

Captain TYLER thanked the Meeting, in the first place, for the way in which his Paper had been received; and Mr. Fell, in the next, for a great deal of the information contained in it. Since it was written, Mr. Fell had made some improvements in the engine, which he would be able to explain in person. He had also to thank Mr. Brunlees, the Engineer of the Mont Cenis Railway, for having prepared the large plan and section of that railway, with the section showing the central rail, and its attachment between the bearing rails.

There was one interesting question to which he had only briefly alluded, and that was with regard to the engines for working both severe gradients and sharp curves, which were advocated by M. Thouvenot, in France, and Mr. Fairlie, in this country. The latter adopted the principle of attaching the boilers of two engines together, firebox to firebox, and carrying them upon two bogie frames, the wheels under these frames being respectively coupled together and worked by separate cylinders. The former, by using peculiar cranks and coupling chains, proposed to transmit the power obtained by his double engines to the wheels of the carriages. There was no doubt much in favour of Mr. Fairlie's form of locomotive for certain purposes. Captain Tyler considered there was frequently a certain amount of extra risk in the employment of tank engines. He had always been of opinion that they were not calculated to run safely at high speeds, especially with passenger trains, and he thought such engines might properly be superseded, at all events for passenger traffic, by engines of a construction somewhat similar to that advocated by Mr. Fairlie. At the same time, tank engines were found to be convenient for the mineral traffic of short lines, for heavy gradients, and for frequent stoppages. In working steep inclines, one tank engine was often placed in front, and another at the tail of the train; and this was in one respect a safe mode of working, inasmuch as if a coupling gave way there was an engine as well as a break-van behind to prevent any of the wagons from running back.

He had omitted all notice of the Pneumatic system, because he did not think it applicable to the working of very steep gradients. It might perhaps be usefully employed in tunnel lines for metropolitan passenger traffic, on account of the absence of steam and smoke; and he thought it was a pity it had not been tried in practice for that purpose.

In contrast to the working by the central rail system on the Mont Cenis, he would refer to some practical results of the working of a steep gradient on a railway which he had recently visited, viz., the Navigation incline of the Taff Vale Railway, near the Aberdare Junction, 16 miles from Cardiff. He was accompanied

by the Engineer of the line, Mr. George Fisher, who had furnished him with the following particulars of the incline, and of the engines with which it was worked. The gradients were, in ascending, successively, 1 in 28, 1 in 21·80, 1 in 20·74, for shorter distances, and then 1 in 17·80 for 420 yards. The average of the whole was about 1 in 20 for half a mile. The system of traction by rope, on which this portion of line was formerly worked, was abandoned two years ago, and since that time locomotives had been employed. The expense for six months was £900 with the locomotives against £700 with the rope and stationary engine. The tank engines, specially employed for working the traffic up this incline, weighed in working order 36 tons. They had six wheels, all coupled, 4 feet in diameter. The diameter of the cylinder was 16 inches, with a stroke of 24 inches. The pressure of steam in the boiler was 130 lbs. The maximum load was 45 tons, and the regulated load 25 tons: the former giving $\frac{1}{8}$ th and the latter $\frac{1}{10}$ th as the coefficient of adhesion. It was interesting to compare these results with the working of the engines on the central rail system. On the Navigation incline, the engine weighed 36 tons, taking a regulated load of 25 tons up an incline of 1 in 20; whereas, on the central rail system, an engine weighing only 20 tons could take a load of 40 tons up an incline of 1 in 12. In fact, the programme of working the Mont Cenis Railway provided for an average gross load, exclusive of the engines, of 40 tons for goods trains, and 25 tons for passenger trains; and the cost of locomotive power was found to be nearly a penny per ton per mile for goods, including fuel, grease, wages and maintenance. Similarly, for passenger traffic, the cost for locomotive power for one journey from St. Michel to Susa was estimated at 96 francs, which gave a little more than a farthing (1·2 farthing) per mile for each passenger.

Mr. FELL said he was glad to have the opportunity of describing some details of the engine, and the improvements to which Captain Tyler had referred. When this project of crossing Mont Cenis by a railway was first laid before the Italian Government, it was proposed to divide the line into two distinct sections, one section being from St. Michel to Lanslebourg, and the other from Lanslebourg to Susa. It was proposed to work the first portion of the line by an engine with three or four cylinders, one pair driving the four outside wheels, and the other pair, or one cylinder, driving the four horizontal wheels, so that the relations of the interior and exterior wheels might be distinct. By that means wheels of comparatively large diameter could be used for the ordinary driving wheels, and small and more powerful ones for the climbing wheels. With the same speed of piston a higher velocity could then be obtained, and time saved in the journey, or more time could be allowed for ascending

the heavier gradients. It would be seen that, with an engine of so novel a kind, the form best adapted for such a line as this could only be determined after a long series of experiments. There were many requirements which could only be ascertained by actual trial. The Directors of the railway had determined to adopt one type of engine only for working both sections of the line, and the second engine having only one pair of cylinders, had consequently been modified with that view. Originally there was no connection between the two pairs of wheels working on opposite sides of the centre rail. Some method of connecting the two was, however, found to be necessary; and on the experimental engine this was produced by the introduction of a series of toothed wheels. The adhesion on the centre rail gave continuity of movement, and when one crank was at mid-stroke it helped the other over the dead point. When running off the centre rail this was not the case, on account of the play between the toothed wheels; consequently the crank on the midstroke passed that point more rapidly than the one on the dead point, thereby producing a shock upon the engine. This shock would not take place if the inside wheels were driven by an independent pair of cylinders; but the pistons, being tied together where only one pair of cylinders was used by the outside gearing, moved in a way which produced that injurious effect. It thus became necessary to substitute some other system in place of the toothed wheels, which were weak and liable to rupture. Various plans had been proposed, out of which two were selected by Mr. Brunlees for experiment. One was the system of levers, jointed to the outside frames of the engine, connected in the centre by a slide block and with two offset cranks by connecting rods. The offset cranks were respectively placed at an angle of 45° with the driving cranks, which gave a leverage of $6\frac{1}{2}$ inches, as compared with 8 inches the leverage at midstroke or 90° , which was enough to carry the cranks over the dead points. The relative position of the four cranks being such, that when one driving crank was at midstroke, and the other on the dead point, the offset cranks were each at an angle of 45° with the driving cranks, and acting with the above-named leverage of $6\frac{1}{2}$ inches. This arrangement had been tried on the Mont Cenis, and had proved successful in carrying the cranks over the dead points without the shock, and without the danger of fracture, which was unavoidable in the case of the toothed wheels; and it was therefore the plan of engine now adopted for the Mont Cenis Railway. Trials had been made of another plan, which had been devised for the same object, but which had the disadvantage of increased weight. The adaptation of the levers added only about 6 cwt. to the weight of the engine, while the other plan, which consisted of a combination of toothed wheels, combined with frictional gearing,

added 9 cwt. to its weight, having besides the disadvantage of greater risk of fracture.

Some other alterations had also been made. The rocking shafts were originally placed in front of the cylinders, in which position they worked very well, but to examine the cylinders and take off the covers, it was necessary to take down the slide bars; it had therefore been decided to move the rocking shafts to a position behind the cylinders. At present they were hung immediately under the boiler.

There was another point of importance, viz., the general insecurity and instability of tank engines at high speed, which had been alluded to by Captain Tyler. It was necessary to consider this point, particularly in an engine with an overhang which exceeded the length of the wheel base. There appeared to be a risk attending such an arrangement, and the question having been considered, it had been decided to adopt a third pair of wheels with a lateral movement, by which it was believed sufficient stability would be obtained to make the engine perfectly safe, but with the disadvantage that 12 cwt. would be added to the weight of the engine, and 2 tons of the adhesion obtained from its weight would be sacrificed.

Another point of great importance was the action of the breaks in descending the inclines. As had been stated, a great amount of break power was necessary for these trains, and this could be obtained by the centre rail system, which might in fact be considered almost unlimited. It had been decided to have centre rail breaks as well as the ordinary breaks, attached not only to the engine, but to each carriage and each wagon of the train; and probably the action of the combined breaks on a single carriage would be sufficient, or could be made so, to stop the whole train on any incline on the line. Then came the question of wear and tear upon the rails. The breaks now proposed were sledge breaks, forced on to the rails by a transverse screw or lever, which would produce a certain amount of wear. Another plan was under consideration for applying the breaks to the horizontal wheels, by which method it was believed the wear upon the centre rail would not be greater than upon the bearing rails. With regard to the comparative economy of the two systems of working inclines, some persons were under the impression that the cost of traction by the centre rail system, when a given summit had to be attained, was greater than under the ordinary system, but it was not so. Supposing an elevation of 2,000 feet had to be attained, it could be shown that in the case of a gradient of 1 in 30, without the centre rail, and in another case, with a gradient of 1 in 12 with the centre rail, the locomotive power, though considerably greater in the latter, being required for a proportionally diminished distance, the expense

of working would not be increased, and time would be saved in the journey.

There were two modes of dispensing with the centre rail at level crossings: one in which it disappeared altogether; the other a simple arrangement by which it took the position of the ordinary rails, and laid flat.

Mr. ALEXANDER remarked that the expedients resorted to in the construction of the engines had already been fully explained. In the plan of toothed gearing, first proposed by him for connecting the inner axles together, he found, as might be expected, a difficulty in getting the inner system to revolve. No apparatus was applied without first giving the opportunity to revolve. The engine was, in fact, tried without spur-wheels in the first instance; but the axles refused to go round, and always came back again. He then anticipated it would be a more simple affair to connect the wheels than it proved to be. With respect to the introduction of the toothed gearing, it was open to the objection that it made a great clatter when the engine worked off the mid-rail. He did not know that that was a fatal objection; but it was at best a rough contrivance, which could hardly be tolerated in these days of mechanical perfection; and there was an objection to the clattering noise, because if the driver were accustomed to so much noise, he would be apt to disregard the noise occasioned by anything going wrong with the machinery.

Many appliances had been suggested to connect these wheels, but serious difficulties arose from the fact that it was necessary to have variable distances between the axles. There was a continual and progressive wear going on at the tires. Also in running upon the mid-rail, which was tapered off to a fine point, the wheels receded from each other, and there was an immediate change of an inch or so in the distance of the centres. It was not like the ordinary coupling-rod system, in which the wheels revolved at the same distances and in the same direction. The system shown in the model explained by Mr. Fell seemed to answer well, and on being tested proved efficient; but Mr. Alexander believed it could be simplified, the same principle being retained. As this, however, had been so far actually tested, and its capabilities were known, and as it was difficult to predict what would be the results with an untried arrangement, it was proposed, in the engines now building, to use the method without alteration.

With reference to the amount of power developed by these engines in proportion to their weight, he, having designed them, was sorry to say he could not agree with Captain Tyler as to the advantage to be derived from the use of steel. He was anxious to use steel, as it was important that these engines

should be as light as was consistent with safety. He had communicated with many Engineers in order to ascertain what had been done in this direction ; but he did not find that in any articles subject to transverse torsional strain, with sudden shocks, like that upon axles, there had been any reduction of weight in consequence of the use of steel ; in fact there was sometimes an excess of weight, and he had been reluctantly compelled to abandon the use of steel under such circumstances. His reason for that was that its extensibility was less than that of iron, its life was sooner exhausted, and it was more liable to give way under shocks. These engines were being made in France, where the use of steel was not carried so far as in this country, as there was not the same confidence in it ; and there were many cases in which iron was used where, in this country, steel would have been employed.

Mr. MENDES COHEN, of New York, would give the results of his experience in working the Baltimore and Ohio Railway, through Virginia. The gradients on that line were generally heavy. On the mountain division, 60 miles in length, there were 37 miles varying but slightly from 1 in 45, at which maximum there were 17 miles in one continuous gradient. The goods traffic was worked by engines weighing, exclusive of tender, about 27 tons, on eight connected chilled wheels 43 inches in diameter, with cylinders of 19 inches diameter and 22 inches stroke, hauling nine cars weighing about 135 tons. In addition to these there were other and much heavier gradients of a temporary character, adapted for the purpose of working over the tunnel ridges during the progress of the construction of the tunnels, to continue the line without waiting for the completion of the tunnel-work. In the first instance the gradient adopted was 1 in 10 as a maximum, and it was not intended to work this temporary line with locomotives. The line was built with a view of hauling car-loads of iron across the mountain by horse-power, and continuing the construction of the works on the other side. However, when the line was laid, it was determined to try the working with locomotives. The engines just described were tried on this gradient and readily took up a load of one car weighing about 14 tons. Under favourable circumstances they could take up two, but one was the usual load. He had ridden over that line on the engines but otherwise had not much experience in the working. As the construction of the line progressed westward, there was another tunnel on which he had been engaged as an assistant in the engineering department in the year 1852. Owing to delay in the tunnel, the Chief Engineer, Mr. Benjamin H. Latrobe, directed the construction of a temporary road across the hill. It was a work of some difficulty, as the slopes of the hill were very abrupt, and he was instructed by his chief to see what he could do in the way of bringing the line

down from the summit to the foot of the hill, with a limit of gradient of 1 in 16, and reversing the direction as often as was necessary. The descent of the summit on the western side was made with five reversals, the narrowness of the ravines and the general shape of the ground not always affording room for curves of even the minimum radius of 300 feet. The reversal was effected by what was termed a Y, from its resemblance in plan to that letter. With this arrangement the slope of the hill was descended on a gradient of 1 in 16 between one pair of Y's, and 1 in 20 between the next pair, and so on alternately, the object of this being to secure the proper protection of the fire-box sheets, which might have been exposed had the rear of the engine been uppermost on the heavier gradient. The line was worked with five reversals on one side and two on the other for a distance of $2\frac{1}{2}$ miles on both sides of the hill, over which the engines carried three cars of 15 tons each. The load was never increased beyond that, because the shape of the ground did not admit of getting longer trains upon any of the Y's. The traffic was carried on for five or six months, till the tunnel was completed. At a later period it was necessary, for a second time, to use the temporary track over the tunnel where the gradient of 1 in 10 had first been tried. On this occasion the gradient was reduced to 1 in 20, or equal to 260 feet per mile, and this Mr. Cohen himself worked with the same engines, which carried up from 65 to 70 tons load. In fact the whole traffic—mails, passengers, and goods—of one of the great American through lines was carried on by this way for many months during the arching of the tunnel. There was no difficulty in ascending the hill; the only difficulty lay in the descent. In effecting this, besides the application of breaks to all the wheels of the train, the engine was reversed and allowed to descend without using steam, thus pumping air through the cylinders. The accumulating pressure against the pistons was relieved by valves placed on the steam-chests, and regulated from the foot-board. The engines were kept, on the heaviest portion of the gradient, on the lower side of the train, to guard against the breaking of the couplings, as well as with reference to the fire-boxes. There were some instances of the trains breaking away, from the failure of the breaks, and some little damage had been done; but no case of serious accident occurred during the whole time.

Sir CUSACK RONEY said he could throw no light on the subject with respect to the engineering details connected with the crossing of mountain passes by railways; but as the nature of his engagements for the last two or three years had taken him a great deal to Switzerland, and as he had been in constant communication with persons who took an interest in these matters, especially with reference to the passage of the Alps, he might be able to adduce a few facts of interest.

The trade between Great Britain and the East was enormous; and it would be seen, by the table of exports and imports, that both the exports to the Eastern seas, and the imports from them, amounted to about one-fourth of the gross trade of the United Kingdom. The

FOREIGN TRADE OF GREAT BRITAIN in 1865, Exclusive of SPECIE.

	Imports.	Exports.	Tonnage of Ships.	
			Inwards.	Outwards.
Total	£. 271,131,967	£. 165,862,402	14,317,866	14,576,206
To and from Eastern Seas	68,117,356	42,897,846	1,492,102	1,869,090

Board of Trade returns showed that the value of the export trade for the year 1866, was 188,000,000*l.*, or an increase of about 23,000,000*l.* compared with 1865. No doubt the same proportion of increase existed with reference to the trade from the Eastern seas to Great Britain. It was, therefore, of the highest importance to this country to have the most rapid modes of conveyance for postal communication with those seas; and no doubt the passage of the Alps by a railway would effect a complete revolution in the communication between Great Britain and the East. It would be seen by the table showing the distances in English miles between London and Alexandria, that a very small proportion of the total distance *viâ* Southampton was by land; while

LONDON TO ALEXANDRIA.—Distances in English Miles.

Viâ.	Land.	Water.	Total.	Time.
				Days. Hours.
Southampton	75	3,353	3,428	15 0
Marseilles	831	1,701	2,532	8 1
Brindisi	1,482	977	2,459	6 7
Ditto				

the total distance was 3,428 miles, as against 2,429 miles by the shortest possible route across the Alps by the Mont Cenis Railway. What Captain Tyler stated, in the interesting Report which was published last year as a parliamentary paper, with refer-

ence to the Brindisi route, was true, viz., that under ordinary circumstances, land conveyance by railway was at least twice as speedy as conveyance for the same distance by water; and on the completion of the Mont Cenis Railway, instead of there being as at present fifteen days between London and Alexandria *via* Southampton, or eight days one hour which was the contract time for the mails *via* Marseilles, the time of transit would only be six days seven hours, so that the journey would, under an arrangement with the Italian government, be shortened by forty-two hours. This was an important consideration with regard to the postal service. The weight of the outward Eastern mails *via* Southampton was in 1865 upwards of 700 tons, and by measurement 1,500 tons; and in 1866 they were still heavier. It was, therefore, of great importance, to England in particular, that a system of railway across the Alps which would give the utmost possible facilities should be carried out. He had no doubt in his own mind, speaking as a person connected with railways for many years, that in the course of the next few months the 1,504 miles, which constituted the distance between London and Brindisi by the Mont Cenis summit line, would be accomplished at an average rate of 20 miles an hour.

He had prepared the following table, giving the different carriage roadway passes which now existed across the Alps; and he had included one or two that were not actually carriage

ALPINE ROADWAY PASSES.

NAME.	Width.	Summit	Distance <i>via</i>	Break
		above Sea Level.	London to Brindisi.	in Railway.
	Feet.	Feet.	Miles.	Miles.
Semmering . . . . .	..	2,893	..	..
Brenner	25	4,650	1,769	73
Stelvio	16 to 18	9,272	..	..
Spugen	15 to 18	6,940	..	..
Bernadino	15	7,115	..	..
Lukmanier . . . . .	..	6,500	..	..
St. Gothard	18	6,808	1,483	146
Simplon	15 to 30	6,636	1,471	114
New Route . . . . .	..	..	1,435	114
Great St. Bernard . . . . .	..	8,200	..	..
Little St. Bernard . . . . .	..	6,780	..	..
Mont Cenis	18 to 30	6,658	1,504	48
Ditto, Tunnel . . . . .	..	4,118	1,498	42
Mont Genevre . . . . .	..	5,850	..	..
Col di Tenda . . . . .	..	5,890	1,833	118
Corniche Road	30	2,200	1,796	127

roadway passes—as, for instance, the Lukmanier Pass, as, although there was no actual roadway across the mountains by that pass, yet it possessed great facilities for the construction

of a railway; and no doubt a line on Mr. Fell's system could be made along that pass. England was more particularly interested in the passes on the western side of the Alps, because it was by means of one or more of them that the nearest communication by railway with Brindisi was to be obtained. It would be seen that, by the Mont Cenis summit line, Brindisi was 1,504 English miles from London, as calculated by Captain Tyler in his Report. When the tunnel, which although it had already been nine years in construction was, on the 15th October last, only half perforated, was completed, a saving of only 6 miles would be obtained at an enormous cost. There was no doubt the cost of the Mont Cenis tunnel would exceed the estimate of Captain Tyler. Sir Cusack Roney believed it would be two-thirds more, and all that cost would be incurred for a saving of 6 miles. In addition to that it would be seen that, though the summit line was at an elevation of 6,658 feet, there was a gain of only 2,500 feet by the tunnel line, in consequence of there being a continuous rising gradient in the tunnel from each entrance to exactly the centre. The nearest route between London and Brindisi would be by the Simplon line; the exact distance by that route being 1,471 miles. With a short line, which would cut off an angle in the railway communication between Paris and Lausanne, there would be a saving of 36 miles, thus eventually reducing the distance between London and Brindisi to 1,435 miles. The only railway now actually existing across the Alps was the Semmering. Its summit was at an elevation of 2,893 feet. An interesting Paper on that railway was presented to the Institution some years ago, and he need not refer to it further.¹ A line of railway through the Brenner pass was in course of construction, and would be opened about August next.

