place in England in the same time, since 110 lbs. had

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 365, Sandberg on "Rail Joints and Steel Rails."

already been reached with, say, rolling stock half as heavy as that of the St. Gothard. He thought that this progressive increase would still continue for the sake of safety, comfort and economy in travelling, and that it would be well for continental railways to follow the example. Mr. Sandberg.

Mr. A. Schucan, of Davos-Platz, in sending printed information with regard to the Landquart-Davos Railway and a plan of snow-defences,[1] explained that in the Klus valley it was necessary to protect the line against stones that might descend from a height of 2,000 feet, as well as against avalanches. A combination of terraces retained by dry-stone walls, and fences of timber and iron rails was employed, and had answered very well. The defences had suffered injury, but the line itself had entirely escaped. Trees had been planted between the line and the terraces. It was intended to gradually make the system of defence more complete. Mr. Schucan.

The general protection of the line against snow was effected by posts standing 5 feet out of the ground, about a foot apart, in rows about 16 feet from each other. If the posts were not placed near together the light snow drove between them. The removal of snow from the line was found a serious item of cost. The total snowfall in 1890 was 15 feet; in 1891 the same; and in 1892 nearly 14 feet. The greatest depth of fallen snow was in 1890, 2 feet 10 inches; in 1891, 4 feet; in 1892, 8 feet 8 inches; in 1893, 5 feet 6 inches. The cost of removal was in the same four years £136, £254, £1,184 and £875 respectively. Fortunately very little drifting occurred. The methods used to remove the snow were, (1) small snow-ploughs attached to the engines; (2) a larger plough on separate wheels; and (3) manual labour. The traffic had only once been interrupted by snow, when, in 1892, an avalanche descended at a place where such an accident had not been apprehended.

The heavier compound engines (Mallet system) had been ordered in consequence of the rapid increase of goods traffic which made it necessary very frequently to put an assistant engine on the trains. There had been a considerable saving in fuel and wages from the use of these engines. Thus, in 1891, the traffic expenses were 20·5*d.* per train-mile; while, in 1893, they were 15·3*d.* per train-mile. The coal consumption was, in 1891, $3\frac{3}{4}$ lbs. per axle per mile, and in 1893, 3·23 lbs. The repair of the Mallet engines was not more

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[1] See Appendix to Correspondence, p. 150; also Appendix to Mr. Collett's Paper, p. 37, col. 10.

Mr. Schucan. costly in proportion to their tractive-power than that of the lighter engines.

It had always been supposed, previously to the construction of the St. Gothard line, that the coefficient of adhesion in the higher Alpine regions was less favourable than at lower elevations, and for this reason the gradients in the higher parts of the St. Gothard line were reduced. The experience of the Davos Railway entirely contradicted this view. The adhesion was lowest in the tracts exposed to fog. The difference was most marked in winter, for the frost was constant in the higher regions and the rails dry, while, lower down, the fog and the frequent alternations of frost and thaw were embarrassing. In the mountains a coefficient of one-sixth could nearly always be reckoned on, while in the valleys often not more than one-eighth to one-seventh would be obtained.

The Landquart-Davos line was sufficiently successful to enable an extension to be made from Landquart to Chur and Thusis, which was now under construction. This line would be 25 miles long, and was expected to be ready for use by July, 1896. It was intended for local traffic, and also to obtain the road traffic now using the Oberalp, Lukmanier, Bernardine, Splügen, Julier and Albula passes. The steepest gradient was 1 in 40, sharpest curve 328 feet radius; estimated cost, inclusive of equipment and financing, £240,000, or £9,600 per mile. It was hoped in future to carry the line into the Engadine valley, either from Davos over the Scaletta pass, or from Thusis over the Albula.

Mr. Trevithick. Mr. F. H. TREVITHICK remarked that he had carried out tests with the locomotives working on the Usui Railway; and in February, 1893, had drawn up a joint report with Mr. Pownall, for the director of railways, on the Usui Railway, and on the working of the four original Abt engines. The frames and other working parts were too lightly constructed to stand the heavy strains when the four cylinders of the combination-engine were working. The fire-grate area and heating-surface were too small to supply steam when working a heavy train up 2½ miles of 1 in 15. Japanese coal was used, which made steam well, although soft and smoky; the consumption was about 300 lbs. per mile with a train of 50 tons.

