Dr. POLE said, he felt something like an apology was due for having presumed to bring before the Institution such a trifling matter as an account of a railway of only 3 miles or 4 miles in length. It, however, possessed some features of novelty. Railways were usually constructed either for dragging heavy loads at moderate speeds, or for conveying lighter loads at higher speeds. In the case of the Rigi railway the loads were light, and the speed was unusually slow, but there was a new feature in the extremely steep gradient of certain portions of the line, namely, 1 in 4. It was singular how little had been known in respect to that railway. Prior to his visit he had heard persons speak of it as a remarkable mechanical achievement, on account of its ascending by locomotive power the very steep side of a mountain; but the notions he had been able to obtain were so confused that he could not form any idea of its details. Under those circumstances he determined to examine it for himself, and was amply repaid for his trouble. He had been under the impression that in the descriptions he had previously received the steepness of the gradients had been exaggerated; but, on taking measurements for himself, he found that in several places the gradient was actually 1 in 4. He afterwards obtained some authentic particulars and some drawings, from which, aided by his own notes, the information now laid before the Institution had been compiled. Considering the extreme steepness, and the ingenuity of many of the arrangements, and, more than all, the financial success of the line, he trusted the description would prove interesting and useful.

With the aid of the diagrams, Dr. Pole gave further verbal illustrations of the arrangements described in the Paper, particularly of the various and multiplied precautions to insure safety, without confidence in which, as he explained, passengers would hesitate to trust themselves on the line. The sensation of running on such a steep gradient was peculiar, and, indeed, in descending, it was almost alarming, as in many places the train appeared to be going headlong into the lake, thousands of feet below; but the slowness and steadiness of the motion gave confidence in the security of the arrangements.

Mr. J. HAWKSHAW, Past-President, said, he considered many of the details were ingenious; but the peculiar kind of rack used was a very old arrangement. It was one of the earliest things he recollected. When he was a boy he used to go and see Brandling's Colliery railway near Leeds, which was worked by a wheel with cogs, like that of the Rigi railway. The rack was fixed to the side of cast-

iron rails. In railways over mountainous districts, where great speed was not required, such an arrangement was a good mode of ascending steep gradients. The method adopted was evidently an adaptation of the system patented by Mr. Blenkinsop. The arrangements for the safety of the train were ingenious. The peculiar apparatus for checking the speed of the engine going down the incline was novel to him. To attain the same end, it was sometimes customary to reverse the engine, and that in great emergencies would be preferable, because the steam was then immediately thrown to the opposite side of the piston, and the speed in consequence immediately reduced. He understood that the object of having the carriage always pushed up before the engine was to give an additional feeling of security to the passengers. He did not, however, think it would make much difference, as regarded their actual safety, whether they were pushed up or pulled up. The Rigi railway seemed, on the whole, to display much constructive cleverness, and it did great credit to its Engineer.

Mr. BRAMWELL said, that both the Author and Mr. Hawkshaw seemed to consider the mode of regulating the descent of an incline by pressure on the engine pistons as new. Mr. Bramwell would call attention to a Paper read by Mr. C. W. Siemens, M. Inst. C.E., before the Institution of Mechanical Engineers on the 4th November, 1869, "On Le Chatelier's plan of using counter-pressure steam as a break in locomotive engines,"[1] in which a description was given of Le Chatelier's steam brake, called in France the 'contre-vapeur' system. Mr. Bramwell believed every engine on the Lyons railway was fitted with it. Le Chatelier's arrangement was to leave the steam regulator open, to reverse the engine, and to introduce a small injection of water into the cylinder to prevent the rise of temperature which would otherwise take place owing to the conversion of the power stored in the train into heat. The water thus injected was turned into steam, and was by the pistons pumped back into the boiler. This system had been tried on several railways in England with success, but it had not been generally used. At Mr. Bramwell's instance, Mr. Beattie allowed it to be tried on the London and South Western railway, and the result was very satisfactory. A train consisting of 16 carriages was employed, the weight of it was carefully ascertained, and a speed of 40 miles per hour was attained on a piece of perfectly