Mr. CONYBEARE said, as Engineer to several lines traversing the mountain districts of North and South Wales he had had a good deal to do, during the last ten years, with the laying out and working of lines of exceptionally steep gradients. On these railways, the longest continuous length of steep gradient occurred on the Brecon and Merthyr, in descending from its summit level (situated on the mountain range known as the Brecon Beacons) to the valley of the Usk. The descent was 900 feet in 6.62 miles, giving an average gradient of 1 in 38.8, and the curves varied from 25 to 40 chains radius. This portion of the line was laid out in 1856, the plans were deposited in 1858, and the line was opened for traffic on April 19, 1863, but it had been worked over with heavy engines for twelve months previously. The rails weighed 70 lbs. to the yard. The total length of the Brecon and Merthyr at present

¹ *Vide* Minutes of Proceedings Inst. C.E., Vol. xv., pp. 349, *et seq.*

completed was 89 miles, and a considerable portion of it was on these exceptionally steep gradients. The ascent from Merthyr to the level of Dowlais was $5\frac{1}{2}$ miles at 1 in 49, and in the 20 miles between Dowlais and Brecon there were $6\frac{5}{8}$ miles steeper than 1 in 39, and 1 mile 70 chains of 1 in 40, making $8\frac{1}{2}$ miles out of the 20 miles, of 1 in 40 or steeper.

As Captain Tyler had observed, the opinion of Engineers regarding the economical limit of steepness of gradients had undergone a great revolution of late years. In closing the last discussion that took place on this subject,¹ Mr. Bidder expressed the opinion that the working expenses alone of a gradient of 1 in 40 with an up-hill load would be from 3*d.* to 4*d.* per ton per mile, and even with a down-hill load, would absorb the whole receipts, leaving nothing whatever for interest on the cost of the rolling stock. This opinion was quoted at public meetings held in 1859, to prove that the Brecon and Merthyr, and the Merthyr and Abergavenny (another line in the district with similar gradients, to which he was the joint Engineer), could not be remuneratively worked. The portion of the line on which the steepest gradients were situated had been used for traffic since the spring of 1862. The particulars of the cost of working, furnished by Mr. Henshaw, the traffic-manager and locomotive superintendent, showed an unusually favourable result, both as regarded adhesion and economy of working. Tank engines were used, having six wheels coupled, of 4 feet 6 inches diameter, with a wheel base of 12 feet; the cylinders were 17 inches in diameter, with a length of stroke of 24 inches. The saddle tank contained 1,100 gallons of water. The weight of the engine in working order was 38 tons. The engines and break vans were furnished with large sand boxes, the supply of which was carefully attended to. The weight of the break van was 8 tons. All the passenger carriages were supplied with Fay's continuous break. The working pressure, 100 lbs. on the square inch, was maintained throughout the ascent. These engines took a regular load of ten loaded wagons and two break vans, weighing altogether 136 tons gross, at the regulated speed of 8 miles an hour, up this gradient of 6 miles 50 chains of 1 in 38.

The engine "Cymbeline" was built by Messrs. Sharp, Stewart, and Co. specially for this line, after a careful consideration of the facts of the case, and of the experience gained in previous working. During the month of December, 1866, this engine ran between Brecon and Dowlais, a distance of 20 miles, out of which there were more than $8\frac{1}{2}$ miles with gradients varying from 1 in 38 to 1 in 40, with the following results:—

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., pp. 69, 70.

Working of the Engine "Cymbeline," December, 1866.

Miles run . . .	1,897		
Coal	703 cwt.	41·5 lbs. per mile.	
Oil	45 pints	·023 pt.	„
Tallow	44 lbs.	·023 lb.	„

The cost per 100 miles, including wages, was 1*l.* 8*s.* 3½*d.*, or about 3¾*d.* per train mile, with a net load of 85 tons.

He attributed the high rate of effective adhesion of these engines, and their economy of working, to two causes—first, that they were specially and carefully designed for the particular work they had to do; and, secondly, that there was only one curve sharper than 25 chains radius on the ascent. According to his experience, Captain Tyler adopted too low a figure in taking the effective adhesion that might be relied on in ordinary working at only $\frac{1}{10}$ th of the insistent weight. On the other hand, he was altogether incredulous as regarded the alleged instances of a maximum of $\cdot177$, or a little over $\frac{1}{6}$ th being exceeded, even under the most favourable circumstances. It was well known from the experiments of Morin and Rennie, that the coefficient of friction of wrought iron on wrought iron, where no unguents were interposed, was $\cdot177$, or, in other words, that it would require a horizontal force of a little over $\frac{1}{6}$ th of the insistent weight to make a mass of wrought iron slide on a plane surface of the same material, and it appeared to be a necessary corollary that, when the resistance of the load exceeded $\cdot177$ of the weight on the driving wheels, the latter must slip on the rails. He was aware of the American instances adduced of the alleged utilisation in draught of as much as $\frac{1}{4}$ th and even $\frac{2}{5}$ ths of the insistent weight; but, on looking carefully into these instances, the data would not be found to warrant such a conclusion. It would be seen that in all the instances, (where really precise data had been given), in which so exceptional a result was claimed, the motor had been a bogie engine; and Mr. Zerah Colburn, in speaking of instances where the effective adhesion was stated to have been as high as $\frac{2}{5}$ ths, remarked that this was the nominal weight on the driving-wheel, and that it must be borne in mind "that when an engine was running, especially upon inclines, there were many circumstances to increase the weight on the driving-wheels. The draught through the draw-bar tended to lift the engine from the front wheels, and thus to increase the load on the driving-wheels. In going up an incline, the water rose at the back end of the boiler; the difference of level upon an incline of 1 in 10, being 19 inches in the ordinary length; and the base of the centre of gravity was thrown further back upon the driving-

wheels." And that "These circumstances materially affected the running condition of the engine."¹

The explanation suggested of the apparent paradox of an effective adhesion being obtained, exceeding that due to the coefficient of friction, appeared altogether insufficient. Mr. Colburn said that, "if the engine was making steam freely, and blowing off strongly, the reaction of the escaping steam against the air sensibly increased the weight of the engine." An engine would scarcely be blowing off steam while dragging a load up 1 in 10. The steam escaping from the blast-pipe might indeed have some effect in the direction indicated, but not a very material one. A more usual explanation of the anomaly alleged was, that by the partial sinking of the wheel into the rail (due to the concentrated pressure of the former) at its point of contact, and the elasticity of the material, the wheel obtained a greater grip on the rail than what would be due to friction alone. But this explanation cut both ways; for such partial yielding would necessarily augment the resistance in front, by raising a steeper gradient, so to speak, in front of the wheel. The interposition of sharp sand would, of course, increase the effective adhesion; but as such increment of adhesion could only be obtained at the expense of the structure of the rail, it would not be desirable to rely on the use of sand in ordinary working conditions. He believed that any engine, having all its wheels motors, might in dry weather exert a tractive force of $\frac{1}{6}$ th of its weight, and, by the use of sharp silicious sand, might do so in all weathers; but that to obtain a higher effective adhesion than that due to the coefficient of friction was as impossible, as to utilize more than 100 per cent. of the entire theoretic duty of a fall of water.

In laying out a mountain line, on which sharp curves were inevitable, it was always desirable to allow for the increased resistance on such curves, by flattening the gradient where they occurred, and thus to equalize the draught on all portions of the ascent. But unfortunately, in attempting this, Engineers had hitherto worked very much in the dark, owing to the want of authentic experiments on the increment of resistance, due to curves of different radii at varying speeds, with engines and carriages of a given wheel base. It was strange that a series of experiments, admitting of such easy execution as these do, should not yet have been instituted, to determine a matter so important in mountain railway making.

Mr. Latrobe, the Engineer of the Alleghany Mountain Lines described in Mr. Isaac's Paper, published in America many years

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xviii. p. 63.
1866-67. N.S.]

ago, the following Table of such resistances, stated to have been founded on experiments on a level :—

TABLE showing the RESISTANCE DUE TO CURVES. By Mr. LATROBE.

Radius in Chains.	Resistance is Equivalent to that of an Ascent of—
40	1 in 1,949
35	1 in 1,747
30	1 in 1,448
25	1 in 1,236
20	1 in 993
15	1 in 734
10	1 in 482
8	1 in 389
5	1 in 248
3	1 in 149

But Mr. Conybeare had found in practice, that the relaxation in gradient prescribed by this table was wholly insufficient to counteract the increase of resistance occasioned by curvature on steep gradients. It appeared, too, that in American practice this table had been found altogether insufficient. In Mr. Isaac's Paper, it was stated that, on the Mountain Top Incline, the gradient was reduced on curves of 300 feet radius, from 1 in 18·87 to 1 in 22·22; and that the relaxation of gradients on such curves (based on Mr. Latrobe's table) was, over the Board Tree Tunnel, 31 feet a mile. This being found insufficient, it was increased on one part of the Mountain Top Incline to 43 feet per mile, and on another portion to 58 feet per mile, and yet even then was found to be insufficient.

“The speed was always diminished on leaving a straight portion of the track, and on entering a curve of minimum radius, although the resistance of gravity, on the latter, was 25½ lbs. per ton less than on the former; a fact evidently proving, that the resistance of the curve must have exceeded 25½ lbs. per ton of engine and train. It is probable, that Mr. Latrobe's experiments give a sufficiently approximate measurement of the increase of friction of the curves, due to carriages of American construction. Assuming, therefore, his allowance of 13 lbs. per ton, as the additional friction of the train, on a curve of 300 feet radius, the additional friction of the engine, due to such a curve, must have exceeded 49 lbs. per ton of its own weight. This friction will of course vary in engines of different construction.”¹

On the American lines the amount of relief, required in the gradient in going round curves, thus appeared to be underrated; but on the Mont Cenis line it evidently had been overrated, as regarded the engine's gross speed on the curves. Perhaps Captain Tyler would state the amount of relief given? It was desirable that a question of such importance as this should be determined by a series of carefully-instituted experiments.

He considered the Cymbeline class as good a type of engine, for

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 59.

working steep gradients with economy, as any in England. It would be an improvement to adopt the American plan, of having four pairs of wheels coupled; and as such engines were used in the United States on curves of much sharper radius than those usual on English lines, there would appear to be no objection to the addition of a fourth pair of wheels on that head. If tank-engines were objected to, the wheels of the tender must be made driving-wheels, either by some system of coupling or by supplemental steam cylinders attached to the tender: the last plan involved a great loss of heat.

The sharpest curve he had ever met with was one close to the town of Rhymney, on a mineral line, called the Old Rhymney, which he had converted into a passenger line. This curve he had ascertained, by two measurements, to be $1\frac{3}{4}$ chain radius. The line was worked by tank-engines, having six wheels coupled, with a wheel base of 11 feet 6 inches, which ground round it at the rate of 3 miles or 4 miles an hour only. The curve by which the Great Northern joined the Metropolitan Railway was $7\frac{1}{2}$ chains radius, on a gradient of 1 in 46; and the North Western had this year deposited plans for an extension to Dowlais, which joined the Brecon and Merthyr at that place, with a curve of $7\frac{1}{2}$ chains on 1 in 40. He thought that at present there was a disposition to underrate the objection to such curves as these.

The results of experiments had proved, that the employment of a single engine, as on the Semmering, gave better results than were obtained by two engines coupled together, as on the Giovi. Mr. Fairlie's plan had all the disadvantages of the Giovi, with the addition of some grave disadvantages peculiar to itself. When tried on the Brecon and Neath line, it had turned out a complete failure, as any expert might have predicted. There was one fire-box to the two engines; thus the escaping products of combustion had two lines of exit to choose between; and it was a fact well known to all who had experience in boiler work, that the products of combustion, on leaving the furnace, took the shortest and hottest path open to them on their way to the chimney; bifurcated flues were, therefore, erroneous in principle. The steam-pipes were always breaking; the driver could not see the state of the fire; and both driver and stoker were without protection from the weather. The great length of the boiler was also objectionable on steep inclines, as it threw too much weight on the trailing-wheels.

In a pamphlet published in 1859, after describing the lines by which the Alleghany mountain had been traversed, he wrote—

“Why should not similar expedients be adopted at the passes of the Alps which still continue to occasion so inconvenient a break in the railway communications of Europe? It has often been proposed to traverse three of these passes by railways; one of which has actually been commenced (though grave

doubts are entertained of its being proceeded with), and a large engineering expenditure has been incurred on the plans and surveys of all three projects, each of which would involve at least one tunnel of unprecedented length and difficulty; but these passes are already traversed by roads which do not exceed in inclination the railway zigzags over the Alleghanies; and the alteration of the existing roads at Mont Cenis and the Simplon into railways of this class would be an improvement of European importance, and one that could not fail to prove remunerative to any company or government that would undertake the work."

Mr. C. H. GREGORY, V.P., said, Mr. Conybeare had alluded to the variations in the estimates of the amount of retardation arising from curves; but he had omitted to mention one circumstance which would account for the difference, viz., the structure of the engine. With engines having a long wheel base, and rigidly parallel axles, serious retardation was unavoidable on sharp curves; but the use of bogies, radiating axles, and other appliances, had already greatly diminished the resistance arising from curves, and further improvements might be anticipated in the same direction.

He would call attention to some local difficulties which would affect the working of a railway over the Mont Cenis, in regard to which Mr. Brunlees would perhaps give some explanations. During four or five months of the year, the district extending from Lanslebourg over the summit of the pass to Molaret (a village about half-way from the summit to Susa), was covered with deep snow, and the wind frequently formed deep and extensive snow-drifts, varying in extent and position with the force and direction of the wind. During that period the traffic was carried on between the places named in sledges; and those who had travelled by that route would confirm the observations he had made, that, without any long warning, the sledges often came to very deep snow-drifts, through which their progress was slow, and from which, at times, they had to be dug out. Besides the drifts, there were in parts of the distance accumulations of hardened snow, so great that the surface on which the sledges ran was many feet above the surface of the road. The changes in the condition of the snow were very rapid, and a few hours would sometimes suffice to render the pass impracticable for days, and travellers were occasionally stopped half-way on the Pass, and had no means of proceeding or returning. He supposed that few railways were exposed to the effects of snow to so serious an extent, and under such peculiar circumstances. There were railways, both in Europe and in America, subject to heavy falls and long continuance of snow, and then the road was cleared by the use of the snow-plough—often a heavy and tedious operation. He was aware that, to a certain extent on the Mont Cenis line, covered ways were proposed, which he supposed were more particularly intended as a protection from avalanches; but he hoped that Mr. Brunlees would inform the Meeting, what he anticipated would

be the effect of heavy snow-drifts, and large accumulations of the snow upon Mont Cenis, in the working of the railway under consideration, how he proposed to meet the difficulties of the case, and what special provisions he proposed to adopt to keep the snow clear from the middle rail, so as to give the necessary adhesion to the horizontal wheels.

Mr. BRUNLEES wished in the first place to remove any misapprehension that might have arisen. To Mr. Fell, as inventor or perfecter of the central rail system, would belong the merit of any success which might be achieved by the Mont Cenis Railway. His own share in the undertaking had been simply to see that the system was properly carried out, and the line efficiently made, and that there was due provision against the accumulation of snow, either by drifting or the falling of avalanches. It was true that there was on certain parts of the route great liability to avalanches; but they had been guarded against as far as possible by the construction of covered ways of masonry. For other portions of the line, comprising the snowy range, where drifts of great depth occurred, timber and iron covered ways were provided; and on the intermediate section, between these covered ways and the avalanche galleries, such observations were now being made as would, it was believed, enable him in the course of next summer to provide screens that would in various places free the line from drifts. From the point where the timber-covered ways commenced on one slope of the mountain, to the termination of the covered ways on the other side, in all about 10 miles, the snow lay for about five months in the year.

With respect to the mode of working the level crossings with the middle rail, the first plan he thought of was that of canting the middle rail over on its side, and bringing it down to the level of the two ordinary rails. To that there were, however, many objections. Mr. Barnes had suggested a method of supporting the central rail at the level crossings on upright bars, hinged at their base and at their connection with the under side of the rail, and which could by a motion similar to that of a parallel ruler, be let down to the same level as the ordinary rails, which were crossed in the usual manner. He believed that this was the best way of dealing with the crossings.

The effect of severe frost was provided against by everything being left free and open so that the ice could not accumulate. The snow-plough he proposed to place on the Mont Cenis Railway was of a form suggested by Mr. Alexander, who had had great experience in dealing with snow in Canada. Various descriptions of ploughs had been adopted by different railway companies, but he believed this would prove the best. The under-part of the plough was fixed, and would clear the snow from the level of the ordinary rails to about the level of the central rail. Then, as it was not

allowed to turn the snow on to the turnpike road, which ran parallel to the railway, provision had to be made for shifting the upper part of the plough from the left to the right, or vice versâ, so as always to throw the snow off on to the side of the railway next the precipice. This was effected by means of a rack-movement at the back of the plough, which enabled the machine to be directed to the right or the left as occasion required. He thought that by this or a similar plan any ordinary snow-fall might be got rid of.

The annexed Table (p. 343), which he had prepared, of the available power derived from the various engines hitherto found most effective in working inclines, showed the superiority of the central rail system.