The ventilation of the tunnels was a very serious question, there being twenty-six tunnels, 2·76 miles, in a distance of a little over 4 miles. The atmospheric conditions in these tunnels were very trying to those on the engine, the immediate cause being the intense heat of the air, caused by the great volume of steam from the four cylinders working together, and almost without expansion, and added to other products of combustion

Mr. Trevithick.

discharged from the chimney. The feeling on the uncovered parts of the body was not far short of acute pain, and to this was added the necessity of breathing the heated atmosphere. The conditions varied with wind and weather; the same tunnel would be passed through on the same day, one time without discomfort, the next with great discomfort. The train on entering the tunnel acted as a plunger or piston, driving the air before it; the exhaust steam was discharged against the tunnel roof, and enveloped the engine in smoke; the vacuum caused by the train entering the tunnel was filled with the air following the train into the tunnel, this volume of moving air being increased as the train proceeded and being also aided by the incline of 1 in 15, and by the condensation of the steam from the engine. Eventually, this volume of air drove the smoke beyond the engine and the carriages. A canvas curtain was now pulled across the mouth directly the train had entered. The vacuum was then filled with air from the front of the train, thereby keeping the smoke behind the engine. This arrangement had acted in a more satisfactory manner than any other appliance which had been tried. The speed with six carriages (50 tons) was about 5 miles per hour.

Mr. Waring.

Mr. F. J. Waring, C.M.G., with reference first to Mr. Berg's Paper, stated that he considered, in treacherous loose formations not liable to slip in large masses but having a tendency to crumble away, the best procedure was to widen the formation breadth of the cutting, and thus to allow room for any material which might come down to fall without interrupting the traffic. It was often, in steep side-long ground, impracticable to flatten slopes beyond a certain angle on account of the great height to which they would extend, and even if this were practicable, it would be often objectionable, as exposing a greater surface to the disintegrating action of the weather. It would, he thought, be interesting if Mr. Berg were to state what was the radius of the sharpest curve on the approaches to the St. Gothard tunnel, and whether it was used on the steepest gradient, or, if not, what was the limit of curve used on that gradient. He could hardly think that Mr. Berg meant that a maximum speed of 35 miles an hour was attained on the St. Gothard inclines of 1 in 37 and 1 in 40, and it would be well to know what was the speed on those gradients.

His own practice of late years on mountain railways in Ceylon, where the super-elevation of the outer rail was sometimes as much as 6 inches, had been to give the full amount at the point of commencement of the curve and to run it out in a distance of 33 feet on the straight. This was, he knew, rather sharp, but

Mr. Waring. where the length of straight between reverse curves was compulsory, sometimes as short as one chain only, there seemed to him to be no alternative. He hardly thought that the practical value of transition curves, such as those referred to by Mr. Berg, was, especially if the speed were low, commensurate with the trouble involved in setting them out. The batter of the retaining walls, shown in *Fig. 4*, was not given, and he hoped Mr. Berg could supply it; by scaling it seemed to be about 1 in 2¾. He was much struck with the very high cost of the cable railways appearing in Mr. Berg's Appendix, but he presumed that, as he believed they had been for the most part made for very special objects, ordinary commercial considerations were hardly applicable to them.