[1] *Vide* "Institution of Mechanical Engineers. Proceedings. 1870. Birmingham," p. 21.

level line. The steam was then shut off, and the train was allowed to come to rest without the use of the 'contre vapeur' or of any brakes. The distance required for the stoppage of the train was noted. The experiment was repeated by getting up the train to the same speed as before, but on that occasion the 'contre vapeur' system was applied to stop it. In a succeeding experiment the ordinary brakes were used, and in the final experiment those and the 'contre vapeur' were applied conjointly. It was found the train could be pulled up by the use of the 'contre vapeur' within the ordinary distance without the application of the brakes to the wheels. The use of the 'contre vapeur' was attended by the following advantages:—1, the momentum of the train was utilized in generating steam; 2, and what was of greater importance, the wheels could never 'skid' and wear flat places on the tires.

Indicator diagrams were taken during the trials, and a curious fact was observed, namely, that there was, whilst the 'contre vapeur' was at work, a great deal higher pressure of steam in the cylinders than there was in the boiler. The notion at first was, that either the indicator was out of order, or that there was some mistake in the experiment. An examination of the indicator and a repetition of the experiment showed that the explanation of the phenomenon was to be sought for elsewhere, and it then occurred to Mr. Bramwell that the rise of steam in the cylinder to a pressure above that in the boiler was due to the fact that the steam was acting as a steam ram in the same way that water is made to act in a water ram. In the particular engine with which the trial was being made there was a long steam pipe from the firebox to the slide jackets; the engine being in reverse gear, the steam, on the port opening, had about one-half the capacity of the cylinder to fill at once. In that way an extremely rapid motion was set up in the long steam pipe, and then when the cylinder was filled, as it was in a small fraction of a second, with steam up to the boiler pressure, that motion could not be suddenly stopped, but was brought to rest gradually, but in coming to rest, it heaped into the cylinder a further quantity of steam, and thus raised the pressure in it above the pressure in the boiler. By that means the 140 lbs. pressure in the boiler became 150 lbs. pressure and upwards in the cylinder, as shown by the indicator. The 'contre vapeur' system was, in his judgment, most successful, and he did not know why it was not in use, inasmuch as he believed it would effect a large saving in the wear and tear, both of the rails and of the wheels of the carriages. It was desirable that the Author

should state why the power was applied to the hind wheels, so as to push the engine, rather than to the fore wheels, so as to pull it. Mr. Bramwell presumed there was some sound reason for the arrangement adopted.

Mr. G. BERKLEY said, the position of the driving wheels between the boiler and the tank for water and fuel was that which would naturally suggest itself. He should feel obliged if the Author would state how the cogs were riveted into the cheeks, and whether the full section of the cog passed through them. It would also be desirable the Meeting should be informed whether the action in ascending and descending had occasioned much wear upon the part of the cog which passed through the cheeks. Mr. Berkley would also ask whether the sleepers were laid on the rock, or were packed in the ordinary manner? The whole structure must evidently work as a machine, and consequently its parts must be built and maintained accurately in position one with the other, otherwise the railway would not have been worked with the safety which appeared to have been attained.

Mr. J. I. THORNYCROFT considered the Rigi railway to be a bold scheme well carried out. There were one or two points, however, on which he thought it desirable the meeting should have further information. He would inquire whether there was any difficulty experienced in keeping the carriage to the centre of the track? Owing to the wheels being loose on the axle, they would not have the same tendency as other conical wheels had of effecting that purpose. It would appear therefore that the rack must act as a guide to keep the train in position. He considered that pushing the carriage from behind—especially with the hinder wheels of the locomotive in going round curves—would cause the two carriages to assume a greater angle than that due to the curve on which they were moving, and thus produce a grinding action on the flanges of the wheels or on the rack.

Mr. J. T. HARRISON said, it would appear that great attention had been paid to the efficiency of the engine; but, judging from the drawing (Plate 18, Fig. 10) the passengers' seats did not appear comfortable or well adapted for a line with gradients varying from 1 in 4 to 1 in 1,000. In order to make the seats at all comfortable, it seemed to him, some arrangement was required similar to that proposed in Mr. Fowler's steam vessel, namely, that the seats should be suspended so that the passengers might always maintain a perpendicular position.