Mr. POLE would offer a few remarks on one or two points that had incidentally been mentioned in the Paper or in the discussion. Captain Tyler's Paper might equally well have been entitled "On the Passage of the Alps by Railways;" and this of itself would form an interesting subject for the Institution. He was surprised to find it so little known in England, that there was already a railway nearly finished across the main chain of the Alps, and, what would probably be thought still more surprising, without any long tunnel or any such very steep gradients as had been referred to in the Paper. This was across the Tyrolese Pass of the Brenner, between Munich and Verona. He had occasion to cross this Pass in 1865, and was amazed to find this railway in progress, of which he had never before heard. Being thus unprepared, he had no means of getting detailed information about it, but he followed its line along the whole length, and would state what he knew. The railway had already been finished up to Innsbruck on the north side, and to Botzen on the south side, the distance between these places in a straight line being about 80 miles by the carriage road, and involving the pass of the Brenner at nearly 5,000 feet above the sea. At Innsbruck the line left the main valley of the Inn, and turned abruptly southward, ascending the small tributary of the Sill, till it arrived at the summit of the Pass, which it crossed alongside the carriage road, without any tunnel through the ridge. From thence it descended the stream of the Eisach, a tributary of the Adige, down to Botzen, where it entered the main valley, and joined the railway already made by Trent to Verona, and communicating there with the railway system of Northern Italy. The rise from Innsbruck to the summit was about 2,850 feet, and the road was 28 miles long; but as the railway made several detours round lateral valleys to gain length, the average gradient would probably be only about 1 in 70 or 1 in 80. The fall from the summit to Botzen was about 3,500 feet, but there was nearly twice the length to do it in. Of course, there were some places where the nature of the ground required steeper gra-

	Dia- meter of Cylin- der.	Length of Stroke.	Dia- meter of Driving- Wheel.	Weight in Working Trim.	Weight available for Adhesion.	Adhesive Power taking 450 lbs. per ton (or $\frac{1}{3}$).	Tractive Power at 90 lbs. mean pressure.	Proportion of Weight of Engine to Tractive Power.	Weight on each Driving Wheel.	Weight which can be taken up 1 in 12, exclusive of Weight of Engine.	
										Top	Bottom
	ins.	ft. ins.	ft. ins.	tons.	tons.	lbs.	lbs.	tons.	tons.	tons.	tons.
Mr. Fell's Engine, four wheels coupled.	15	1 4	2 3	17	17	7,650 10,800 18,450	12,000	3.17	4.25	29.6	43.
Mountain Top, six "	16 $\frac{1}{2}$	1 8	3 6	24.5	24.5	11,025	11,670	4.70	4.1	3.3	31.5
Oldham Engine, six "	15	2 0	5 0	29.15	29.15	13,117	8,103	8.06	4.86	3.5	11.
Ditto, six "	15	2 0	4 0	29.15	29.15	13,117	10,130	6.44	4.86	3.5	21.5
Fairlie's ditto, eight, four cylinders	15	1 10	4 6	42	42	18,900	16,507	5.70	5.25	5.7	41.
North London, four wheels coupled.	17	2 0	5 9	42	30	18,500	9,050	10.39	7.5	0.0	3.2
Oldham Goods, six "	17	2 0	5 0	49	33.65	15,142	10,410	10.54	5.6	0.0	3
Semmering, eight "	18.7	2 1	3 7 $\frac{1}{2}$	55.25	55.25	24,862	18,000	6.87	6.9	7.4	35.
Giovi, eight, four cylinders	14	1 10	3 6	55.25	55.25	24,862	18,500	6.69	6.9	7.4	35.

dients; but he was informed the steepest did not exceed about 1 in 40, which was quite practicable for locomotives of ordinary construction. There were several short tunnels through spurs, and a good deal of heavy rock work, but he did not observe any extraordinary difficulty in the line. It was far advanced when he passed it; and he was informed the works had been vigorously continued since, and that the line was to be opened towards the end of the present summer, when there would be direct railway communication between cis-alpine and trans-alpine Europe.

The Brenner Railway was of high importance, both in a commercial and a political point of view. It had no doubt been encouraged by the Austrians, as it would have been of immense value to them when they possessed Venetian Lombardy; and even now, by its passing through the heart of the Tyrol, it was a useful line to them. But it was also looked forward to with interest by the Italians, as being likely to facilitate their commercial relations with Germany and Northern Europe generally. To Great Britain this line was of much consequence, as it opened up a railway communication (*viâ* Ostend and Brindisi) with the Mediterranean and the East, independent of France. The Mont Cenis Line, when finished, would be rather the shorter; but if at any future time political complications unhappily closed that line to English traffic, the Brenner route would be of vital importance; and even in time of peace, it would be a question whether its little extra length might not be more than compensated for by its better gradients and the absence of the long tunnel. If any members of the Institution connected with Italian railways could obtain detailed particulars of this, the first, and probably the best railway across the Alps, he was sure they would be very acceptable.

The atmospheric system of propulsion had been alluded to as a means of crossing Alpine Passes. Mr. Pole had had occasion lately to look into the history of this system,¹ and he would offer a few observations on this application of it. The system had been tried somewhat extensively some years ago, and had failed to establish itself; but there was a good deal of misapprehension as to the causes of this failure. Many people supposed it was from mechanical defects, and that the whole thing was a delusion. But the facts, as far as he could ascertain them, did not bear out this view. Mr. Robert Stephenson, who was one of the most determined opponents of this system, never called its mechanical efficiency in question; and Mr. Bidder had declared that he considered the mechanical problem as effectually solved. In some of the applications in this country, the system worked the traffic regularly for a considerable

¹ *Vide* "Life of Robert Stephenson," by Jeafferson and Pole, vol. i., chap. xiv. London, 1864.

time; but the most extensive trial was on the St. Germain Railway, near Paris, where it worked successfully from 1847 to 1860.¹ The chief reason of the non-success of the atmospheric system where it had been tried, was that it was not suitable, as a system, for general railway traffic. Mr. Stephenson predicted this, but he always admitted that there were exceptional cases where it might be applied with advantage. Such cases appeared to be occurring in the present day; one might probably be for underground lines, where the use of the ordinary locomotive was objectionable; and another was on exceptionally steep gradients, such as those necessary in carrying railways over high abrupt mountain passes. Under these latter circumstances, the atmospheric system appeared to offer several most important advantages; as for example,

1. It would allow of the convenient application of any amount of power that might be necessary, and therefore would admit the use of any gradient desired.

2. The great power necessary to drag the locomotive and its supplies of water and fuel up the incline would be saved.

3. The use of a locomotive in such a situation would considerably enhance the dangers otherwise due to the steep inclines and sharp curves; but the atmospheric system would give absolute safety, both in ascending and descending.

4. The atmospheric system would also offer a feasible means of making use of the large water power generally found in such localities.

It might be objected that in such inclement situations as the Alpine Passes, the valve of the atmospheric tube would be liable to derangement; and this objection was doubtless entitled to grave consideration, but he conceived it was not insuperable. Many competent judges were of opinion that in any case a railway at such altitudes must be covered in, if it was to work during the winter season, and if so, this would at once make atmospheric propulsion practicable, either on Vallance's plan, or on that heretofore used.²

Something had been said as to the use of steel in locomotives. Mr. Pole was inclined to fear that this metal had lately been

¹ Vide Perdonnet, "Chemins de Fer," vol. ii., chap. xi., page 348, 2nd edition, where M. Flachat, the engineer of the line, recommends the use of the atmospheric pressure for inclined planes. He says, "Le chemin de fer atmosphérique de Saint Germain n'a jamais failli. . . . Jamais un accident ne s'est produit; la sécurité du service y est absolue; sa félicité est telle, qu'il me semble mériter à ce titre l'attention la plus sérieuse des ingénieurs." This was in 1860, after nearly fourteen years' trial.

² Since making these remarks, Mr. Pole has had an opportunity of seeing a pamphlet, by Mr. George Edwards (Système de Chemin de fer Hydro-pneumatique pour le passage des Hautes Montagnes, Turin, Octobre, 1865), in which the practicability of working Alpine Passes by atmospheric pressure is fully discussed and warmly advocated. It is not published; but will be found in the library of the Institution.

employed for railway purposes somewhat too hastily and inconsiderately, and he was inclined to hope, from the remarks of Mr. Alexander, that a wholesome re-action was taking place. Mr. Pole had had occasion to watch carefully great numbers of attempts to substitute steel for iron in armour plates and guns, but these trials had only shown how unfit the metal (at least in its present state of manufacture) was for purposes where it was exposed to sudden shocks and concussions. It was frequently supposed that because steel had greater tenacity than iron, it was therefore proportionately stronger; but this did not necessarily follow, except for strains perfectly quiescent and purely statical. When motion was introduced, and when shocks and concussions took place, simple tenacity was by no means the measure of strength; for a metal of high tenacity might be very brittle and unyielding, and therefore much less fit to withstand such concussions than a less tenacious material that was softer and more ductile. This seemed to be the case in a large degree with steel, as compared with good iron. In cases where hardness and durability under wear were the principal desiderata, as in tires, no doubt steel was very suitable; but even in these cases much caution was necessary. Instances had occurred, within Mr. Pole's own knowledge, where steel tires had been broken by the wheels being rather roughly handled in carriage. This was not caused by any fault of the tires (which were made by one of the best houses), but was due to their being shrunk on too tight, which showed, however, how much greater caution was necessary with this material; and that, without such caution, steel might prove worse than good iron. To guard against this, some of the steel-makers were now producing so soft a quality that it could hardly be distinguished from iron, and in this state its advantages over the more simple and well-known material became problematical. He could not further yet satisfy himself that the manufacture of steel, under the large production and cheap price at present aimed at, had attained such certainty as to render it trustworthy, in cases where its failure would involve serious consequences. All these matters were well worthy of investigation, and he hoped they would have the careful attention of such members of the Institution as were in a position to obtain information upon them.

Mr. G. W. HEMANS, in reference to what had fallen from Mr. Pole with regard to the atmospheric system, stated he had been engaged in considering the mode of traction to be adopted on an Alpine railway, part of which had been for some years completed and in operation. Amongst other modes he had considered the atmospheric system, but he found that frost and snow would prove fatal obstacles to it. The main principle of that system was a tube, of the same length as the railway, which had a continuous

valve along the whole of its length. That valve was hinged upon leather, and the adhesion of the flap of the valve to the other side of the opening was effected by grease or a glutinous substance; but frost and snow destroyed the adhesion between the valve and its seat, and the whole, under such circumstances, became useless, as the vacuum could not be maintained in front of the moving piston. The atmospheric system was tried on the Dalkey branch of the Dublin and Kingstown Railway, which had succeeded at first, but the effects of frost, in conjunction with the heavy cost of that system of traction, had led to its discontinuance.

Mr. WM. NAYLOR thought it quite possible that on the Mont Cenis line, the plan suggested for dealing with the central rail at level crossings might be simplified, and that the middle rail might be lowered down to the level of the ordinary rails, so as to allow vehicles to pass over it, gates being provided on each side to prevent anything crossing when a train was due. He would remark that he did not see any provision for shunting. He apprehended it was necessary that there should be some means of getting one train past another; and this he thought could be accomplished by making a siding on the steep part of the incline, when the horizontal wheels could be lifted above the rail, and a portion of the middle rail be made into a switch to clear the way for the wheels to get from one rail to another. In ascending the incline, there must be an expenditure of power equal to taking the train up a certain distance, and raising it from one level to another, no matter what the motive power was. It was also necessary to look carefully to the means by which the train could safely descend the incline. If the rope system or the atmospheric system were adopted, and a snow-drift occurred with the train going down the incline, it would not require much to compress the snow so as to lift the flanges of the wheels above the line and allow the train to make a track for itself: and that might lead to serious consequences where there was a deep valley for the train to fall into. The middle rail, however, was a guard against such a casualty. It was well known what difficulty there was in driving a train through deep snow in this country; and he felt, on that account, it would be impossible to get a train up these inclines without more adhesion than was afforded by the bearing-wheels upon the ordinary rails; and that was in a great measure obtained by the extra adhesion of the middle rail. At the same time it was important to see what could be done with inclines in climates where snow did not exist. Captain Tyler had stated, from information he had received from the manager of a railway in Wales, that an incline of 1 in 17 was worked by an engine of 36 tons weight, in working order, with wheels 4 feet in diameter, cylinders 16 inches in diameter, and a length of stroke of 24 inches, and with a pressure

on the boiler of 130 lbs., the regulated load being 25 tons. That seemed to him to be a light load; and from inquiries he had made about the same incline, he had ascertained that the engine weighed in working trim 36 tons, and that the fixed load was 40 tons, but on one occasion the locomotive superintendent had himself taken up 45 tons. The Lickey Incline, of 1 in 37, had been worked for a number of years with engines weighing 35 tons, which took up loads of 140 tons, or nearly four times the weight of the engine; the gravity on that gradient was $60\frac{1}{2}$ lbs. to the ton, and taking $9\frac{1}{2}$ lbs. or 10 lbs. for friction, to meet the force of a strong wind, or other sources of resistance, then the total resistances would amount to 70 lbs. per ton. That required a tractive force of 12,250 lbs. at the periphery of the wheels, which were 4 feet in diameter, the cylinders being $16\frac{1}{2}$ inches in diameter, and having a length of stroke of 24 inches. It would be found, therefore, that it would require 90 lbs. pressure of steam throughout the entire stroke to give that amount of traction, and that the engine at that pressure would take 140 tons up 1 in 37; 50 tons up 1 in 17; and $27\frac{1}{2}$ tons up 1 in 12. If this were correct the same engine with 112 lbs. pressure of steam would take 183 tons up 1 in 37 (exclusive of the engine); 73 tons up 1 in 17; and 42 tons up 1 in 12. It might be said that 112 lbs. was rather a high pressure; but on the Vale of Neath Railway there were two tank engines, with cylinders $18\frac{1}{2}$ inches in diameter, and having a length of stroke of 24 inches, in which a pressure of 112 lbs. to the square inch was found to be necessary, in order to take a gross load (engine included) of 300 tons up 1 in 47, the wheels being 4 feet 6 inches in diameter. If that could be done in this case he saw no reason why the same thing should not be done on the Lickey Incline. The coefficient of adhesion was taken at one-fifth. With an eight-wheeled engine, the cylinders being 18 inches in diameter, with a length of stroke of 24 inches, the wheels being 4 feet in diameter, and the pressure of the steam 110 lbs. to the square inch, a load of $83\frac{1}{2}$ tons (excluding the weight of the engine, 40.4 tons) could be taken up 1 in 17, and $46\frac{8}{10}$ tons up 1 in 12.

As to the relaxation of the gradients on curves and the amount of resistance due to curves; assuming the chord of a curve as 15 feet, and the versed sine as $\frac{1}{6}$ th of a foot, or $\frac{3}{4}$ of an inch, giving 450 feet radius, with a six-wheeled engine with the wheels 7 feet 6 inches apart, and $\frac{3}{4}$ of an inch play on the line, which was usually allowed, the fore and aft wheels would be close to the outer rail, and the flange of the middle wheel to the inner rail. With an eight-wheeled engine, having the same aggregate wheel base, and wheels 4 feet in diameter, the two end pairs being 4 feet 3 inches apart, and the middle pairs 6 feet 6 inches, giving a total wheel base of

15 feet, then with $\frac{1}{2}$ an inch of lateral play in the axle-boxes each way, in the leading and trailing axles, as on the Vale of Neath Railway in the case of these heavy engines, and as adopted by Mr. George Berkley for the Great Indian Peninsula Railway, such an engine would travel round a curve of 225 feet radius (or half the other) without the wheels jamming. In fact he might state, that one engine made for the Great Indian Peninsula Railway went freely round a curve of 200 feet radius; but that was merely in the workshop. On the question of what was the amount of friction on curves: the inner rail was 4 inches shorter than the outer rail, on a wheel base of 15 feet—the gauge being 4 feet $8\frac{1}{2}$ inches, and the radius of curvature 225 feet—and assuming the weight for adhesion to be 1 ton on each of the four wheels which rested on the inner rail, 4 tons would have to slide along 4 inches of rail in traversing this length (15 feet) of a curve of 225 feet radius. To find the increase in the resistance per ton of load to the tractive force due to such sliding motion, the 4 tons should be multiplied by 4, and be divided by 180 (the number of inches in 15 feet), when the result would be found to be 5 lbs. This amount of increased resistance due to the curvature would be important on a level, as it represented about 60 per cent. of the total force required to propel 1 ton on a straight line on a fair day. But on a steep incline of say 1 in 12, on which the gravity of 1 ton was equal to $186\frac{1}{2}$ lbs., or, with the addition of friction, the total resistance was equal to about 196 lbs., it would be comparatively unimportant, as it would amount to only $2\frac{1}{2}$ per cent. of the total force.

Mr. W. LLOYD had been engaged during the last twelve years in the construction of some of the principal steep inclines in the world. Most of the illustrations and ideas connected with this subject had been derived from Europe alone. His own experience was that many things which were good in Europe frequently caused a great deal of difficulty in foreign countries; and there was one thing in Mr. Fell's engine, admirable as it was, which struck him would cause difficulty in practical operation on a railway abroad—that was the extreme intricacy of the machinery. Simplicity was an essential element in all things connected with a railway in countries distant from the great centres of industry. He had never doubted that the Alps might be crossed by a railway. The notion was also entertained of going over the Andes, and if that were done the altitude achieved by Mr. Fell and Mr. Brunlees would be greatly surpassed. There would not be the same difficulty with regard to the line itself, but the elevation to be reached was nearly double. It was found in the investigations of the Andes, that there would be no necessity to approach an inclination anything like that of 1 in 12. In the majority

of cases a gradient of 1 in 20 or 1 in 25 was the utmost that would be required. The line with which he was principally connected in Chili was the Valparaiso and the Santiago Railway; and he alluded to it more especially because he thought practical results could not be too often referred to. The theoretical features of a scheme might be discussed; but those who were connected, as he had been, with the practical working of railways, as well as with their construction, knew that the results of actual experience afforded the best guide. He had stated in a Paper read before the Institution,¹ that in his opinion it was most essential that engines of the ordinary class and all of the same class should be used on distant railways abroad. Directly two classes of engines on such railways were introduced, the difficulties in the workshops were quadrupled. He knew instances in which an engine of 40 tons had carried a load of 163 tons up 1 in 50 at 10 miles an hour, or four times its own weight on the driving-wheels. The maximum gradient on the Valparaiso line was 1 in 44, and an engine of 37 tons carried 74 tons load up that at 10 miles an hour, or twice its own weight on the wheels. These figures were easily remembered, and he had no doubt the effective duty of the locomotive would be increased by improvements in the machinery. He was delighted to hear that a load of 40 tons could be taken up an incline of 1 in 12, because many expedients had been tried to get over the difficulty of so steep an ascent.

He would now advert to the Copiapo Extension Railway, from Pabellon to Chanarcillo, for which Mr. E. Woods, M. Inst. C.E., was the consulting Engineer in this country. The summit at Molle was upwards of 4,450 feet above the sea, and Pabellon, where the line commences, was about 2,200 feet above the same level. It had been in operation since February, 1861, and was worked by Messrs. Hawthorn's engines. It was 26 miles in length, and the cost, including equipment, was £6,500 per mile. It consisted of three inclined planes, one rising 2,276 feet in $14\frac{1}{2}$ miles, with an average gradient of 1 in 33, but for short distances of 1 in 26, and 1 in 28 over a portion of the incline. The second was a descending gradient from Molle to Pajonales, 1,990 feet in $9\frac{1}{6}$ miles, with an average gradient throughout of 1 in 24. On one portion, however, there was a gradient of 1 in 20, with curves of 720 feet radius, and on other gradients of 1 in 21 and 1 in 24 there were curves of 490 feet radius, in some cases reversed two or three times, and without any intermediate straight line. The last-mentioned inclined plane was an ascending one, with gradients of 1 in 34 and 1 in 25, in the direction that the chief loads were carried, the principal traffic being from the silver mines to the coast. He was sent by the government of Chili to determine the

¹ Vide Minutes of Proceedings Inst. C.E., vol. xxiii., p. 376.

kind of engine that was best adapted for working such lines. The train he took up weighed 57 tons; it went over the gradient of 1 in 20, with curves of 720 feet radius, without difficulty. The retardation by the curves was not more serious than could be overcome by moderating the weight of the train; and there was never any occasion for the weight to exceed 70 tons or 80 tons, as the traffic did not require heavier trains than that. The cost had generally to be regarded in working steep inclines; but in a country like that of which he was speaking it did not enter into the calculation, inasmuch as the price paid for the transmission of goods was so high, that almost any cost would be more than remunerated by the rate of prices charged. The engines had six coupled wheels, 4 feet in diameter; the cylinders were 16 inches in diameter, with a length of stroke of 24 inches; and the fuel burnt was, at the time he spoke of, about an equal quantity of coal and coke. The paying load was two-thirds of the weight of the train. The consumption of fuel was $75\frac{1}{2}$ lbs., and of water $66\frac{1}{2}$ gallons, per mile. He considered one-fourth of the weight on the driving-wheels was fairly taken up by the engine.

Subsequently a trial was made on another incline in Chili of 1 in 13, over a tunnel under construction, with an engine of the ordinary character of those which were being used in the country at the time; but it was found that the ordinary class of engine could not be utilized for such a gradient as 1 in 12 or 1 in 20. He was, however, reluctant to make special arrangements for a locomotive to work that small portion of the road temporarily; he therefore took a four-wheeled engine off its wheels, placed it as a stationary engine on the top of the tunnel, and worked the incline by a rope. By that means four heavy trains were worked daily; and that during four years, with scarcely any difficulty or accident occurring. Such an instance he thought would afford a useful precedent to Engineers under similar circumstances in foreign countries.