With reference to the Appendix to Mr. Collett's Paper, he would only remark that the Kadugannawa incline of the Ceylon Government Railway had been to a large extent dwarfed by the inclines on the extension of the railway to Nanu Oya, a description of which, with the engines and rolling stock in use thereon, had been given to the Institution by Mr. Mosse and himself,[1] as well as by the inclines on the further extension of the line to Haputale and Bandarawela which had only lately been finished. He had read Mr. Pownall's Paper with much interest, and feared a serious mistake had been made, the gravity of which the growth of traffic that always follows on the construction of a railway would in a few years render abundantly manifest. The line over the Usui Pass was a trunk-line connecting the eastern and western railway systems of Japan, and it seemed to him that the introduction into the centre of any trunk-railway system, of a short section of line requiring special appliances for working it, was a question demanding the gravest consideration and one only to be adopted in very extreme cases. It was apparent that even at present the traffic over the Pass, the summit of which from the west coast had been already reached at Karuisawa by an ordinary locomotive line with gradients of 1 in 40, was considerable. There was only therefore the descent on the east side to Yokogawa to be considered. It was stated that a route 15¼ miles in length, with a maximum gradient of 1 in 40 and with curves of ten chains radius, and an aggregate length of tunnels of 4¾ miles, could be obtained at a cost of £300,000. For such a line he thought there would be no difficulty in designing an engine without having any excessive weights on the coupled wheels which would take up trains weighing say 140 tons at about 12 miles per hour, and the journey would thus

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 96, and vol. xc. p. 319.

occupy about one hour and twenty minutes. In the place of this, a line 7 miles in length, with gradients of 1 in 15, having 2¾ miles of tunnel, had been built at a cost of £298,669, or for practically the same sum as the alternative line was estimated to cost. On this line the rack locomotive, with an average load of 11·15 tons per axle on each of the three coupled driving-wheels, took up, ordinarily, loads of from 60 to 70 tons at 4·7 miles per hour; about one hour and a half was thus occupied in ascending the incline. Mr. Waring.

The adoption of the rack and adhesion system therefore, in this instance, had not been attended with any saving of time in the journey nor of money in the cost of construction, while the weight of the train had been reduced to about one-half of what it might have been had the ordinary locomotive line been adopted. He ventured to hope that Mr. Pownall would be able to add some statistics as to the cost of working the Usui Mountain Railway, and be able to compare them with similar statistics relating to the cost of working the incline of 1 in 40 by which the Usui Pass was approached on the western side, and this would, he considered, add much to the value of his already interesting and valuable Paper.

Mr. Weightman. Mr. W. J. WEIGHTMAN observed that the Stanzerhorn incline, described by Mr. Berg, did not appear to differ very materially in details from its predecessors; the division of the whole ascent into sections could hardly be claimed as a novelty, as this had already been done both on the São Paulo and on the Khojak inclines. The arrangement for crossing the cars in the centre was similar to that used on the Bürgenstock incline, and was a modification of the plan first adopted at the Giessbach, but, on the latter, instead of the outer wheels having double flanges, and the inner being without, the wheels of one car had outside flanges, and of the other had inside flanges. Both these arrangements were open to the objection that the wheels of both cars had to pass over the rope at the upper crossing, and should the rope omit to drop into the gap in the rails prepared for it (and this had been known to happen) it would be liable to be damaged.

The brake arrangement was ingenious, and was somewhat similar to that adopted many years ago on the Croix-Rousse incline at Lyons, but had the advantage of being able to be applied by hand or foot, whereas that at Lyons only came into action when the rope broke. He did not, however, think that a brake of this description was as reliable as a rack-brake. If the car once attained any considerable velocity the friction-clutch would, in all probability, not work. With a rack-brake the danger of the pinion mounting the rack, which Mr. Berg was afraid of, was

Mr. Weightman. guarded against in a very simple manner on the Chiaia (Naples) incline by means of an inverted T-shaped bar suspended from each car, and running between the two rack-bars.

The weight of a fully loaded car on the Stanzerhorn incline was not given, but would appear to be not more than 6 tons. Were it more than this it was doubtful if the method of winding the cable would provide sufficient friction. All the older rope inclines on the Continent, such as the two well-known lines at Lyons, and that at Lausanne, followed the old English colliery practice of having large drums on which the whole cable was coiled; two cables were used, one being uncoiled as the other was coiled, and *vice versâ*. The more modern inclines used, as in this case, a single cable, passing round two or more pulleys, each with several grooves, to obtain the necessary friction. The use of clip-drums, so common in England, did not appear to have extended to the Continent, probably owing to the erroneous idea that they injured the rope. He had carefully examined ropes which had worked for more than a year over a Fowler clip-pulley, and could find no perceptible flattening.