Mr. JAMES BRUNLEES said, the statement that out of the earnings, amounting to £15,105 per annum, the working expenses were only

£3,420 per annum,[1] appeared to him to be, at first sight, a most extraordinary result, and might lead people to infer that the steeper the gradients of a railway the better it would pay. But, he supposed, the explanation would be found in the slow speed at which the line was worked, and the high fares charged.

With regard to the mechanical appliances available for ascending very steep gradients of, say, from 1 in 4 to 1 in 12, he considered that, with a tolerably straight line, fixed engines and a rope would be the most effective for the conveyance of the greatest amount of traffic at the least cost. The rack, as worked on the Rigi, was, however, well suited for a tortuous line on similar gradients, and from it a greater effective result could be obtained than from any other application of locomotive power. For gradients ranging from 1 in 12 to 1 in 25 he believed the centre rail system would be found to give the best results. The trials of a centre-rail engine at Whitby last autumn proved that the adhesion gained from the horizontal wheels fully equalled that obtained from the ordinary vertical wheels, thus making the engine equal in effect to one of twice the weight.

The use of back pressure on the pistons for providing the brake power necessary for holding the trains whilst going downhill was not novel, inasmuch as it was adopted some years since on the Mont Cenis Summit railway on the descent from Grande Croix to Susa, a distance of 12 miles, on an average gradient of 1 in 14. In that case both cylinder cocks were opened, and the reversing lever put into back gear, in the first or second notch from the centre. To prevent the cylinders from heating, a small jet of water from the boiler was introduced through a $\frac{1}{4}$-in. pipe, regulated by a cock worked from the foot plate. About one-third of the brake power required was obtained by the use of the back pressure, and the proportion could be increased to one-half or more by putting the reversing lever farther into back gear.

Dr. POLE, in reply, said that, with regard to the 'air brake' in use on the Rigi railway, he thought the chief novelty was in the use of atmospheric air, and in the mode of regulating it with a cock, by which the velocity of exit of the compressed air could be regulated to a great nicety, thus insuring perfect control over the engine. The speed with which the air escaped from the cylinder effected the control of the train. He saw the driver when the engine was going a little too fast touch the cock handle a little, and instantly the speed was checked.

[1] *Vide* ante, p. 116.

The teeth of the rack were cut from a rolled bar, and the ends, having had the corners rounded off to make a shoulder, had been riveted firmly in the cheek plates—so firmly that he did not think that any yielding would take place. He believed the principal fear of the designers was that of the tooth tearing itself out of the cheek plate, and that had been provided against, as described in the Paper.[1] The sleepers did not rest entirely on ballast, for it would not do for the permanent way to be subject to those slight variations, which comparatively were of no practical effect on an ordinary line. The designers went back to the system, now abolished on ordinary railways, of rigidity. The sleepers were supported at intervals upon masonry foundations carried up from the rock. The intervals were then filled in with ballast; but the sleepers really rested upon a rigid foundation.

There was no difficulty that he was aware of in keeping the carriages in the centre of the track; and he believed that at the slow speed adopted no inconvenience arose from any difference of angle between the carriages and the curve round which they were running. The form of the seats best adapted to the comfort of the passengers—like every other point which had a practical bearing—had been studied by the Swiss, and their reasons for adopting the form selected would be obvious to any one who considered the statical arrangements involved.

With regard to the disproportion of expenditure to receipts, it might be accounted for by the very high fare charged—about 1*s.* per mile. The persons who used the railway willingly paid it, inasmuch as it was not half the expense of going up on horseback; and they would rather pay that high fare than ascend on foot. Since the expenditure was only of the ordinary kind, that would account for the great disparity between receipt and expenditure. The figures given in the Paper were taken from the returns made to the shareholders, which he supposed might be depended on.

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[1] *Vide* ante, p. 108.