He would now briefly allude to what was proposed on the Mexican Railway, because he had heard some doubts expressed as to what an engine would be likely to do on that line. The proposition was this: The altitude to be reached was 8,400 feet above the sea; and for a distance of 23 miles the average gradient was nearly 1 in 25, with curves of 350 feet radius, and there was one length of 15 miles almost continuously of this gradient. The engine proposed was a double-tank engine, with tender and auxiliary power between. The object of the tender was to carry the necessary supply of water, none being obtainable at the top of the incline. The water from the tender was to be first exhausted, leaving that in the tanks to assist adhesion in the ascent. He calculated that two engines with 21 tons on each pair of driving-wheels, or 42 tons together,

ought to take up a train of 100 tons, independently of the weight of the engines; and that would be the maximum load required, inasmuch as the present traffic amounted to only about 80 tons per day. As the rate charged was a shilling per ton per mile, the money value of a train of 100 tons for 15 miles would be £75, so there was little need to take into consideration the cost of working such inclines under similar circumstances.

Mr. BEYER said, with regard to friction, he was satisfied the adhesion was about the same under all circumstances, if the rails were in good condition. He had taken some trouble to collect what might be considered reliable information on this subject, and had obtained the results of many experiments. He was convinced in his own mind that, under a good condition of the rails, the adhesion of the wheels was at least one-fifth, and probably as much as one-fourth. When the rails were in bad condition, whatever the weight of the engine, the wheels would slip. With regard to inclined planes, he did not know that it made any difference to the locomotive whether it had to do its work on a level or up an incline; it was simply a matter of how much cylinder power was necessary to pull the load.

Mr. E. WOODS could corroborate what had been said with regard to adhesion under favourable circumstances; and it was confirmed by the results of Mr. Lloyd's practice in Chili. Table No. 1, page 353, showed the actual work done on the railway of which Mr. Lloyd had given a description, and which had now been worked by locomotive power for six years. He had stated on a former occasion,¹ that this line was not originally designed for locomotives, but was intended to be worked by animal power. It was so worked for two or three years, but the expense caused it to be abandoned, and locomotives were substituted. The lightness of the rails (42 lbs. to the yard) compelled him to design engines in which the weight on the driving-wheels should not be greater than those rails would stand, and the engine he had designed (Table No. 2, p. 353) had outside cylinders, six coupled wheels, 4 feet in diameter, with a four-wheeled bogie in front, to pass round curves of 500 feet radius. The weight of the engine, in working order, was 32 tons, and that of the tender 25 tons; on the driving-wheels it was 24 tons. A comparison of that with the work of the engine given in Table No. 3, p. 354, showed that the coefficient of adhesion was as nearly as possible one-fourth of the driving weight. The climate of Chili was, however, peculiarly favourable for working steep gradients. There was very little rain at any time, and the rails were almost always in good order. The line had been worked four or five years entirely without accident, until about

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxiv., p. 379.*

half a year ago, when one occurred owing to the breaks not acting. Mr. Lloyd had correctly stated that the chief loads were from the mines to the coast. They were carried on a gradient averaging 1 in 23, or 1 in 24, up to Molle, before they could be sent on to Pabellon; thence they were carried along the Copiapo Railway (extending for a distance of 60 miles) to the coast. The load had on one occasion been 77 tons, exclusive of the engine and tender, making a total of 134 tons. Under ordinary circumstances, the weight of the load was not more than 50 tons, the total being 107 tons. The Tables which he had prepared, independently of Mr. Lloyd's observations, and without communication with him, were confirmed by that gentleman's personal experiments on the line. The speed was necessarily limited in descending: the rule was that the trains should not descend at a greater speed than 12 miles an hour; but that was sometimes a little exceeded. The average speed up and down was about 13 miles an hour. A question had been asked as to the relative amount of coke and coal used for fuel in working these trains. The proportion of coal was greatest. In the first instance coke alone was burnt; then coke and coal mixed together; and now coal was almost exclusively used. He thought a well-proportioned 'all-coupled' engine could take itself up an incline of 1 in 4 with its own wheels, if the rails were clean and in good order.

COPIAPO EXTENSION RAILWAY, 1860.

TABLE I.

Particulars of Engines.

Outside cylinders.	Six coupled wheels, 4 feet diameter.
Four-wheeled bogie.	Cylinders 16 ins. diam., and 24 ins. stroke.
Weight of engine in working order . .	32 tons.
Ditto tender " "	25 "
Total	<u>57</u> "

TABLE 2.

LOADS taken over the line, gradients averaging 1 in 23 and 1 in 30.

Heaviest train ever taken over the line:—

Engine	32 tons.
Tender	25 "
Gross load of wagons and carriages	<u>57</u> tons.
Total weight	<u>77</u> "
	<u>134</u> tons.

Ordinary trains :—

Engine	32 tons.		
Tender	25 "		
			57 tons.
Mineral trucks	Tare 11 tons.		
Minerals, &c.	Nett 26 "		
			37 "
Passenger carriages, with passengers	13 "		
			50 "
Total			107 tons.

Mean speed of train, $13\frac{1}{2}$ miles per hour.

Heating surface :—

Fire-box	75 square feet.		
Tubes	926 "		
Total	1001 "		

Area of grate $14\frac{1}{4}$ square feet, or $\frac{1}{70}$ th of heating surface.

TABLE 3.

Greatest load taken up gradient of 1 in 23 = 134 tons.

Gravity	97 lbs. per ton.		
+ friction	12 " "		
Total	109 " "		

Traction = 134 tons \times 109 lbs. = 14,606 lbs.
24 tons (= 53,760 lbs.) on driving-wheels.

$$\text{Coefficient of adhesion} = \frac{14606}{53760} = \frac{1}{3.7} = 0.27.$$

Ordinary load taken up, 1 in 23 = 107 tons.

Traction = 107 tons \times 109 lbs. = 11,663 lbs.

$$\text{Coefficient of adhesion} = \frac{11663}{53760} = \frac{1}{4.6} = 0.22.$$

In the 1st case,

14,606 lbs. traction corresponded to a mean pressure in the cylinder of 114 lbs. per square inch.

In the 2nd case,

11,663 lbs. traction corresponded to a mean pressure of 91 lbs. per square inch.

Mr. VIGNOLES remarked that extensive experiments, as to the friction of iron upon iron, showed that the utmost amount of adhesion that could be got, under the most favourable circumstances, was one-fifth. He appealed to mathematicians whether he was not correct in stating, that the amount of adhesion, on railways deviating from the horizontal, depended also on the sine of the angle of the inclination of the plane.

Mr. CALLCOTT REILLY said, in reply to an observation made by Mr. Vignoles that, upon a gradient, the pressure of the wheels of a locomotive upon the rails would be less than the weight of the engine.

The normal component of the weight of the engine would be the product of the weight into the cosine of the inclination of the gradient, and therefore the adhesion on the gradient would be diminished in that proportion. It might be worth while to see what would be the amount of that diminution in a practical case. Suppose an engine, weighing 24 tons, to stand upon a gradient of 1 in 20, all the wheels being coupled. Then the diminution of the pressure normal to the rail, owing to those circumstances, would, upon that gradient, be only 70 lbs.; and upon a gradient of 1 in 12, the diminution would be only 201 lbs.—of course a most insignificant trifle. He had supposed the case of an engine having all the wheels coupled; but in the very common case of an engine having its leading wheels uncoupled, or with its front end supported by a bogie, the diminution claimed by Mr. Vignoles would be much more than counteracted, by the shifting backward of the centre of gravity of the water in the boiler, thereby transferring a part of the weight from the uncoupled leading wheels, on to the coupled drivers; so that the adhesion of such an engine would be greater upon any workable gradient than upon a level. Mr. Conybeare had called attention to the coefficients of friction, and gave 0·177 as the coefficient of friction of wrought-iron surfaces, from which he inferred that the adhesion of an engine could not possibly exceed about one-sixth the

TABLE 4.

“FRICTION OF REST” OF WROUGHT IRON UPON WROUGHT IRON, from Mr. Rennie's Experiments, Phil. Trans., 1829: showing how the coefficients of friction increase with the increase of pressure. Surfaces dry.

Pressure per Square Inch.	Coefficients of Friction.
lbs. 32·5	0·140
186·0	·250
224·0	·271
261·0	·285
298·0	·297
336·0	·312
373·0	·350
410·0	·376
448·0	·376
485·0	·395
522·0	·403
560·0	·409

weight of the engine. He supposed Mr. Conybeare must have quoted that coefficient from the Tables of General Morin. But it was well known that Morin's results were obtained with pressures of very light intensity, in no case exceeding 30 lbs. per square inch. The actual figures deduced from Morin's Table No. 68 as the average were about 0·138, as the coefficient of friction of motion, with dry

surfaces; and 18 lbs. per square inch as the intensity of the pressure.¹ Of course there could be no analogy between those results and the friction resulting from the pressure of a locomotive upon the rails, the intensity of which would probably be 1,000 times as great as in Morin's experiments. It was well known that the late Mr. George Rennie made a series of experiments,² with much greater pressures than those of General Morin. These experiments, Table No. 4 (page 355), showed that when the intensity of the pressure was 32·5 lbs. per square inch, the coefficient was 0·140; but when the pressure was increased to 560 lbs. per square inch, the coefficient was 0·409; the coefficients increasing steadily with the pressures, although not in direct proportion. Referring to the best performance of Mr. Woods' engine, it would be seen that its coefficient of friction was 0·27, which was much less than Mr. Rennie's higher coefficients.

Mr. PHIPPS observed, with regard to passing over mountainous regions by means of railways, that it was of course always to be expected that numerous steep inclined planes and sharp curves would have to be introduced, and hence arose the necessity of dispensing as much as possible with all unnecessary weight in the engine and train. Every one, therefore, whose attention was turned to this subject naturally looked at first with favour upon systems, such as haulage by ropes, the atmospheric railway, &c., which accomplished the necessary tractive power without the necessity of dragging up a heavy locomotive along with the train. This was the purely theoretic view of the matter; but, in the practice of mechanical engineering on a large scale, every-day experience showed, that some compromise must be made between abstract theory and general convenience—just as in the designing of ships, no one single property could be attained in its highest degree of excellence. In the same manner the locomotive engine often came to be used in situations where it was certainly not economical, motives of convenience in its use often outweighing the deficiency in economy. If, for instance, upon some mountain line of railway, several tolerably level portions of the line alternated with steep gradients, the delay and inconvenience of resorting to rope traction at each of those changes would be very great. The atmospheric system had also, by pretty general consent, been admitted to be unfit for regions in which the changes of temperature were so great. He thought that the system of Mr. Fell was a good compromise, between a heavy engine capable of dragging itself and the train up the ascent by the adhesion due to gravity alone, and the other methods before referred to, where the retarding effect of

¹ *Vide* Nouvelles expériences sur le frottement, 1834, p. 68.

² *Vide* Phil. Trans., 1829, p. 159.

the weight of the propelling power was altogether dispensed with. As an instance of the sacrifice of purely economic views sometimes found convenient to be dispensed with, he would refer to the case of the Metropolitan Railway, where engines weighing about 45 tons were used to draw trains of a total weight, including the engine, of about 90 tons. Hence the net power to draw the useful part of the train was doubled; but this was not all, because, in consequence of the numerous stoppages upon the above line, in order to obtain a comparatively moderate average speed, it became necessary to get up the speed from a state of rest in a very brief time after stopping at each station. Supposing the requisite ordinary tractive power of such engines on a level to be $\frac{1}{2}$ a ton, to get up a speed of 10 miles an hour from rest, if acquired in the length of 100 yards, would require an additional tractive power of about $1\frac{1}{8}$ ton, making altogether $1\frac{5}{8}$ ton of tractive power, where the useful load of 45 tons would only have required about $\frac{1}{4}$ of a ton; and yet, up to the present time, no one had been able to propose a satisfactory substitute for the locomotive engine in the above situation.

He would now pass to a part of the subject of the resistances to railway trains, which had engaged attention during this discussion, namely, the resistance due to curves. There appeared to be a desire to draw a comparison between the resistance on inclined planes and that due to curves, with the object of enabling those engaged in laying out such lines to render the resistance of the trains as nearly uniform as possible. He was afraid that any attempt to calculate the resistance due to curves on purely theoretical considerations would prove a failure. He had attempted to do so on the principle of taking the slip of the wheels on the exterior diameter of the curve (those on the interior diameter being supposed to travel with the velocity of the train) to be equal to the distance travelled by the train in any short space of time, taken into the fraction expressed by the gauge of the line for a numerator and the radius of the curve as a denominator. Then $\frac{1}{2}$ the weight of the train into the fraction for adhesion, into the above distance, would represent the power consumed on the curve. But the result was so exceedingly small as to admit of scarcely any comparison with the effects of inclination. For instance, in the case of a gross load of 33 tons, on a gradient of 1 in 12, on a curve of 3 chains radius, taking the adhesion at $\frac{1}{6}$ th of the weight, the result would be:—

$$\frac{\overset{\text{Tons.}}{33} \times \frac{1}{6} \times \frac{1}{3\frac{1}{2}}}{2} = \overset{\text{Ton.}}{0.05}.$$

The gravitation down the plane would be—

$$\frac{\overset{\text{Tons.}}{33}}{12} = \overset{\text{Tons.}}{2.75}.$$

He was thus satisfied that there were causes for resistance on curves far more influential than the above. This subject had been examined in a Paper by Mr. Isaac,¹ in which it was stated that the resistance to traction due to a curve of 400 feet radius was supposed to be double the resistance on a straight line on a level.

Mr. BRAMWELL said he rose with some diffidence, after the remarks of Mr. Phipps, for he was about to address a few words to the meeting on the subject of the increased resistance on curves; but as that gentleman had said he could not arrive at a satisfactory solution of the cause of the increase, it might be presumption in him to attempt to do so; he would, however, venture a few observations on the subject. An opinion had been expressed, that the principal cause of the resistance on curves was the different distances travelled by the inner and outer wheels; and it was shown that in a distance of 15 feet, the difference, with a particular curve, was 4 inches. It was then alleged that, by taking the friction of iron upon iron, and ascertaining from this the resistance due to the weight of the engine, the power required to make a slip of 4 inches, while the engine travelled this 15 feet, could be ascertained. But Mr. Bramwell thought there was some error in this method of viewing the matter; because if, for example, it were assumed that the outer wheels were going at the right speed due to the distance travelled, and the inner wheels made all the slip, it was not right to multiply that slip by the whole weight of the engine, because half was on the wheels that were going the right pace. If, on the other hand, the slip were multiplied by the whole weight of the engine, it would have to be assumed, either that the centre of the engine was making half of the total slip, or else, if the centre of the engine were supposed to be going at the true mean pace, then the wheels would each make one-half the total slip, the outer wheels going too slowly, and the inner wheels too quickly. Another error in the calculation was, that no account had been taken of the correction obtained by the cone of the wheels, which, if there were a little play, to a certain extent reduced the slip; but no allowance had been made for that. It was evident, however, that the effect of the cone varied with the diameter of the wheel; for, if the wheel were of small diameter, and the angle of the cone the same as in a wheel of large diameter, the amount of ease given by the cone would be less in a large wheel than in a small one; for the cone gave only a constant difference, whatever might be the circumference, and the proportion of this constant to a large circumference was, of course, less than to a small circumference.

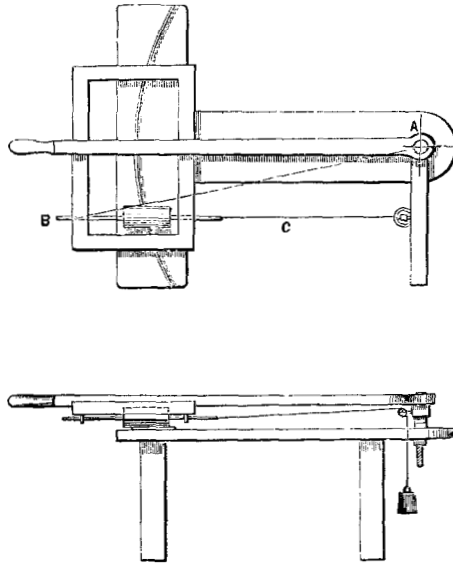
But, irrespective of these considerations, which tended to show that the resistance on a curve was less than it was thus made to

¹ *File Minutes of Proceedings Inst. C.E.*, vol. xviii., p. 59.

be, and which therefore increased the difficulties which had been indicated, he thought it could be shown that there was another cause of resistance, the effect of which would be very considerable, and which was irrespective of the difference between the lengths of the inner and outer rails on a curve.

He had represented in a model only a single rail struck to a sharp curve; and he had connected the framework representing the engine or carriage to a radius arm centred at the point from which the curve was struck, and, for convenience, he had taken a roller of some length in the direction of the axle to represent the wheel. Now, if the axle were made radiating from the centre of the curve, as at *A B*, Fig. 1, the carriage would pro-

Fig. 1.



gress with no more resistance than it would have in a straight path. If, however, as was the case in an ordinary engine, the axle were not radiating, as at *B C*, Fig. 1, but merely parallel to a radius (the radial arm in the model), and therefore pointed to one side or the other of the centre of the curve, then it followed that the tendency of a wheel on such an axle would be to progress in a direction at right angles to the axle, and therefore it would tend to run out of the curve, and, if left at liberty while the carriage was compelled to follow the curve, the wheel would move endways in the carriage in the direction of the axle, and the successive points of contact of the wheel

with the rail would be found to occur in a helical path on the surface of the circumference of the wheel. But if, as in practice, the wheel were compelled to move with the carriage, so as to follow the curve, then the wheel would be continually dragged endways (*i. e.*, in the direction of its axle) over the rail, to the extent of the endway movement it would have if left free, and the power expended in overcoming the resistance due to this cause would, therefore, be something very considerable, as it would be represented by the total weight on the wheels, multiplied by the coefficient of friction and by the amount of the endway movement (the resistance was shown in the model by a weight). It must be remembered that in this instance both wheels of a pair had to be taken into account, as both were moved endways over the rail. Moreover, the resistance arising from the endway motion of the wheel over the rails would, of course, increase as the wheel base of the engine was lengthened, because the farther the axles were from each other, the more would they deviate from a radius of the curve.

In both these respects, this species of resistance was unlike that arising from the slip due to the different lengths of the inner and outer rails in which, as he had before said, the weight on one wheel only could be taken with the total slip, and on which the length of the wheel base had no influence.

In reference to this question of resistance on curves, the Author of the Paper said, it was found that the engines under consideration gained speed on the curves instead of losing it. Looking at the construction of these engines, Mr. Bramwell was not surprised at this, when he heard that the steepness of the gradients had been diminished at the curves, as no doubt this diminution had been such as would have been suitable to an ordinary engine; and the Mont Cenis engines would not require so much allowance in this respect as ordinary engines, for the following reasons:—In the first place, the wheel base was very short—not more than 6 feet, or 6 feet 6 inches; therefore the deviation of the axles from radial lines was but slight, and the resistance he had pointed out as arising from this was consequently small. In the next place, as these engines did not depend principally on their weight to make adhesion on the rails, there was opportunity to make them as light as possible without diminishing their tractive force, and hence the weight on the bearing-wheels was comparatively small, when considered in reference to the power of the engine, and with a light weight the endway movement of the wheels over the rails, and the slip necessary to allow for the different lengths of the inner and outer rails was of little moment; moreover, the gauge was narrow, which rendered the slip due to the different lengths of the inner and outer rails of no great extent. The wheels with vertical axles that bore against the central rail, and gave thereby the large amount

of tractive force, were of course unaffected by either of the causes of resistance on a curve.