To the particulars in Mr. Collett's Tables might be added that engines in use on the Great Indian Peninsula Railway[1] hauled trains of 250 tons up the Bhore and Thul Ghats (1 in 37); this gave 4·4 tons per ton of engine. This method, however, of comparing the efficiencies of different engines on different lines was not a very satisfactory one, as it took no account of the gradient. He had adopted instead the following method:—Knowing the adhesive weight of the engine, a calculation was made of the load which theoretically it should take on the gradient with a coefficient of $\frac{1}{7}$; this was called 100. According as the engine in actual practice took more or less than this amount, the number 100 was proportionately increased or decreased, and this figure was called the efficiency of that particular engine on that particular line. For example, the efficiencies of the engines in columns 1, 6, 16, and 22 were respectively 96, 84, 118, 133, and that of the rack engine in column 12 was 262, and of the Fell engine in column 17 was 260.

In his description of the Usui Railway, Mr. Pownall had explained that all bridges were built with brick arches because it was feared that girders on a gradient of 1 in 15 would be forced downhill; it would be interesting to have the opinion of other

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[1] Similar to those mentioned in the Appendix to Mr. Collett's Paper, p. 38, col. 16, *ante*, and also described in Minutes of Proceedings Inst. C.E., vol. cxii., p. 311.

Mr. Weightman.

engineers on this point. On the Nilgiri rack-railway, which he (Mr. Weightman) was now engaged in constructing, there were altogether eighty spans of girders (20 feet, 40 feet, and 60 feet) being built on a gradient of 1 in 12½, and he thought there was no occasion to anticipate trouble with them. On single-span bridges a stout angle-bar was riveted to the lower boom and butted against the masonry of the lower abutment; the lower ends of the girders also were built in solid, the expansion taking place upwards. Where the bridge consisted of more than one span, a heavy cast-iron bed-plate with its top-surface parallel to the gradient was securely bolted on to each pier.

The opinion was expressed in Mr. Pownall's Paper (p. 50) that under certain circumstances 1 in 15 was too steep for a rack railway, and it was stated that the Austrian Government had fixed 1 in 22½ as the limit. He was not aware of any rack railway which had been constructed on the Continent with a gradient so flat as this. The flattest rack railway ever made was the temporary 1 in 25 line in the Bolan Pass, and notwithstanding the marvellous feat of a single Abt engine of 51 tons taking a 304-ton train up this incline, the opinion generally appeared to have been that such a gradient was too flat a one to bring out to the full the advantages of the rack system. The unsatisfactory working of the engines on the Montserrat Railway was, he thought, due to the pinions being fixed on the carrying axles. This system was now, he believed, very generally condemned; as the tires of the carrying wheels wore, the pitch line of the pinion was lowered with respect to the rack and the gearing obviously became imperfect. It might be as well to point out that the curves of the rack portion of the Hartz were of 918 feet radius and not 656 feet as shown in column 12, p. 37.

He could not agree with Mr. Pownall's method of expressing traffic-capacity in terms of speed-tons. The factor which most determined traffic-capacity was the distance between block- or crossing-stations. Mr. Pownall's calculation was based on the assumption that these distances were equal on the two lines being compared, but as a matter of fact they were not, being very much less on the Hartz and Eisenerz Railways than they were on the Gotemba. If an engineer were submitting alternative schemes for a rack and an adhesion line, the speed on the one being less than on the other, he would naturally place the crossing stations closer on the former than on the latter, so as to make the carrying-capacity of the two lines equal. Reference had been made by Mr. Collett to the cheapness of construction of the Montserrat Railway, but he did not state what the cost actually was. It

Mr. Weightman. would be interesting if these figures could be given. The question of cost was perhaps the most important consideration in determining which of several alternative lines of different gradients and systems was most suitable. Mr. Weightman had compiled from various sources the cost per mile of the principal mountain railways in the world, the most expensive on record appearing to be the Semmering Railway in the Tyrolese Alps, which cost £98,000 per mile, while the cheapest were lumber railways in Pennsylvania, which cost about £2,000 per mile. The figures appeared to show that a rack railway did not cost more, mile for mile, than an adhesion line passing through similar country, while the saving in length in the former was usually very great. It was, however, dangerous to attempt to draw any inferences from this, or to try to lay down any hard and fast rules. Every mountain railway was a problem in itself and required to be solved independently as such.