These considerations would tend to explain why an engine on Mr. Fell's construction would not be affected in going round curves to the same extent as an ordinary engine. A remark had been made that, in the case of these engines, the correction by the conical form of the wheel could not apply, because the central rail prevented any side-way motion of the engine upon the bearing-rails. He thought, so far from not applying, it would apply with greater force and certainty, because, if the so-called central rail were (on a curve) set a little out of the centre, it would insure that the large part of the cone in the outer wheel bore on the rail, and that the small part bore in the inner wheel, and thus the advantage afforded by the cone would be rendered definite and certain, and not be left to the vagaries of the engine.

Mr. Fell stated that he had experienced some difficulty with the sledge breaks, and proposed to apply breaks to the wheels. Mr. Bramwell could not see how that would effect an improvement; the resistance must ultimately come upon the rail, which therefore must be worn; and if breaks were put on the wheels, two vital parts would be worn instead of only one. It would be better, in his opinion, to wear out the rails only by a distributed wear, rather than to wear first of all the wheels into irregular shapes, and then to wear out the rails with the action of these imperfect wheels.

On the subject of breaks, he would refer to a matter which he had heard from French Engineers in Paris, with respect to a system of breaking now in operation in trains in France working on inclines, viz., by reversing the engines, and without using the ordinary break contrivances, or using them only to a limited extent. One reason, he believed, why engines were not ordinarily kept in reversed gear in descending inclines was, that the cylinders became so heated that there was danger of the pistons cutting. The French Engineers had met that difficulty in this simple manner: they provided, when the engines were working in reversed gear, an inlet of steam, and also a small inlet of water into the exhaust; as the locomotive came down an incline, it worked the pistons, converting them into compressing pumps, which drew into the cylinders the steam and water from the exhausts, and the regulator being of course open, pumped them into the boiler; the heat in the cylinders was used in vaporising the small quantity of water thus admitted; and in this way, while going down an incline in reversed gear, the cylinders were really generating steam, which was conveyed into the boiler.

The Author of the Paper had alluded to the Blenkinsop rail. Mr. Bramwell had succeeded in obtaining a specimen of an actual

rail, which he exhibited, and he had bought a copy of the specification of Blenkinsop's patent, dated 1811. This rail was made in accordance with the specification, which stated :—

“ By preference, I do cast one of the sides or range of pieces forming the said railroad with teeth or protuberances, or other parts of the nature of teeth, standing as aforesaid, so that the same side or range shall constitute my said toothed rack or longitudinal piece, and at the same time afford a regular and even bearing for the wheels, and for the toothed wheel, which (if its plane be vertical) may be made with a side rim to bear upon the smooth part of the rail, and prevent the teeth from locking too deep.”

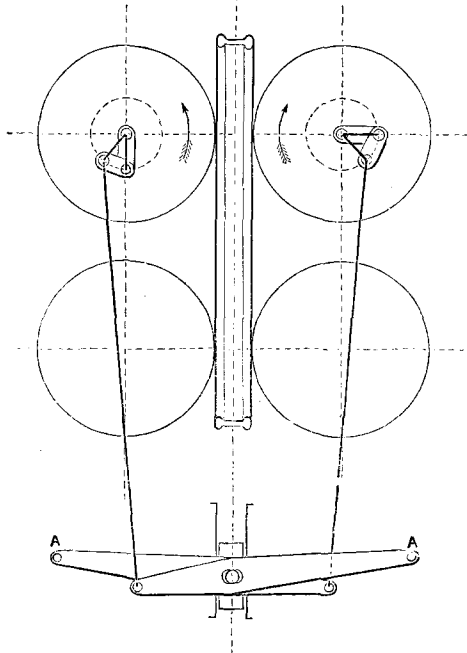
As a historical fact, the Blenkinsop rail was undoubtedly very interesting, and it offered the advantage of affording a means of utilizing the power of an engine for traction without increasing its weight. But the Patentee appeared to have overlooked the objection, that the path of the smooth wheel was not coincident with the pitch line of the rack; and therefore, as the rack determined the rate of progression, there would be a certain amount of slip between the smooth wheel and the rail, as the diameter of the smooth part would differ from that of the pitch line of the toothed part. No doubt the remedy for this was simple, viz., leaving the bearing-wheel loose on the axle. In the Mont Cenis engines, the same end, of increasing the tractive force without adding to the weight, was aimed at, and they were free from the objection he had just mentioned, and from other objections connected with the Blenkinsop rail.

He apprehended that any system which was, as compared with an ordinary locomotive, equally efficacious for traction, but was unaccompanied by the manifest defect of increasing the weight for the sake of adhesion, deserved attention. There was nothing more shocking than the idea of adding to the weight of the machine, not to get the requisite power, but to get the requisite adhesion. To add to the weight of an engine, in order that a small portion of that weight might be available in getting up an incline, was clearly most objectionable; and he thought any one who helped to get rid of that stigma upon mechanical engineering deserved the thanks of the profession.

It would be remembered that Mr. Fell and Mr. Alexander, when speaking of the engine to be used on the Mont Cenis Railway, both alluded to the contrivance for getting the cranks of the vertical axles over the centres. He found, on examining the model, that this engine had two cylinders, working two pairs of driving-wheels on the ordinary rails, and also two pairs of driving-wheels on a central horizontal rail; for these two latter pairs the ordinary method of coupling the engines together was not applicable, as the vertical axles on one side would not serve as the means of coupling both engines, and therefore some fresh expedient must be resorted to. The method that was employed was

shown in the model he had referred to, as well as in Fig. 2. In Fig. 2, the piston rods and ordinary connecting rods were not shown, but only the cranks of which they took hold. From these cranks, return cranks were made, in such position as to bring their two crank pins so as to be similarly situated on each

Fig. 2.

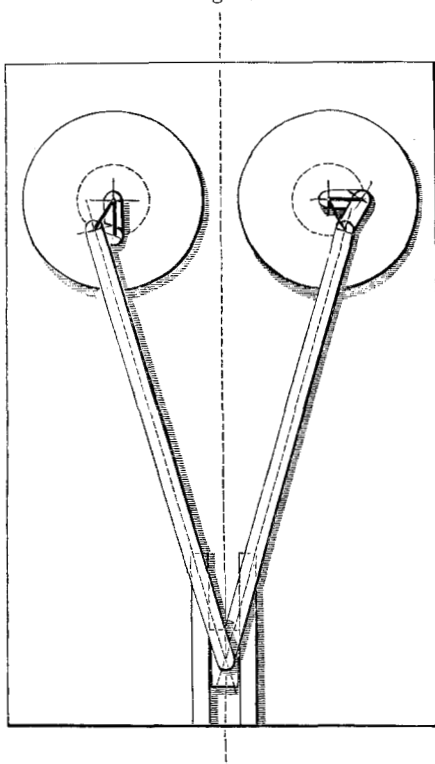


side of the rail. From these latter crank pins, connecting rods, shown by lines in Fig. 2, were led to a pair of levers having their fulcras at A A, and placed near the front of the engine, which levers were connected by a common pin, so that one could not be moved without the other. It would be seen that when either one of the piston cranks was on the centre, the lever cranks were at an angle of 45° ; and thus the piston that was not on the centre could, by means of the levers, work the other piston so as to get its crank over the centre.

It had been stated that, when it was made, this contrivance was not liked, and that some substitute would have been acceptable. It was possible that what he was about to propose might have been thought of before, and though, in a mechanical point of view, it might be regarded as not strictly orthodox, yet he believed it

would answer the purpose, and would be more simple. It would be seen in the Mont Cenis engine that, by the arrangement of levers, it was practicable to bring the two connecting rods that joined the ends of the levers to the cranks into such position that their average centre line should be parallel to the centre of the engine; but if, as he would suggest, this position of parallelism of the connecting rods were slightly varied, they might be brought together to a central block, and the levers be entirely dispensed with.

Fig. 3.



Without, however, interfering with the efficiency of the apparatus in getting the engines over the centres, the cranks for these connecting rods would of course require their position to be slightly altered, to suit the different average centre line of the rods.

Mr. Pole had cautioned Engineers against the use of steel. No doubt, of all metals, steel was one which varied most in quality, as there might be one quality of steel which would melt with a low heat in an hour, while another quality would

take four hours in a Siemens' furnace to melt it at all. Two such materials (both steel) differed, of course, very widely; but he thought it was wrong, on account of such variation in the same metal, to deprecate altogether the use of steel. Provision should rather be made against the uncertainty of the quality, by endeavouring to bring the steel trade into the same state of uniformity of excellence as had been attained in the Yorkshire iron trade, and thus to make sure that the same quality of steel should always be had for a given brand. Mr. Ramsbottom (M. Inst. C.E.) had stated that he had experimented with steel tires, bored out, afterwards made red-hot, and in that state placed upon solid cast-iron centres, and then left to cool; and this without a single case of fracture of the steel. He had also stated that since he had used steel axles, the fracture of a straight axle was unknown. Mr. Bramwell thought these were evidences in favour of the use of steel. In his opinion, the end to be aimed at was to be able to rely on obtaining a proper and uniform quality of steel; and he thought it would be highly impolitic to discard the use of steel altogether, merely because some steel was bad.

Mr. MARGARY would remark incidentally, on the subject of steel, that it was to be feared that Engineers sometimes endeavoured to beat down contractors' prices, and that contractors, in their turn, endeavoured to pull down the manufacturers' prices, and a bad quality of metal was afterwards the result. On the subject of the atmospheric system he would remark, that having been Mr. Brunel's assistant in the South Devon atmospheric experiments, he might be able to answer Mr. Hemans' observations with regard to the effects of frost upon the valve. Frost did affect the valve to some extent. It might be said that on the south coast of Devon there was seldom frost of long duration; but there had been 16° of frost there this year, and when the atmospheric system was in operation there had been as much as 12° , but it was obviated by the substitution of a different grease from that used in summer. The great drawback was the difficulty at all seasons of sealing the valve at the commencement of pumping; but Mr. Brunel considered that might be overcome. It was only due to the memory of Mr. Brunel to say, that he conscientiously backed his opinions, with regard to the atmospheric system, with his own purse. If he had had the national purse to resort to in the case of experiments on this system, as was now the case with experiments on guns, &c., no doubt Mr. Brunel would have carried out the atmospheric system to a success; but the shareholders pulled their purse-strings at the moment he thought he was about to bring the system to perfection. The atmospheric system led to steep inclines being adopted on the South Devon Railway, over which the trains were now worked with locomotives. The curves varied from 15 to 20 chains radius.

The goods engines, having cylinders 17 inches in diameter, with a length of stroke of 24 inches, and six coupled wheels 4 feet 9 inches in diameter, took up the Dainton incline a load of 180 tons at a speed of about 10 miles an hour, the weight of the engine being 38 tons. The passenger engines having cylinders 17 inches in diameter, with a length of stroke of 24 inches, and four coupled driving-wheels 5 feet 9 inches in diameter, with bogie wheels 3 feet 6 inches in diameter, took seven loaded carriages, making a total load of about 90 tons, up the same incline at a speed of about 10 miles an hour. He hoped that other Engineers would state what was done on the inclines under their control. There were a great many inclines which ought to be mentioned, as, for instance, that at Bromsgrove, and that on the South Western Railway between the two Exeter stations, where two engines were frequently employed to take up the trains; and he should be glad to be informed what was their ruling load. He had received, from Mr. David Murray, some particulars with respect to the contractor's incline at the North Eastern Defences at Plymouth. The tank engine used on this work was built by Messrs. Fletcher and Jennings, of Whitehaven. It had four coupled wheels 4 feet 6 inches in diameter, the cylinders were 11 inches in diameter, the tank was underneath the boiler, and the total weight of the engine was 18 tons; the gauge of the line being 4 feet 8½ inches. This engine took up the Woodlands incline of 600 yards, with a gradient of 1 in 27½, 70 tons dead weight at an average speed of 10 miles per hour; the maximum steam pressure was 110 lbs. to the inch, reduced in running to 95 lbs. and 90 lbs. The Knackers Knowle Bank was on a gradient of 1 in 22, for a length of 400 yards; with steam as above the engine took up 50 tons dead weight at the same average speed.

Perhaps Captain Tyler would say, whether the sledge breaks acted upon the middle rail or on the running rail; because if they acted upon the running rail, he could state from his own experience that they would be most dangerous. The tank engines introduced by Mr. Brunel on the South Devon line had sledge breaks at first, which constantly went on the wrong side of the crossings and greatly damaged the rails generally. They also considerably reduced the weight on the engine wheels.

Captain TYLER said the sledge break was on the centre rail.

Mr. MARGARY added, that he would have been glad to have heard Mr. Fell's opinion as to the economy of his system for branch railways, and whether he recommended it in the case of short lines, as it would require different working plant from that on the main line. As the load that could be taken in a train was small, it appeared to him there would be much delay in dividing trains, which a line of less steep gradient would obviate. He would re-

mark incidentally, that good ballast should always be put on inclines.

Mr. ALEXANDER DOULL described, by means of a diagram, a system of atmospheric railway, which he suggested as applicable to the working of steep gradients.¹ The motive power consisted in a hollow revolving drum, fitted with four blades, at the mouth of the tunnel, by means of which air was either forced into or extracted from the tunnel.

Mr. FAIRLIE said, Mr. Fell's engine was of special design, and had attracted a good deal of attention. Those who were acquainted with the subject of locomotive construction would admit that in a first design it was almost impossible to arrive at perfection; such no doubt had been Mr. Fell's experience, as it had been his. With reference to his engine, the question of draught in the fire-box, selected as one of the main objections by Mr. Conybeare, was considered when he gave the specification of the engine to the manufacturer; and it was decided that putting a water partition across the fire-box would be a disadvantage instead of an advantage. The objection to the engines now working on the Neath and Brecon line was, that there was no water partition across the fire-box, and that the draught from one engine counteracted the useful effect of the other, by drawing the cold air down the chimney into the fire-box. Since he had put a brick partition across the fire-box of one of these engines it was found that the draught was perfect. One of these engines, with four cylinders each 10 inches in diameter, and having a length of stroke of 16 inches, was working on a line having inclines varying from 1 in 50, with curves of 10 chains radius, where there was not a piece of straight line of more than half a mile. It took daily a load of 100 tons, exclusive of its own weight, for 14 miles, with a mean ascent of 1,250 feet. With regard to the steam pipes, it was considered at first sufficient to put in a single coil pipe, one end being attached to the boiler in the usual way and the other to the cylinders. This was found not to possess sufficient elasticity, and gave way when working a curve of $2\frac{1}{2}$ chains radius on a gradient of 1 in 30; but he subsequently put in a pendulum steam pipe which had worked perfectly to the present day. He was sorry the locomotive superintendent of the line, on which these engines were employed, was not present to give some further facts with regard to their working. The double boiler duplex bogie engine, a model of which he exhibited, had four cylinders 18 inches in diameter, with a length of stroke of 24 inches, and wheels 4 feet in diameter. The wheels were disposed in groups of six coupled together, the whole engine weighing 72 tons, divided equally over the twelve wheels, or 6 tons on each. The water was carried in tanks, made in the form of box girders,

¹ *Vide* "The Mechanics' Magazine," vol. xvi. (New Series), p. 55.

placed horizontally the whole length of the engine on each side, and capable of containing 2,600 gallons. These tanks formed a strong framing, running the entire length of the engine, and supported the boiler. They were tied together by transverse frames under the boiler, which had attached to them what were termed the bogie pins. The strains of tension or compression were transmitted from one bogie pin to the other through the box girder tanks, without affecting or communicating with the boiler in any way whatever; thus the two bogie engines were made one, while they were at liberty to swivel or conform to any curve they might happen to be on. The fire-box was in the centre of the boiler, with two sets of tubes running in opposite directions, and there were three transverse water partitions to make the draught perfect. It was fed from the top, through a large steam dome, by four fire-hole doors, from which every part of the fire was accessible. The heat from the box acted as a superheater to the steam collected in the dome; the coal was disposed on each side of this dome, or by fire-holes in the sides, as now in use. The engine-man and stoker were housed under a hood, while the foot-plate on which they stood was common to both fire-boxes, a clear passage being open at all times from side to side of the engine. The engine could be started, stopped, or reversed at either side, and the breaks applied in the same manner. It was perfectly under the control of one driver and one fireman, although capable of exerting twice the power of the most powerful ordinary engines.

The single boiler duplex bogie engine was a great improvement over the engine with a tender, inasmuch as in the former everything carried was made available for adhesion. It differed from Mr. Sturrock's arrangement, inasmuch as the boiler, and the water and fuel bunkers were made part and parcel of each, by means of a strong framing running the entire length of the engine, with the bogie pins fastened thereto in the manner before described. This framing formed a cradle on which the boiler was placed. There were six coupled wheels forming the group on the bogie frame under the barrel of the boiler, driven by two cylinders of 18 inches diameter, with a length of stroke of 24 inches. The group under the water and fuel bunkers was composed in this case of four wheels, but six might also be used in a bogie frame. These bogies allowed any curve or reverse curve to be followed; and the centre line of the boiler frames, &c., formed the chord of an arc described by the bogies when placed on a curve. Precisely the same position was taken in the case of either engine, and it had this advantage, that the centre of gravity of the boiler and its accessories forming the chord passed nearer to the centre of the radius of any curve, by a distance equal to the versed sine, thus to a large extent overcoming the centrifugal force when the engine passed round curves at considerable

velocities. The ordinary type of engine when requiring the most trifling repairs had to be laid up, and another put in its place. This was not so with his system, because the engine was divided into four distinct parts, the boiler, the carrier frame, and the two bogie frames, which, while forming a whole, were complete and distinct within themselves, so that should one of the latter fail or require repairs, it was only necessary to unfasten six bolts and the steam pipe connections, remove the bogie and substitute another, all of which could be done without lowering the steam. This was a matter of grave importance, particularly in countries where skilled labour was difficult to be had, as described by Mr. Lloyd. His own experience, in the construction of a railway in Venezuela was, that skilled labour was the greatest difficulty he had to contend with, especially that of Englishmen, who seemed to forget their proper position the moment they left their own country. It was he believed a fact, that on the Great Western and London and the North Western Railways every engine at work was laid up for about two months out of each year for repairs. He claimed for his engine that the arrangement was simplicity itself, and he did not hesitate to assert, that it was impossible for any two engines coupled together in the ordinary way to do an equal amount of duty. The measure of a curve round which an engine would travel was the length of its wheel base. In the ordinary construction the wheels could not be placed so close together as in his engine, because the weight of the engine would be unequally distributed on the wheels. The effect on the permanent way of placing all the wheels under the barrel of the boiler was well known; each end overhanging the wheels, especially the fire-box and foot-plate, could be best likened to a loaded lever, which, when forced up and down by the oscillation of the engine and by the momentum, destroyed the rails. It was a well-known fact to those acquainted with the subject, that it was not the normal load upon the wheels of the locomotive which caused the destruction of the permanent way, but it was the extra weight of the superstructure caused by the momentum which gave the blows, as before described; this weight being borne on four, six, or eight points, went bounding from one point to the other, and it was these blows through the wheels, indicated by the rise and fall of the boiler, &c., on the springs, which destroyed the rails. He had hoped to have been able to bring forward the subject of his locomotives, with the statistics of their performances, in a more perfect manner, but he regretted he could not do so at present.

With respect to the performance of the engines of Mr. Fell and Mr. Woods, it would seem that, to carry a load of 77 tons, Mr. Woods required an engine weighing 57 tons, only 24 of which were effective for adhesion. The average load on the Chili Railway was only 57 tons, and the exceptional load 77 tons. Mr.

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Woods' engine had only about 38 per cent. of the total weight effective for adhesion, while, to contrast with this, Mr. Fell had, it was said, 200 per cent. effective adhesion—a difference which required explanation. He believed that an engine on his principle, weighing only 50 tons, with twelve wheels, or four less than in the Copiapo engine, all available for traction, would draw double the load up the same incline.

Mr. ABERNETHY thought justice had scarcely been done to Mr. Brunlees in bringing the Mont Cenis Railway forward at this juncture, because there were many difficulties to be overcome, which no doubt would be successfully surmounted. His attention was called to the Mont Cenis Railway some years ago, when he was constructing works in Italy. As to the possibility of engines working over the gradients of the Mont Cenis line, he was convinced that the mere question of traction had been completely solved. But the difficulties to be overcome were these:—There was a great depth of snow over Mont Cenis during the winter months. He understood it was the intention of the Engineer of this railway to construct covered ways, partly of wood and partly of a more solid character, at points where the road was exposed to avalanches; but he was convinced from his experience—having often crossed Mont Cenis during winter, and having been on one occasion detained on the summit thirty-six hours—that it would be necessary in regard to all Alpine passes, beyond a certain elevation, to form continuous covered ways, and that not of a slight character, as a provision against the great depth of snow, apart from the question of avalanches. He had recently crossed Mont Cenis, and could see but little of the railway from the great depth of snow. It then occurred to him, that neither by snow-ploughs nor by any other means, would it be possible to clear away and overcome a depth of from 10 feet to 15 feet of snow. The length of covered way required affected materially the question of economy of construction, as between a tunnel through the mountain and covered ways over the summit or snowy region. He thought the covered ways should begin at an elevation of about 5,000 feet above the level of the sea, and be provided continuously above that level. He repeated his conviction that, if this system was to be adopted, in mountain passes of this description above a certain elevation, there must be continuous covered ways; and, at those parts which were exposed to avalanches, tunnels of a thoroughly substantial character. He was, moreover, of opinion that the railway should be laid, as far as possible, on the inside of the public road, and not upon the outer edge of it, because, after the melting of great masses of snow, the outer edge was apt to be disturbed. From Lanslebourg to St. Michel the road was exposed to the action of violent torrents, and before the end of the winter a good deal of it might be destroyed.

It was advisable, therefore, in executing a railway of this character, to make it as independent as possible of the ordinary road. He had no doubt of the success of this railway as respected the question of traction simply.

Mr. J. A. LONGRIDGE said, the subject of the Paper was not upon the construction of the Mont Cenis or any other railway through the Alps, but upon the best way of working steep gradients, supposing they were absolutely necessary; and on that subject he would give the results of his experience. He had laid out a railway in the Mauritius some years ago, which was subsequently executed; and, though not worked by himself for passenger traffic, he had worked it for ballasting and for the transport of materials. The ruling gradient of that line was 1 in 27. The ballast-trains consisted of twenty wagons in fine weather, with an engine at the front and back, which he believed was a safe way of working these heavy gradients, because it rendered them, to a great extent, independent of the breaks. Each of these engines weighed 37 tons, and each truck-load weighed $13\frac{1}{2}$ tons, making a total load of 270 tons, besides the two engines weighing 74 tons. It was found that in fine weather, when the rails were dry, the inclines of 1 in 27 could be ascended, with wheels 3 feet 9 inches in diameter, at about 8 miles an hour; but when the rails were wet from rain or dew, the load had to be reduced by four, or six, or more trucks: the coefficient of friction, under these circumstances, came out as one-fifth. There could not be a doubt that it might be worked with a coefficient of from one-fourth to one-fifth; but it was not at all desirable that such a coefficient should be depended upon, because, on a dewy or damp morning, the train might come to a standstill. He believed, in any extreme gradient, particularly such as had to be dealt with in Alpine passes, the central rail system was the only one that could be depended upon. At the same time he did not entirely like the engine Mr. Fell had adopted; it was very complicated. He preferred to have two pairs of cylinders, one for working the horizontal, and the other for the vertical wheels; but further experience would settle that question. If he required an engine to work over long gradients of 1 in 12, or 1 in 14, he would depend entirely upon the horizontal wheels, and would make the whole of the other wheels simply bearing wheels, each wheel revolving on its own axle. He believed there would be an immense gain of tractive force if the wheels were not fixed to the axles. He had had lines under his notice on which, as a rule, the gradients were generally good, but with here and there a steep gradient for a distance of half or three-quarters of a mile; and where this had to be got over with a heavy load, there must be an engine sufficiently powerful to draw it. Under such circumstances, he thought it worthy of consideration, whether it would not be best

to have an eight-wheeled engine, having four driving-wheels, with a balance lever supported near the centre of gravity of the engine, and provided with a lever arrangement by which the springs could be screwed down when the engine was running, so as to throw the whole weight upon the driving-wheels when going up a gradient, and, when running on a level, distribute the weight over the whole of the eight wheels equally. Such an arrangement would obviate the use of sand in going up an incline; it would be simply necessary to screw down the springs, and throw the weight upon those springs while going up the gradient. In that case the steep gradients might be laid with heavy rails, and the light gradients with light rails. In this proposed engine, the axles of the driving-wheels would be placed within 5 or 6 feet of each other, while the leading and trailing axles would be fitted with Adams' radial axle-boxes; and such an engine could move with ease round curves of very small radii.

With respect to steel, he had been informed by a gentleman who had been for many years at the head of the working department of the Belgian railways, that his late experience with regard to steel was such, that he recommended the Minister of Public Works to go back to iron entirely. A great price had been paid for steel rails, but they were so inferior, owing to the competition amongst the manufacturers, that they could not be depended upon.

Mr. W. I. ELLIS observed, with reference to the more prominent subjects of the Paper, that it seemed necessary to point out that Mr. Fell's engine did not supply any recognized deficiency in the locomotives hitherto used on steep gradients in this country; it being, rather, a very creditable and ingenious adaptation of the locomotive to a particular purpose, in which the speed of the engine had been reduced to augment its tractive force; whereas it had been found that the weight of an engine, and more particularly of a tank engine, gave sufficient adhesion to resist the tendency to slip at speeds considered necessary on ordinary lines. In confirmation of this he might remark, that, the large engines used upon the Vale of Neath Railway in 1856 and 1857 were found to take as heavy a load, after being altered from tank engines into engines with a tender, as before the alteration. These engines weighed upwards of 50 tons, not equally distributed on the six wheels, and the alteration was made after the Company found that this excessive weight had caused great destruction to the permanent way. This also was altered from a longitudinal sleeper road with light bridge rails, into one with transverse sleepers, chairs, and heavy double-headed rails. The presumption was, that a weak permanent way was quite out of place on steep gradients and sharp curves, the rails being rapidly worn by slipping and by the action of the breaks. This wear might be aggravated when there was an excessive weight on any of the

wheels of the engines, but must in all cases be great where the traffic was heavy. He was of opinion that the English were much behind the French in the construction of engines for steep gradients. Some Engineers were reproducing designs which had been tried and abandoned on the Continent. By reducing the diameter of the engine-wheels to 3 feet 6 inches, the French had been enabled to reduce the height of the frames, on the top of which they had placed the boiler, instead of between them; and being thus able to extend it laterally over the wheels, they were practically independent of the width of the gauge of the railway, and had constructed engines with boilers of great size. The following were the principal dimensions of some tank engines, built by Gouin and Cie, for the Northern Railway of France in 1863. The engines were each on twelve wheels, arranged in one frame, with four outside cylinders, the wheels being coupled together, as in two separate six-wheel coupled engines. The diameter of the wheels was 3 feet 6 inches; the diameters of the cylinders, and the length of the stroke, were each $17\frac{5}{8}$ inches. The area of the fire-grate was 35 square feet, and of the heating surface 2,200 square feet. The length of the wheel base was 19 feet 8 inches. With this dimension it would be impossible to pass easily round sharp curves. There were also defects in the boiler which would cause a liability to prime, though it had been attempted to remedy this by the use of a large super-heater. There was also a deficiency of break power; the break blocks being limited, for an engine weighing about $67\frac{1}{2}$ tons, to four break blocks acting on the middle wheels, though twice as many could be used by applying them to the leading and trailing wheels. The conditions of economy in the steam-engine required that the functional parts should be as few and as large as possible; this was well carried out in the engine just described, but was lost sight of in some of the designs, lately put forward, of boilers with duplicate fire-boxes or barrels. In 1858 the Vulcan Foundry Company constructed for Mr. Cubitt some tank engines, with a wheel base of only 10 feet 5 inches, in which the diameter of the wheels was 4 feet, the diameter of the cylinders 16 inches, with a length of stroke of 24 inches, and the weight about 30 tons. The unusual shortness of the wheel base enabled these engines to travel with great ease round sharp curves on the Rhymney Railway, and on some other lines in the same neighbourhood, the Directors of which had been induced to adopt them by their success on that line. In 1864 two engines were built by the same firm for the Vale of Neath Railway, for which he had designed the boiler. The rings of the barrel were made of one plate, each jointed near the top of the boiler, and the longitudinal seams were designed to be covered by strips, or plates, riveted on, each ring breaking joint with the one next to it; but he was not aware whether these joint plates were applied exactly

as designed or not. The boilers worked at 150 lbs. pressure per square inch, and had fire-grates of $18\frac{3}{4}$ square feet area; a fire-box with a transverse midfeather; two hundred and fifty-one tubes, 2 inches outside diameter, and a total heating surface of 154 square feet; the cylinders were 18 inches in diameter, with a length of stroke of 2 feet; and with a 1,200 gallon tank, the engines were estimated to weigh 43 tons. Two other engines were built at the same time by Messrs. Slaughter, in which the same plan of boiler was adopted. The copper fire-box was put into the casing either from the top or the front, before the casing-plate was riveted in, by which means the fire-box could be widened out at the sides, so as to overhang the wheels, when they did not exceed 5 feet in diameter; and the usual number of tubes, about one hundred and eighty for a narrow-gauge engine, could be raised to two hundred and fifty-one, or even more, increasing the boiler power in proportion. The economical advantages of powerful engines were so great that, he believed, there was a desire to increase the power of the goods engines on the principal lines in the kingdom, and this appeared to him the most available plan for the purpose. The weight was divided as equally as possible on the six wheels, with a wheel-base of 15 feet 6 inches; and on these and the Rhymney engines the break was made to act on all the wheels. Messrs. Slaughter's engines had eight coupled wheels, with a wheel-base of about 14 feet 3 inches; and two similar engines, ordered, he believed, for goods traffic on the Metropolitan Railway, were at work in the goods station at King's Cross. As to adhesion, both the Vale of Neath and the Rhymney engines worked on a gradient of 1 in 47; and the load conveyed was equal to four and a half times the weight of the engine, beside the engine's own weight; and this load would correspond with an adhesion of one-eighth. He had received a letter from Mr. Bishop, the Locomotive Superintendent of the Vale of Neath Railway, in which it was said of the engines that weighed about 43 tons, "I never tested them as to the exact weight they would take up the Glyn Neath Incline (gradient 1 in 47 for 5 miles), but the ordinary load I allot them, when the traffic requires it, is 190 tons, net. This they take up at the rate of 7 to 8 miles an hour: with one of the eight-wheel coupled engines, the weight of which is 56 tons, when in trim to start with a train, I have taken up the same incline 300 tons, at the rate of $6\frac{1}{2}$ miles an hour. The ordinary load allotted to these is 230 tons. The adhesion in all these cases, with the exception of the 300-ton load with the eight-wheeled engines, is nearly one-sixth." The limit of weight on each pair of wheels (14 tons) having been reached in the Vale of Neath engines, and the length of the wheel base not allowing more wheels to be coupled together, and the limit of the power of the engine being its weight, to obtain more powerful engines the frame or carriage must be a jointed one,

if a tank engine be employed; or the tender wheels must be made available for adhesion, if a tender be used. This latter had not yet been done advantageously, but by the use of four cylinders taking steam from one large boiler, a tank engine might be made capable of passing round any main line curve, and possibly with a break acting on all its wheels, the relative economy of the engine increasing with its size. Continental Engineers had been beforehand in appreciating the true condition of a carriage passing round a curve. In this country it had been generally taken for granted, that an engine was impeded on a curve by the leading and trailing wheels on one side rubbing against the outer rail, and the driving-wheels on the other side against the inner rail; the fact being, as might easily be imagined, from the tendency of the wheels to run in a straight line, that one of the leading wheels was brought into contact with the outside rail, and the opposite trailing-wheel with the inside one; the middle wheels occupying an intermediate position, not touching the rail with the wheel flange on either side, thus showing the inutility of taking the flanges off the middle wheels as had been so frequently done. Great reliance had been placed on the coning of the wheels, for ease in passing round curves; but it was evident that this operated prejudicially in trailing-wheels, and was so slight, and the play between the wheels so small, that it was of little benefit in the leading wheels, being insufficient at the best, except when the tires were newly turned on small wheels running on curves of large radius. The gauge of rails on a curve should be widened until the play of the wheels between them was equal to twice the versed sine of the arc of which the longest wheel base was the chord; if not, extra resistance would be caused by the vehicle being jammed between the rails. Having been in the habit of timing the passage of trains round curves for some years, more particularly on one of 10 chains radius, he soon found that all trains were reduced very nearly to one uniform speed of about 15 miles an hour on that curve, and as (beyond these observations) he thought it would be admitted that a train might as safely run round a curve of half a mile radius at 60 miles an hour, as round a 10-chain curve at 15 miles an hour, it followed that a complete circle would in all cases be described in just the same time, irrespective of the length of the radius, provided the highest speed was in the capability of the engine. It further followed that, as the centrifugal force of a body varied as the square of the velocity and inversely as the radius or as the angular velocity, the greatest cant or elevation of the outside rail should be on curves of the longest radii; except that the cant might also be useful on sharp curves in throwing the engine in the direction the leading wheels should take. He believed that more accidents from running off had happened to express trains

on curves of large radii than on sharp ones, which might probably be thus accounted for. On the same 10-chain curve he had noticed circumstances which had led him to conclude, that the resistance to the passage of an ordinary six-wheeled engine was as great as on a gradient of 1 in 85. It was greatly to be desired that experiments to determine the resistances on curves should be undertaken; but he thought it would be found, that a six-wheeled coupled engine created double the resistance of an uncoupled one, and that in different carriages on the same curve the resistance would be in proportion to the square of the wheel base, and on curves of different radii inversely as the radius. This almost necessarily followed from the fact that, within any limits that could possibly occur on railway curves, the versed sine of an arc of a curve varied as the square of the chord and inversely as the radius; so that a reduction of the wheel base was the most effective method of diminishing the resistance. The minimum radius of curve round which a carriage could be run was proportional to the wheel base and the gauge of the rails, and should not be less than nine times the product of these two, if speed was any consideration, or the factor might be reduced to four times, if a slow speed were used; but in this case the resistance and the wear of the wheel flanges would be excessive. The means that had been adopted to facilitate the passage of long carriages round curves were all governed by the idea of placing some of the axles in a swivelling truck, or frame, so that they could take a radial direction on the curve—the system of having loose wheels having been abandoned on trial. Of these, the original plan was to have a bogie turning round a fixed centre; but the more modern plan of placing the real or supposed centre of swivelling much further back than the centre of the truck, as in Bissell's bogie and the radial axle boxes of Mr. Adams, was far superior, from the action being the same as if the carriage were divided into two separate and independent ones, and he mentioned this to point out that there was a position in which this centre might be placed when the bogie or radiating axles would take a radial direction, and the longitudinal centre line of the truck be a tangent to a curve of any radius whatever.

Mr. E. A. COWPER said, Mr. Woods had spoken of the adhesion of the wheels being sometimes as much as one-fourth on dry clean rails, and as the fact appeared to be doubted, whilst he knew it to be the case, Mr. Cowper had made a rough model with a stout iron wire, firmly bearing on a strong piece of wood to represent the rail, with a heavy weight bearing on a small surface on the rail, to represent the wheel.

The amount of adhesion of metal upon metal depended very much on the presence of a lubricator, but also much more than was commonly taken into account, on the weight per square inch on the

surfaces; for whilst surfaces such as 'bearings' would work well with about 700 lbs. per square inch, or even a little more, they were certain to squeeze out the lubricator, and cut, if anything like 10 tons per square inch came on them, as the two metals then came into absolute contact. The inclination at which the model was then fixed was 1 in 4, and the wire had been 'drawfiled' in the direction of its length, in order to have it perfectly dry and clean, and as nearly as possible in a like condition to the rails, say at the entrance to a station—the weight stood perfectly at that inclination of 1 in 4; and with great care he had made it stand at 1 in 3.

The rail was represented by a piece of wire $\frac{3}{16}$ ths of an inch in diameter, and the weight, composed of two railway chairs, rested upon a piece of wire on the wire rail, and so, to some extent, represented the condition of a line of railway, though the weight was far less per square inch than in the case of a railway wheel having 7 tons on it. The ordinary rail was rounded to a certain extent on the surface, while the tire of the wheel was rounded in the other direction; the two curved surfaces coming into contact, mathematically speaking, only touched at a point; but it was well known that the ultimate crushing resistance of iron was such that it could not by any possibility bear the whole of that weight on a point. However, supposing the place of contact was something like a quarter of an inch square, or one-sixteenth of a square inch, and that there were 7 tons on the wheel, that would amount to 112 tons per square inch, and with such a weight, without lubrication, the surfaces would cut or tear if there was any motion between them. So in the case of the model, the pieces of wire touched only on a very small surface, and the weight of the two chairs, giving probably about 10 tons per square inch, was sufficient to make the surface cut, and enabled them to stand at that steep inclination of 1 in 4—whether the surfaces were fresh, or whether the weight had been forcibly slid up and down the incline several times. This showed that an engine would go up an incline of 1 in 4. He thought the model was as nearly as possible in the condition of a rail when the wheels had been slipping. On a line where the wheels were commonly stopped and slipped on entering the stations, they acted as sledges on the rails, and they tore the surface of the rails. That was the condition of the metal on this model, as it had been smoothly drawfiled in the direction of its length; the wire was cutting more or less; but the least amount of grease made the weight slip down.

From the average of a large number of experiments, carefully conducted by different persons who had used the model for the purpose, it was found that with a dry and clean rail it required the utmost care to succeed in removing all grease, the rail not only

requiring to be first wiped perfectly clean, but to be afterwards filed up with a fresh clean file free from all grease, or the experiment would be entirely fallacious. The results of the experiments were given in the following Table, the exact condition of the rail being stated in each case.

EXPERIMENTS ON ADHESION,

With a pressure of about 10 tons per square inch.

Surfaces burnished and greased with tallow	1 in 9 $\frac{1}{2}$
Surfaces drawfiled and greased with tallow (after some wear)	1 in 9
Surfaces fresh drawfiled and greased	1 in 8
Surfaces burnished and wetted with water	1 in 5
Surfaces burnished and dry	1 in 4
Surfaces drawfiled and dry	1 in 3

Mr. R. P. BRERETON remarked, that it had been assumed by several speakers, that adhesion to the extent of one-fourth was quite possible under certain conditions. It appeared to him that if such were the case no engines in use in this country would be able to avail themselves of it. He had made experiments on inclines on a broad-gauge line, in order to see what inclination could be surmounted, by one of the heavy broad-gauge goods engines that had been constantly taking a load of 200 tons up an incline of something over 1 in 40. The engine ascended 1 in 17 $\frac{1}{2}$, 1 in 15, and 1 in 12, which he found was the limit; it invariably stuck fast beyond that gradient. This arose not from want of adhesion, but from want of power in the engine to do any more. At particular points when it stuck fast, he had no doubt there was an amount of adhesion of 1 in 8·8, but then there was only one cylinder at work and available to start with. He had never seen an instance of want of adhesion at that gradient, as the engine always worked its way up assisted by a rope: if the adhesion had been less he presumed the wheels would have skidded. Mr. Fell did this by some nipping apparatus with small radius of the wheel as compared with the cylinder and crank. Anything of nipping on a running rail would be very small indeed with engines in ordinary use in this country, and but small effect would be got from it. Much of the increased resistance, frequently met with at sharp curves, did not really arise from anything in the curves themselves, but was due to a considerable steepening of the gradient at the commencement of a curve, brought about by the raising of the outer rail. This was sometimes done on a broad-gauge line to the extent of 6, 8, or 10 inches, in a length of a chain or thereabouts, adding a gradient of 1 in 80 or 1 in 100 for one half the weight of the engine and train to be taken up, in addition to the general gradient of the railway. Assuming an engine to be just doing its work with a heavy train on a steep gradient, the above addition was severely felt, and might perhaps have been attributed entirely to resistance offered by the curve, particularly as it

appeared to be so both at the commencement and at the termination of the curve in ascending as well as descending. In the former case, on entering the curve from the straight line, there was the direct increased resistance of the gradient, and on leaving the curve the diminished resistance due to a corresponding flattening. In the latter case, in descending, on entering the curve increased resistance was offered by the flattened gradient, and on leaving diminished resistance was felt upon the steepened portion. The pressure of steam in the case where the engine would not go up a gradient of 1 in 12 was 120 lbs. to the inch without any load; but that was not maintained long after starting.