Mr. Collett. Mr. Collett, in reply to the correspondence, considered the result of the trial on the incline between Madison and Indianapolis mentioned by Mr. Becker to be highly interesting. The load hauled by this adhesion engine, 2·72 per ton of engine weight, over $1\frac{1}{3}$ mile of incline averaging 1 in 17 gradient, was an extraordinary performance; but, as was well known, these trial trips could not be used as a gauge of the regular adhesion working of the incline, and must be taken for purposes of comparison with the exceptional loads of the Table, appearing therefore to correspond with the Hartz Railway with a similar grade. It was a pity Mr. Becker did not mention the ordinary load hauled in every-day practice. As regards the greater economy claimed for these adhesion engines, it must be remembered that the rack engines and appliances in use from 1847 to 1868 could not be compared, as regards economical working, with the rack appliances used at the present day. The situation as regards climate must be very good for adhesion work, when Mr. Becker mentioned that "No want of adhesion had ever been experienced in any weather," and could not be taken as a guide for other inclines not so favourably situated. As regarded mountain survey work mentioned by Mr. Bell, Mr. Collett had also often been surprised, when working in mountainous parts of Brazil, to find how 1 in 50 gradients and five- or six-chain curves sometimes enabled a fairly economical line to be laid out through narrow valleys with precipitous sides, which on first inspection seemed to offer insuperable difficulties to the passage of a railway without expensive work. His illustration of the 40-ton engine which could not haul four empty flat cars up 1 in 22 in

Mr. Collett.

foggy weather, strikingly illustrated the advantage of a special system in similar climates. In regard to wear, Mr. Collett did not refer specially to the wear of the teeth, but to the general durability of a ladder-rack consisting of so many parts. It had been stated by Mr. Rinecker that the speed measurement by horizontal distance traversed was fallacious when applied to mountain railways. Mr. Collett agreed with him as regarded very steep inclines. The method of comparison of engines proposed by Mr. Weightman was interesting, but did not seem to Mr. Collett to give a fair comparison as between adhesion-engines and light pure-rack engines; moreover it began with the assumption that rack-engines had only one-seventh available for adhesion, which was incorrect. As regards the pinions being fixed on the axles, this was not found to be a cause of trouble on the Montserrat engines; as on most inclines, a great deal depended on the driver. He agreed with the remarks of Mr. Martineau as to facing a hill at once, especially where railways were required to develop a sparsely inhabited country like Brazil.

Mr. Pownall.

Mr. C. A. W. Pownall, in reply to the discussion, considered, after studying the results obtained on the heavy adhesion inclines at Gotemba and the rack-adhesion line at Usui, that no such study could be complete without including the factor of speed. The introduction of this factor, alluded to in the Paper, had been fully endorsed by Mr. Burnett, who had said that it was impossible without it to make any useful comparison. Indeed, figures might otherwise become entirely misleading; for example, the cost of working at the Hartz rack-and-adhesion line had been compared[1] with that at the Semmering adhesion inclines to the advantage of the former by 23·4 per cent. But the speed had not been mentioned, and was, by the schedule, over 22 miles an hour at the Semmering, but only one-third as much at the Hartz. Such saving in cost would therefore be dearly bought where the traffic was large, on account of the loss of power to pass trains over the line. With regard to the remarks of Mr. Carruthers as to the expenditure of the same power by two engines, one with and one without a rack, he thought it was merely a matter of fact that the effective power was not the HP. an engine could theoretically develop but that which it could practically use. So, on the Kicking-Horse Pass the 52-ton engines of the Canadian Pacific Railway were doing work equal to 250 HP., while the Hartz engines of 55 tons—almost the

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[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 135.

Mr. Pownall. same weight, and weight and power went together—were producing and using 486 HP., because one-half their work was done on the rack independently of the factor of adhesion. Mr. Carruthers appeared to have supposed that at the Usui there had been some possibility of running the railway on the level for 10 miles west of Yokogawa, and then "springing the whole height" to the summit. But as this was but 4½ miles west of Yokogawa, as the crow flew, such a question could never have arisen. The issue had lain between increasing that distance by development for an adhesion line, or accepting it nearly as found by starting a 1 in 15 incline a short distance from Yokogawa, as shown in the section (*Fig. 1*, p. 45) of the line as made. The Government returns showed that in Japan the cost of maintenance was £150 per annum per mile of railway; for 10 miles therefore it would be £1,500, or ½ per cent. on the capital expended at the Usui.[1] Weighed against the possibility of more than doubling both the present loads and speeds over the line by the addition of those 10 miles, the reduction of ½ per cent. from interest for their maintenance would have been quite immaterial. The essential difference between the broken gradients over undulating ground at the Hartz and the long continuous incline at the Usui had been at once grasped by Mr. Holtham, whose opinion as to a Japanese problem rested on a thorough knowledge of the country. He suggested that for the latter line a pure rack engine, instead of one with rack and adhesion, might have been preferable. This point had been considered in 1890, when the 1 in 15 incline had been proposed; but the rack-and-adhesion system had been adopted because on such a gradient the engine could draw a weight equal to itself by adhesion, leaving only the tractive-effort for the difference between train- and engine-weights to come on the teeth of the rack. In this plan, under present conditions, the strain and the wear and tear on that vital part had been reduced fully one-half. Of course that might be met, as on the Delagoa Bay Railway, so appositely cited by Mr. Sawyer, by helping the train up with a rack locomotive as auxiliary to the adhesion engine; but then on the return trip the latter was a superfluity in the descent, while on the ascent the weight of the two together must exceed that of one combination engine. The diminution of work thrown on the rack-bars by the use of the combination instead of the pure-rack engine had been referred to by Mr. Worthington, who, having visited the Usui

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[1] On the St. Gothard Railway the cost of maintenance was less than 1 per cent. of capital.—*Engineering*, January 11, 1895, p. 42.

Mr. Pownall.

line, had also been able to testify to the difficulty there experienced with the ventilation.

For the performance of the original engines, 294 HP. had been stated by Mr. Fairholme, instead of the 200 HP. given in the Paper. The former figure would have been in accordance with the power that had been expected to be developed, but the usual formula applied to the loads and speeds as given would show that the latter represented the work available. Indeed, the inventor of this system laid it down as a rule[1] that a well-designed combination engine would develop 3 HP. per square metre of heating-surface at a speed of 8 kilometres per hour, and as these engines had 75 square metres of heating-surface, their ideal performance would be $75 \times 3 = 225$ HP.; so that the 200 HP. which was being obtained by the Japanese drivers was not much below the maximum, although stress had been laid on want of skill and experience on the part of these men. In the new engines to be shortly supplied by Messrs. Beyer, Peacock & Co., there was to be a total heating-surface of 118 square metres. The statement in the Paper that 1 in 15 was regarded as too steep for the rack, should have been qualified by its limitation to heavy lines, but it was only with such lines that the Paper dealt, and no allusion was intended in it to light-tourist traffic. The keynote to this discussion had been struck nearly fifteen years ago by Dr. Pole, who had said[2] of the Rigi line that "the rack principle there used ought to be considered as an exceptional thing, only to be applied in extreme cases where no other system was possible." Such extreme cases occurred more and more frequently, and when they arose he believed that the Abt rack, properly applied, would be found a valuable auxiliary.