Mr. WM. LYSTER HOLT observed, through the Secretary, that the defects in the construction of Mr. Fairlie's engine had long since been remedied, and that instead of being complete failures they were a great success, and combined all the "good" qualities of bogie and twin engines without any of their bad points. It was true that at first the draught in the fire-box was baffled, and consequently steam could not be maintained on the banks with heavy loads; but this arose from the fire-box being constructed without a transverse water partition in the centre, as originally intended by the inventor. Since the fire-box had been divided transversely by a temporary brick partition the draught was perfect. There was an abundance of steam, and the result was so satisfactory, that these engines already burnt 10 per cent. less fuel than those of the ordinary type with equal loads over the same road. When the water partitions which were being made were completed, it was believed that a saving could be effected of at least 20 per cent. of fuel per H.P. exerted over the engines in general use. It was true also that one method of the many that could be applied for conveying steam from the smoke-box to the cylinders, failed from insufficient elasticity in the single coil copper pipe used for that purpose. But this occurred when the engine was working over a temporary road of $2\frac{1}{2}$ chains radius on a gradient of 1 in 30. In an engine fitted with an improved construction of steam pipes, there had not been the slightest difficulty, and the swivelling motion of the bogies did not affect them in the least. This engine, having four cylinders 10 inches in diameter with a length of stroke of 16 inches, eight wheels 4 feet in diameter coupled in sets of four, and with the boiler pressure at 120 lbs. per square inch, constantly took loads of 100 tons up gradients of 1 in 50, having numerous S curves of small radius, while it had hauled as much as 130 tons over the same road. No other kind of engine would, he thought, under the same conditions, and with the same tractive force at the rails, draw an equal load. These engines possessed many advantages which rendered them especially fit for working on steep gradients and curves, as they passed round sharp curves with great facility, and with remarkable

steadiness and perfect safety, even at high speeds. The wear of the permanent way and tires was reduced to a minimum. The whole weight was available for adhesion, and this weight was distributed equally over all the wheels. The peculiar form of the engine admitted of the use of a boiler of almost unlimited size, and therefore large quantities of steam could be generated. An increased tractive force could be obtained by four cylinders, and these afforded greater facilities for working expansively than two cylinders, and being smaller were more easily attached to the frames; while the power of the engine being divided into four, the strains and jerks would not be so violent on any particular part of the machine. Two men had perfect control over the engine, of which the motion was not more complicated than that of ordinary engines. It was very accessible for repairs, the bogies being easily removed from under the boiler barrels in a few minutes, and the expenditure of fuel was small.

Mr. BRAMWELL begged permission to offer a few words in explanation of what he had previously said. He was sorry to find he had unintentionally misquoted Mr. Naylor's observations. Mr. Naylor informed him that, in speaking of the increased retardation on curves caused by the slip due to the difference of length of the inner and the outer rail, he only took half the weight of the engine as being influenced by the slip, instead of the whole weight. He was under the impression that Mr. Naylor had taken the whole weight. So far, therefore, as his remarks on Mr. Naylor's observations referred to the whole weight having been taken with the slip, he wished those remarks to be considered as withdrawn.

Mr. PHIPPS called attention to a formula expressing the resistance due to curves generally. This he hoped would usefully supplement the particular demonstrations which Mr. Bramwell had given. He would endeavour to show, as briefly as possible, what were the circumstances attending the development of resistance upon curves, and in what manner this general formula was arrived at.

In the passage of a train round a curve there were, when the axles of the carriages were parallel and the wheels cylindrical, two principal sources of resistance. One, which might be called the radial resistance, arose from the tendency of the wheels to travel along the same straight line on which they were originally placed, which line being the chord of an arc of the curve, any progress along it would cause the wheels to leave the rails, and therefore also to be more remote from the centre of the curve. The relation of the above distance to the distance travelled forwards by the train in any given small portion of time, taking the former distance into the total weight, and again into the proper coefficient for

adhesion on the rails, would give the resistance due to the foregoing. The second, which might be called the tangential resistance, was to be found in the excess of the average distance travelled over by the outer wheels, and the shorter distance gone over by the inner wheels. The formula was founded upon the consideration that the distance moved radially was to that moved over by the train, in any short space of time, in the ratio of the wheel base to the diameter of the curve. The tangential distance was in the ratio of half the gauge of the line to the radius of the curve, or, what was the same thing, in the ratio of the gauge to the diameter. The motion radially being thus as the wheel base, and tangentially as the gauge, these two being at right angles, the hypotenuse would be the actual distance rubbed over in the given time. The formula would then be as follows:—

Resistance of Curves.

- Let a = gauge of railway.
 „ b = wheel base.
 „ c = ratio of adhesion to weight of train.
 „ D = diameter of curve.
 „ W = weight of train.
 „ R = resistance of curve.

Then, 1st, where the axles were parallel and the wheels cylindrical,

$$R = \frac{W}{D} \sqrt{a^2 + b^2} \times c.$$

2nd, where the axles radiated, and the wheels were cylindrical,

$$R = W c \frac{a}{D}.$$

In both the above cases the effect of the centrifugal force was neglected, as the object of the formula was chiefly in its application to sharp curves when the motion was slow and the centripetal force of the engine's traction balanced very nearly the centrifugal force.

Mr. ROBERT TREFUSIS MALLET referred to a tramway constructed for Mr. Crampton on the Ottoman Railway on which he had been engaged, which he believed showed the extreme limit of what could be done on inclines by ordinary locomotives without special means of adhesion being applied, as in the case of the central rail on the Mont Cenis line. There was a gradient of 1 in 11 with curves of 500 feet radius. One difficulty was experienced in consequence of the extreme severity of the gradient; that was, the necessity of turning the engines at the summit, to avoid laying the fire-box bare by the gravitation of the water to the lower end. The engines could only pull one loaded wagon up this incline. The results were not brought forward as an instance of the greatest economy that might be obtained by using special engines, but rather to show what could be done with existing

plant. He presented to the Institution diagrams showing the section of the tramway and the statistics of the engines used.

Mr. T. R. CRAMPTON said there was nothing peculiar about the incline just referred to, but it had acted most perfectly. The gradient was 1 in 11 for a length of 2,400 feet, 600 feet of which had curves of 400 feet radius, descending about the same distance with inclines of 1 in 15 and 1 in 20, the total length being about one mile. About 100 tons per day were taken over this gradient of 1 in 11, and about 10,000 tons had been carried over the whole length up to the present time. The gross load was about 23 tons, of which the engine weighed 10 tons, leaving 13 tons of working load behind the engine. The adhesion was about one-fifth, so that the maximum was almost attained.

Mr. E. A. DREW remarked that the cost of working over the whole of these inclines—that was up half a mile of 1 in 11, and down half a mile of an average gradient of about 1 in 15, over which the loads and return empties were transported—was at the rate of two shillings per ton per mile. That tramway was successful, inasmuch as it served the end intended, by transporting, during the six months it was in operation, about 10,000 tons of material, which could not possibly have been carried by any other means so economically. Taking into consideration the price of coals there, and the difference in the wages of skilled labour, it was probable the same end under similar circumstances could have been achieved in England at half the cost. The engine was not made specially for this incline, but was an ordinary contractor's tank engine, built by Mr. Hughes, of Loughborough, the principal dimensions of which were—

Diameter of cylinders	11 inches.
Length of stroke	18 ”
Diameter of wheels	30 ”
Wheel base	54 ”
Four wheels coupled.	

The weight of the engine complete was 10 tons.

With a pressure of steam of 90 lbs. to 100 lbs. per square inch, the gross weight taken up the incline of 1 in 11 was 23 tons, including the engine.

Mr. HAWKSHAW, Past President, thought Mr. Drew was under a mistake with reference to the cost of working these inclines. It showed how frequently mistakes were made in dealing with estimates. He could imagine a ton of goods costing two shillings for half a mile or a mile, if the engine used had to be kept in steam all day and only employed occasionally to take up a load of goods; but it could not cost two shillings to take an engine up 800 yards of

incline of 1 in 11. In some cases, no doubt the effect of steep gradients might be to increase very greatly the cost of transit. If they occurred, for instance, on a coal line, where large loads could otherwise be taken, the intervention of these inclines would be objectionable. In other cases where frequent loads of moderate weight were dealt with, steep gradients did not increase the cost in the same ratio. Therefore, unless the nature and amount of the traffic, the frequency of the trains, and the necessity for frequent trains, were known, but little could be made of these questions of cost. Taking the railways of this country generally, they varied greatly in gradients. On one railway, the Lancashire and Yorkshire, for instance, which had steep gradients almost throughout, it would be found carrying at a certain amount of profit and working at a certain percentage of cost. On another line with good gradients, such as the North Eastern or the Great Western, it would be found that the percentage of expenses and the amount of profit did not greatly differ from that in the other case. That merely showed, having regard to average loads, gradients had not that effect generally which obtained in special cases where they had only great loads to carry. The question of steep gradients was much discussed twenty years ago, and it seemed to be raised now as if it were new. He could give a little information with regard to some steep gradients which had been worked for many years with the heaviest traffic perhaps in the kingdom. Some of the statements put forward as doubtful, or remaining to be proved, had been satisfactorily proved by long experience. Between Manchester and Oldham, for instance, the traffic was enormous. That railway consisted of gradients beginning with 1 in 59, 1 in 49, and varying from that to 1 in 124 till it approached Oldham, where the gradient rose to 1 in 30 and 1 in 27. Inclines of 1 in 30, or 1 in 40, at the time that railway was made, were considered unsuitable for locomotives, and those inclines were accordingly fitted with apparatus to get rid of the difficulty. He had occasion to remove that apparatus, and since that period locomotives alone were relied on, and from that day to this the traffic had been worked satisfactorily. The locomotives were nothing very unusual: they were of the sort commonly used on the Lancashire and Yorkshire line, and their performances were as follows:—The engines for ordinary trains had six wheels coupled, and weighed 29 tons each exclusive of the tender; they ordinarily took a load of 80 tons, exclusive of engine and tender, to Oldham; but in slippery weather 15 or 20 tons less. Another class of engine used for heavier trains had also six wheels coupled, weighed 33 tons 13 cwt. exclusive of tender, while both together weighed 49 tons. These took up a load of about 120 tons exclusive of their own weight; and in slippery weather about 20 tons less. These classes of engines had

been working for many years; and for such traffic it was clearly not worth while for the company to lay out a large sum of money to get rid of those gradients. The question as to how far extreme gradients might be pushed, was one that could not be solved unless all the details were known of the nature and extent of the traffic; but it was quite clear that for a traffic like that between Manchester and Oldham the gradients he had mentioned were worked without difficulty. On some other parts of the line there were gradients of 1 in 44, 1 in 50, &c., and several of the important towns on the line were approached by such inclinations, while the traffic was second to none in the kingdom in magnitude; and yet the average working expenses were not greater than on other lines which had not these heavy gradients. But, in reference to the question of expense, he did not wish to be understood to say, that gradients of 1 in 27, or 1 in 30, were good, and to be adopted lightly, or that there might not be cases in which it would be better to lay out a large sum to get easier gradients.

With regard to engines, he might mention that some were now being constructed under his direction for the Mauritius Railways, which had eight wheels coupled, and weighed 47 tons exclusive of tender, by which he got the whole adhesion due to that weight. The total wheel base of these engines was only 15 feet 6 inches. He expected they would work well on gradients of 1 in 27. The radii of some of the curves were 1,000 feet.

MR. CRAMPTON, in explanation, stated that the total distance run at the expense of two shillings per ton was two miles—viz., from the commencement of the gradient of 1 in 11 to the end of that of 1 in 20, including the return empty. He agreed that it was useless to give any particular expense of working, unless all the circumstances of the traffic were at the same time taken into consideration. It might be assumed that this incline could be worked for an expense of something like 40s. per day for haulage at the outside, and carry 100 tons. He was not aware of 1 in 11 having been worked so successfully on any previous occasion with an ordinary engine. The climate was good. The cost of working such an incline could be calculated to a certainty according to the circumstances of the case. He had decided to use this incline, as no other means presented itself which would enable the material to be carried over the mountain to complete the railway in the time required.

MR. G. R. STEPHENSON said, about twenty-five years ago, when the Oldham branch of the Lancashire and Yorkshire Railway was being made, he had the management of the designs for that work under the late Mr. George Stephenson and Mr. Gooch. As Mr. Hawkshaw had stated that he had to alter certain works that were executed,

it was only just to the memory of those who originally carried them out that he should explain the cause of the alteration. The Oldham branch was made at a comparatively early period of the locomotive engine, which was not then so well understood as now, and when it was attempted to serve by branches the traffic of towns lying at some miles distance from the main line. It was at that time considered that the Oldham branch would form the terminus of the line in that direction, and therefore it was thought expedient to use the most economical plan of working the incline, which amounted to 1 in 27, and that of the rope was considered to be so, as well as the most simple. The plan of working was this:—on the arrival of the train at this part of the incline, it was pulled up by a rope round a large pulley at the top of the incline, balanced at the top by the weight of trucks and engine attached, which assisted the ascending train; and the consequence was the incline was worked with great economy, great regularity, and with perfect success. But the time came when the public traffic demanded that the line should be carried beyond Oldham, and, therefore, it was evident that the rope system combined with the locomotive would be expensive as well as fraught with peril. When the line was extended, it was found as a matter of course that it could not be worked successfully with a mixture of the rope and locomotive systems, and the former was consequently abandoned at a period when fifteen or twenty years' experience in the improvement of the locomotive had made it capable of doing that which it was formerly unable to accomplish.

Mr. JOHN CLARK thought that the retarding force to the passage of railway vehicles round sharp curves arose from two causes;—first, from the unequal lengths of the outer and inner rails; and secondly, from the change in the position of the train. The action of these causes of retardation had been illustrated, during the discussion, by comparison with the action of the screw, but he thought the comparison did not hold. He considered the retarding effect was equal to the friction due to the weight of the vehicles when moved, as on a metal base plate, to their altered position. He had introduced a system of construction applicable to railway vehicles, which permitted all the axles of each vehicle approximately to radiate to the centre of curvature of the rails. This mode of construction had been applied by Mr. Edward Woods upon a South American railway to a considerable number of wagons and carriages, and had worked satisfactorily for the last eighteen months. These vehicles had six wheels; the two endmost axles were free to turn in the horizontal plane about the centres of their length, so as to permit their movement into positions normal to the curve of the rails. This was effected by the pressure of the inner rail against the flange of the inner wheel upon the central axle, which was free

to move endways parallel to itself. The amount of this endlong movement of the central axle was always equal to the versed sine of the circular arc whose chord was equal to the wheel base of the vehicle. A system of linkwork connected the axle-boxes of the central axle with those of the two outer axles, and it was so adjusted that the endlong movement of the central axle imparted, through the linkwork, a motion to the axle-boxes of the outer axles, which placed their centre lines approximately normal to the curve. The vehicles were adjusted to pass round curves as sharp as 60 feet radius. The length of the wheel base in these wagons was 12 feet, but there was no reason why a much longer wheel base should not be adopted. Some vehicles designed by Sir Charles Fox and Son for the Queensland Railways, upon this system, had a wheel base of 30 feet, the length of the vehicle being 48 feet, the gauge of the railway 3 feet 6 inches, and the sharpest curve 5 chains radius. In a mile of continuous curve of 5 chains radius, on the ordinary gauge, the length of the outer rail exceeded that of the inner rail by about 80 feet, and he considered that, if the axles radiated to the centre of the curve, the usual 'coning' of the wheel tires made up for about 60 feet of this slip; on a curve of $7\frac{1}{2}$ chains radius they were nearly equal. But unless the axles radiated, he thought that the 'coning' of the wheel tires provided no compensation for the excess of length of the outer rail.

Sir CHARLES FOX, in referring to the observations made by Mr. Hawkshaw, said a few months ago he went to Oldham to inspect the incline plane of 1 in 27, on the Lancashire and Yorkshire Railway Company's branch to that town, and was not a little surprised at the admirable manner in which the ascent of that incline was performed by the locomotive. There was one point which caused him some amusement, if not instruction. On that occasion he asked the enginemmen whether, in going up the incline, they ever had such a train load as to be beyond the power of the steam in the engine. They replied that such was the case occasionally, and in that event they put on the breaks, and waited till the steam got up sufficiently to enable them to walk up to the top of the incline. They added that they never had to run back with their trains. The boilers of their engines being strong and good, they had great confidence in them, and so they waited on the incline till there was sufficient pressure of steam attained to take them up.

The other subject he would refer to was to the opinion expressed by Mr. Hemans, as to the inapplicability of the atmospheric system to steep inclines; but he did not understand that gentleman to apply the same remark to the pneumatic system. He looked upon the atmospheric system as having failed from several causes, two of the most serious being the following:—

First of all, there was extreme mechanical difficulty in keeping the long valve in good order, so as to be air-tight; and secondly, the evolution of heat that took place in the air-pumps, from the air exhausted from the tube being rarefied, and having its capacity for caloric thereby increased, made them so hot, as to prove a serious obstruction to their proper lubrication. If ever there was a good opportunity of making experiments on the amount of latent heat in air of different densities, that was certainly one of them. Sir Charles Fox looked upon the pneumatic system as perhaps the best that could in many cases be adopted for steep inclines; as in that case no locomotive would be employed, and the power required for lifting it from the bottom to the top of the incline would be saved; and as, by having recourse to this means of traction or repulsion, carriages of a much lighter character than those at present in use on railways might be adopted, obtaining thereby a far more favourable proportion between the dead and living load than now existed. As no power would be expended upon the air in the tube except at starting, and in overcoming its small friction against the sides of the tube when in motion, he considered that this system would be worked with economy, and certainly with safety. In working a railway by the atmospheric system, it was often found necessary to use a vacuum which was represented by a column of 15 feet of water, or about 15 inches of mercury; but on the pneumatic system, an experiment made on the line at the Crystal Palace showed that a dead weight of 30 tons could be taken from a state of rest, up an incline of 1 in 15, at the rate of 12 miles an hour, with a vacuum which did not represent more than a column of water of 6 inches or 8 inches, which was only one-thirtieth, or one twenty-second part of what was found necessary in working the atmospheric system. Looking at it as a whole, he believed the pneumatic system was the one best adapted for surmounting the heavy gradients which were necessary in crossing Alpine passes, &c.

Mr. G. W. HEMANS quite concurred in the opinion that the pneumatic principle was most worthy of consideration for the working of these inclined planes, and that the atmospheric system was utterly unsuitable.