In reply to the correspondence, Mr. Pownall desired to add that the figure $2,000,000 (£300,000), for the alternative proposal of a development line at the Usui, was, as he had expressed it, only an approximate estimate, and that it might have been exceeded in the execution of the works by that method if it had been adopted. There would, however, have been no great margin for such excess, for the cost of the tunnels, which formed the heaviest item, had been stated in the estimate of 1889 at $150 a yard, and so amounted to nearly $1,200,000, while the cost of tunnelling for the rack line in an adjoining valley was $155 a yard, or only $5 more. A

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[1] Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, Vienna, 1888, p. 108.

[2] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 92.

Mr. Pownall. further confirmation of the estimate of $2,000,000 was that it amounted to $145,666 per mile of railway, while $148,146 per mile was the figure separately and previously arrived at by a Japanese engineer, Mr. Minami, for a railway over the same valleys. Special features in each case being allowed for, the two estimates were practically identical.

15 January, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President,
in the Chair.

The discussion on the Papers on "Mountain Railways" occupied the evening.

22 January, 1895.

JOHN WOLFE BARRY, C.B., Vice-President,
in the Chair.

The discussion on the Papers on "Mountain Railways" was continued and concluded.

APPENDIX TO CORRESPONDENCE.

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List of Documents referring to Mountain Railways presented to the Institution by various Correspondents.

[*The name of the donor is given in brackets in each case.*]

"Chemin de fer funiculaire Territet-Glion," by A. Vautier, 1885.

"Die Drahtseilbahn Territet-Glion," by Emil Strub, Aarau, 1888. Two plans entitled "Disposition des freins" and "Modification du profil en long" respectively. [Chemin de fer de Territet-Montreux-Glion.]

"Locomotives operating by Total Adhesion on Curves of Small Radius," by A. Mallet, Paris. Reprinted from Transactions of American Society of Mechanical Engineers, vol. xiv. (Chicago Meeting, July, 1893). [A. Mallet.]

"Chemins de fer à fortes pentes," by N. Riggenbach, 4th edition, 1883.

"Chemins de fer à fortes pentes et à crémaillère," by N. Riggenbach; 5th edition, 1889.

Nine longitudinal sections of rack railways, four drawings of permanent way (Riggenbach system), nine photographs, and eleven blue prints of rack-driving locomotives made at the Esslingen Works. [Maschinenfabrik Esslingen, Würtemberg.]

"Die Vitznau-Rigibahn Locomotiven" and "Oberbau der Vitznau-Rigibahn," by E. Strub. Reprinted from the "Schweizerische Bauzeitung," Bd. XVI. Nos. 21 and 22, and Bd. XVII. No. 12. [— Fellmann.]

"Schweizerische Bauzeitung," Bd. XVI. Nos. 9, 10 and 11 (with description and drawings of Landquart-Davos Railway by — Johner, Zurich).

General plan of defences against stones and snow in the Klus Valley.

Report and accounts of the Landquart-Davos Railway for the year 1893.

Regulations of the Landquart-Davos Railway (containing, on pp. 15 and 16, particulars of the locomotives, wagons and carriages). [Landquart-Davos Railway Company.]

Sheet of diagrams entitled "The Abt System at Oertelsbruch." [Roman Abt.]

"The Incline Plane Railroad at Madison, Ind.: its History and Operation," By M. J. Becker, M. Am. Soc. C.E. Extracted from the Transactions of the American Society of Civil Engineers, vol. vii., March, 1878.

Three photographs of locomotives used on the Incline Plane Railroad at Madison, Ind. [M. J. Becker.]

"Mountain Railroad Construction," by William Barclay Parsons, M. Am. Soc. C.E. Extracted from the Transactions of the American Society of Civil Engineers, vol. xxv., July, 1891, p. 119. [W. B. Parsons.]

Photograph and blue print of Shay geared locomotive.

Plan and diagram of gradients of the Tiadaghton and Fahnastalk Railroad, Pennsylvania, U.S.A. [Foster Crowell.]

Drawing of rack-and-adhesion engine used on Brünig Railway.

Sheet of particulars with regard to the Brünig Railway. [Jura-Simplon Railway.]

"Eine Strassenbahn mit Zahnstrecken (St. Gallen-Gais)," by Professor A. Goering, Berlin. [Appenzell Street Railway.]