Mr. J. W. GROVER remarked that, though his practical experience in working gradients did not extend beyond those of 1 in 45, yet he had reflected upon the subject a good deal. If it was wanted to get as much friction as possible out of a certain weight, whatever it might be, and the weight were resolved into two forces, each acting at an angle of 60° with the vertical, the pressure on any substance at right angles to them by each of these forces would be equal to the weight; and with both, of course, they would produce the effect of doubling the weight. This result would be effected by

V grooves in the driving-wheel. The same point had occurred to other Engineers fifteen or twenty years ago, but no one had ever tried the thing in practice, and he brought it before the Institution now, in the hope that some gentleman possessed of an engine might be induced to make the trial, by turning up the tires in the way he had pointed out. The grooves were cut V-shaped; and if a roundheaded rail were used, the principle of the wedge would come into operation by the two bearing surfaces on the rail; and if the angle of the groove were 60° , double the effect of the weight of the locomotive would be obtained without actually increasing the weight of it at all. Mr. Grover illustrated his views by reference to a model, in which three equally weighted discs of wood represented wheels with the ordinary concave form, and V grooves cut at different angles; a moveable strip of wood, with a rounded upper edge, represented the rail, and was raised or lowered to show various gradients; the wheels being placed upon the rail, and prevented from turning on their axles by means of keys, the rail was gradually raised at one end, until it assumed such a slope as to make the disc slide down it, thereby representing relatively the gradient that the respective wheels would climb. By this it was shown that, whereas the ordinary form of wheel in wood would slide on a gradient of 1 in $7\frac{1}{2}$, the V groove of 90° would just move on 1 in 6, and the V groove of 60° on 1 in 4. Several patents had been taken out involving this principle, but nothing practical appeared to have been done.

Captain TYLER, in reply upon the discussion, said, in the first place, he had referred at the commencement of his Paper to the system brought forward by Mr. Grover. He had said:—"Grooved wheels afford obviously increased bite; but there must be, when they are used for locomotive purposes, continual abrasion from unequal travel of the surfaces in contact, with increased friction on curves, and some loss of power, in proportion to the increased bite obtained, from what may be termed back-adhesion." He thought he had described fully, though briefly, in that sentence, the real difficulties in the way of the application of that system.

The most important question of all was, perhaps, that of the coefficient of adhesion. He understood Mr. Conybeare to say that it was independent of climate; but he thought the widely varying opinions which had been expressed showed very clearly that the contrary was the case,—viz., that the value of that coefficient varied, as might be expected, to a great extent in different climates; and he thought that such variations from climate afforded the only explanation by which to account for the wide differences of opinion that had been expressed. Mr. Cowper had produced an ingeniously simple instrument for testing the adhesion

to some extent of iron upon iron; but he had adopted, in the experiment before the Institution, the process of filing the rails. He had taken the opportunity of making some experiments privately with this apparatus; and he found he could not get the "rolling load" to stand at all on an inclination of 1 in 4 till he took a file in his hand and used it pretty freely. He had cleaned the grease off, but until he used the file he could not make it stand at 1 to 4; and he observed that Mr. Cowper had also used the file before he could make his moving load stand on that gradient. It was quite clear that it could not be expected, in practice, to file wheels and rails before going up an incline, and to keep them filed for the purposes of railway traffic.

On the Mont Cenis there were greater difficulties, in one respect, than were met with under ordinary circumstances in other places. It would hardly be supposed that the item of dust would, at or near the summit of Alpine ranges, materially affect the question of adhesion; but the fact was, that the fine dust which was blown from the road upon the line in dry summer weather was of a most slippery description. It was the dust of the schistose rock with which the roads were mended, and when it was wetted it caused the rails to be in a worse condition sometimes in summer than they were from the snow on a winter's day. When the snow was swept off the rails in winter, it left them clean and dry, so as to yield an adhesion of one-sixth; whereas this dust, combined with moisture, reduced the adhesion to one-eighth. But, whatever the exact coefficient under different circumstances, it was clearly important, on this extreme gradient, to allow a greater margin for adhesion than on more moderate gradients.

He would, in the next place, advert to the Navigation incline, to which he had alluded in his remarks following the reading of the Paper. Mr. Naylor had brought forward some figures stated to have been received from the Locomotive Superintendent of the Taff Vale Railway Company, which did not quite agree with those he had produced from Mr. Fisher, the Engineer of that Company. He had read, from Mr. Fisher's note, that the two engines, with six wheels coupled, which worked that incline, weighed when loaded 36 tons; and that the maximum load of each, on an average gradient of 1 in 20 for half a mile, was 40 tons, and the regulated load 25 tons; and he had stated that the coefficient of adhesion which had been calculated upon in the latter case was about one-tenth. Mr. Naylor said he had received a higher regulated load, and different figures in other particulars. Captain Tyler had written again to Mr. Fisher, who had also communicated with the Locomotive Superintendent, Mr. Tomlinson. From this correspondence it appeared, that the regulated load of 40 tons, referred to by Mr. Naylor, had, after a mishap, been reduced by Mr. Fisher to 25 tons; though it would also appear, from Mr. Tomlinson's statement, that the men had not

of late worked in practice to a load so low as their instructions required.

So much, then, with regard to gradients which had been worked by a locomotive for passenger traffic in this country. The gradients which had mostly been referred to varied from 1 in 27 to 1 in 40, and 1 in 50; but these gradients could hardly be compared with that mentioned by Mr. Crampton, of 1 in 11, with those which had been temporarily used in America, or with those on the Mont Cenis Railway.

In speaking of certain railways in South America, Mr. Lloyd had expressed the opinion, that it would rarely be necessary to employ a steeper gradient than 1 in 20 in crossing mountain ranges. He supposed Mr. Lloyd applied that remark to the Alps, as well as to other mountains. But it was not, in practice, so much a question of what could be done if money were no great object. The question was, rather, whether, having a certain height to surmount, it was better worth while to go to the greater expense of making gradients of even 1 in 20 for longer distances, or whether it was not more advantageous to make a shorter line with steeper gradients, at a greatly reduced cost. Whatever might be the ruling gradient—1 in 20, or 1 in 12—the same height would in such a case have to be overcome, and the same depth to be descended again; and when, by constructing a shorter line at a cheaper rate, with gradients of 1 in 12, the journey could at less speed be made in as short a time, he did not see why it should not be done. He would demonstrate his meaning by the aid of some figures, showing the relative cost of certain lines with different gradients and curves on some others of the Alpine passes.

For the passage of the Simplon, with gradients of 1 in 25, and curves of 200 mètres radius, the estimated cost for 255 kilomètres, from Bouveret to Arona, was 156,410,000 francs; while for the same pass, with gradients of 1 in 16, and curves of 150 mètres radius, the estimated cost was only 130,410,000 francs; and with gradients of 1 in 12, and curves of 40 mètres radius, the cost of a line, laid on a portion of the public road where available, was estimated at only 65,000,000 francs.

For the Lukmanier Pass, from Coire to Bellinzona, with gradients of 1 in 40, and curves of 300 mètres radius, the tunnel line, 116½ kilomètres long, was estimated to cost 223,282,108 francs; while in the case of a summit line for the same pass, without any public road on which to lay it, and therefore with all new works,—with gradients of 1 in 20, and curves of 150 mètres radius,—the cost for a length of 145 kilomètres was estimated by the same Engineer at 53,749,954 francs.

Much of the discussion had related to the effect of curves, and to the reasons why engines and trains did not travel round them so

easily when the curves were sharp; but those remarks had not been accompanied by any good practical suggestions for getting over the difficulty. Mr. Fell had done so to some extent on the Mont Cenis experimental line, by flattening the gradient on the curves; and the question was asked, to what extent this had been carried out. Mr. Fell had so far altered his original section that, on very sharp curves, he relaxed the gradient from, say, 1 in 13, to 1 in 15, or $15\frac{1}{2}$, at the same time that he increased the gradient on the straighter portions to about 1 in 12: he then found that his engine gained speed on the curves, and that, in fact, he had done rather too much. But the circumstances of this case differed materially from those which were ordinarily met with. The various vehicles—of short wheel-base—travelled with extra ease round the curves of this line, because the horizontal guide-wheels of the wagons and the horizontal wheels of the engine, acting upon the central rail, tended to keep them in their proper positions on the curves, and to prevent some of the prejudicial action from coming into play. When very sharp curves were used—and he believed they must be used more and more—it was thought necessary, under the prevailing system, to employ engines of short wheel-base, and that necessitated overhanging weights in front of the leading and behind the trailing-wheels, and led to the use of an objectionable kind of engine. And there were other objectionable things, to which he would take the opportunity of referring. The weight on the driving-wheels was frequently so enormous, that it became a matter of difficulty alike with the Engineers who had to construct, and with those who had to maintain a railway. He thought it was time some decision was come to as to the limit of weight that should be placed upon each pair of wheels. He was afraid, now that steel tires were so extensively used, those weights would be greater than ever. Locomotive constructors had hitherto been checked by the tendency of wrought iron to be crushed. There was a risk of squeezing the tires out when they were loaded beyond a certain point; but now that steel tires had come into common use, he feared the weights on the driving-wheels would be further increased, and that still heavier tank-engines, with overhanging ends, would inflict greater strains on the bridges and the permanent way.

He thought Mr. Conybeare had been rather hard upon Mr. Fairlie's engine, the principles of which tended to remedy the evils he spoke of. The system of employing a double engine, placed upon two bogie frames, could not be regarded as novel, for it was applied to every railway car in America, and by that means they went round curves, and over inferior descriptions of permanent way, better than they would otherwise do and with far greater safety. Mr. Fairlie further connected two boilers together upon one frame. The dif-

ference between this application and that employed on the Giovi incline was very great. Mr. Fairlie fastened the boilers together at the ends and worked them as a rigid mass upon moveable bogies, while on the Giovi the two tank engines were run fire-box to fire-box with separate boilers and framing. He would not assert that Mr. Fairlie's system was the best that could be devised, but it possessed an advantage on curves in drawing from the bogie frame instead of from the framing of the engine, and it was well worthy of consideration and further experiment. M. Thouvenot was endeavouring to get a similar system adopted on the Continent; and had prepared for the Paris Exhibition the diagram of an engine on this principle, added to the system of Mr. Fell. M. Lömmel, the Engineer of the Lukmanier Railway, proposed to adopt such a combination on that line; and it appeared, therefore, that this form of engine was likely to have a fair trial on the Continent, as he hoped it might also have in this country. The defect of the leakage of the steam pipe would no doubt be overcome by special arrangements, and the difficulty of equalizing the draught up the two funnels, either by the mid-feathers which were to be placed between the fire-boxes, or by separating the fire-boxes completely from one another.

He would now say a few words with regard to the atmospheric and pneumatic systems as applicable to the working of steep gradients. He had not intended to refer in the Paper to the old atmospheric principle, which he had looked upon as a thing of the past; and he was surprised to find that Mr. Pole and Mr. Margary still thought it should not be abandoned. Sir Charles Fox was evidently of opinion, as he believed others were also, that the pneumatic system was applicable to very steep gradients; and he had said that in applying it to steep gradients, there was nothing to overcome except the dead weight of the train itself. He did not suppose, however, that Sir Charles Fox meant that the air did not weigh something. With the central rail an engine of 16 or 20 tons had to be taken up the incline and to be got down again. Some said that was a wrong principle; but whatever was used there must be weight of some kind, whether in a rope of air or a rope of wire; and in point of fact the weight of air was very considerable. For instance, the weight of air in a tube one mile long with a sectional area of 60 feet—which was a small one for the pneumatic system—would be ten tons; and the weight of air in a tube three miles long would be 30¹ tons,—a greater weight to set in motion than the locomotive itself. Allowance must also be

¹ These being the weights of the air *in vacuo*, the actual weight of air to be drawn up an incline would be computed in proportion to the excess of pressure inside the tube over that of the atmosphere.—H. W. T.

made for the pressure of the air in the tube, which would be higher than that of the atmosphere.

Several questions had been asked with regard to the snow. This would have to be provided against, on the Mont Cenis Railway, in the case of avalanches, drift snow, and fallen snow. With regard to avalanches it was pretty well known at what runs they generally came down, and at those places, as Mr. Brunlees had explained, masonry covered ways were to be provided, backed with rubble, so as to allow the snow and other matters to slide over them. In the case of drift snow, which sometimes attained in known positions to a depth of—say 70 feet, strong wooden covered ways must be provided. Then there was the case of ordinary snow fall. Where there was no drifting, the fallen snow was not very deep. Mr. Abernethy had said that such a line should be carried over the summit completely under cover. But he thought that was hardly necessary, for he understood that the snow never laid to a greater depth than 3 feet over the greater portion of the summit of the pass. There were, in some respects, both advantage and economy in clearing away the snow on parts of this line, which ran more or less along the sides of precipices. Instead of having to remove the drift snow as was sometimes required in this country from a deep cutting, involving a difficult and laborious operation, it had only to be pitched on one side or the other down the precipice. There would be, he believed, less difficulty in clearing the snow from the line than was at first expected; and the engine in going down these steep inclines, would have its own weight to assist it in pushing the snow away.

The difficulty of level crossings was not easy to get over. Mr. Brunlees had explained the mode he proposed of making the centre rail moveable. But it was a question whether that could not be done better with a vertical action than a parallel ruler action. He thought the rail might perhaps be so connected with the gate, that it might sink down when the gate was open, and be raised up when it was closed, by a self-acting arrangement.

It was proposed to place the chairs, which rested on the longitudinal sleepers and carried the middle rail, not over the cross sleepers, but between the cross sleepers, and to fasten those chairs down to the longitudinal sleepers with wood screws. There were also longitudinal ties in front of these chairs fastened with through-bolts to the longitudinal timbers. He would wish to see through-bolts employed instead of merely wood screws to secure the chairs of the central rails to the longitudinal timbers, in order to obtain sufficient power to resist lateral action upon the central rail. He thought wood screws through the longitudinals only would not effect that object, while through-bolts through the chairs, the cross sleepers, and the longitudinals would be efficient. He was the

more anxious to make this observation, because it would be found he stated in his official report upon this railway two years ago—“The safest portions of the proposed railway ought, indeed, under proper management, to be those on which the gradients being steeper than 1 in 25, the middle rail will be employed. There is no difficulty in so applying and securing that middle rail, and making it virtually one continuous bar, as to preclude the possibility of accident from its weakness or from the failure of its fastenings, and the only question in my mind is whether it would not be desirable still further to extend its application to gradients less steep than 1 in 25. It would apparently be advantageous to do so, not only for the sake of obtaining increased adhesion with less proportional weight, but also with a view to greater security, especially on curved portions of the line.” He considered the safety of the system depended upon the middle rail, which should be thoroughly well secured in its place and protected against the effects of lateral action. The bolt through the tie and the middle of the longitudinal timber would not give lateral steadiness; he wanted to see a bolt from each side of each chair through the transverse as well as the longitudinal sleeper, to give lateral steadiness. From the experience which had been obtained with wood screws he had not much faith in them. They were used on the Great Western Railway in the first instance, but Mr. Brunel had them all taken up, and there was not now a wood screw on the line, through-bolts being used from end to end of the broad-gauge system.

Mr. BRUNLEES remarked, that Mr. Abernethy had stated that in mountain passes, where so much covered way had to be introduced, it might be as well to resort to the ordinary mode of tunnelling at once. Mr. Brunlees would state in explanation that in the case of the Mont Cenis, the cost of the various plans for crossing would be as follows, viz.: for the Grand Tunnel of the Alps, now making, the estimate was over $2\frac{1}{2}$ millions sterling. The cost of ten miles of covered ways in masonry for Mr. Fell's system would be £176,000; and the covered ways, as actually being carried out in timber and iron, would be under £50,000.

Mr. Brunlees would also remark, in reference to the floods alluded to by Mr. Abernethy, that the French government were now repairing the whole of the road in a most substantial manner at their own cost, and in addition to that would pay to the Mont Cenis Railway Company two-thirds of the loss sustained by them, and this did not exceed £8,000.

Mr. Fell's locomotive possessed the great advantage of getting rid of dead weight. This was always a matter of consequence, but in such a case as the Mont Cenis, where a high summit had to be overcome, he considered it of vital importance. Mr. Fell's engine of 16 tons weight, with the 24 tons pressure obtained from the

horizontal wheels, gave an adhesion of one and a half times more than that derived from the weight of the engine itself; so that with a coefficient of a fifth the total adhesion obtained was equal to one-half the weight of the engine. He felt much indebted to Mr. Fairlie and others who had taken up the subject of distributing the weight on the driving-wheels of locomotives, as he considered that the English system of permanent way was quite unfit to carry 18 tons on a single pair of wheels, which he understood was the weight now used on some railways.

Mr. GEORGE EDWARDS communicated, through the Secretary, the following remarks:—He had been resident among the Alps about fourteen years, and was first occupied in the construction of the Victor Emmanuel Railway, in Savoy, which wound its way among the lower spurs of the Alps until stopped, by the steepness of the valley, at about 2,300 feet above the level of the sea. He was led to consider how this line could be connected with those on the other side of the Alps; and he had aided the late Mr. Thomas Bartlett in completing and trying his drilling machine, which, slightly modified, was now used in boring the Great Tunnel under the Mont Cenis. His attention, however, had been principally directed to the application of the water power, which abounded in the Alpine districts, and which was proportioned to the steepness of the valley. Where a railway following the valley would require a gradient of 1 in 10, the water power available, with an equal amount of diversion or damming, was ten times as great as when the valley only fell 1 in 100, and this exactly corresponded with the difference of tractive force required. How to apply this power advantageously to the traction of trains was, in his opinion, a problem worthy the serious consideration of Engineers. Since long tunnels like that under the Mont Cenis seemed to be out of the question, from their enormous expense, and the long time required for their construction, it was evident the line would have to be carried higher up the mountain to shorten the summit tunnel or surmount the pass. Personal observation in all seasons of the year had led him to conclude that, whatever system of railway was made at an elevation exceeding an average of about 4,000 feet above the level of the sea, it must be protected by a covering of some kind, if regular service during the winter months was to be depended upon. Every portion of the line would be subject to heavy snowfalls, and a great part of it to snow-drifts, which in a few seconds were sufficient to bury a train and defy all snow-ploughs and manual labour that could be brought to bear upon them, and another part was subject to avalanches and slips of earth and rock. Where the line from its position was not subject to avalanches or rock slips, a light covering only would be necessary; but to guard against these avalanches and slips, he would strongly recommend, wherever practicable, tunnelling from horizontal side

headings into the mountain at a few yards from its surface ; and, where open-cut tunnels were made of masonry, to cover them with several yards depth of earth. Very frequently in spring large portions of rock were detached from the mountains, and, falling from a great height, swept all before them. He had witnessed this on his own works, where, on one such occasion, a block of about 300 tons of rock fell from a height of 1,000 feet, breaking into pieces as it bounded from ledge to ledge, but leaving blocks of sufficient size to break the rails of the permanent way like so many bars of glass.

Snow-drifts, though less dangerous, were of more frequent occurrence than rock slips, and were very annoying. He had been dragged over some of them in the courier sledge on the sides of a slope of $1\frac{1}{2}$ to 1, while twenty men, unable to cut a benching large enough for the sledge, held it from turning over by ropes attached to the top. Taking an average from some of the principal Passes of the Alps, as the Mont Cenis, Simplon, St. Gothard, Lukmanier, St. Bernardino, Splugen, and Septimer (all of which he had passed, and most of them during winter), it would be found that ordinary railways might generally be made to an elevation of about 4,000 feet above the sea, without the necessity of lengthening the line for the purpose of reducing the gradients. At this elevation, however, the circumstances changed rapidly ; the valleys rose faster, or left the natural course of the line altogether. Snow, avalanches, and slips were of frequent occurrence, and pointed to the expediency of shortening the line as much as possible. Thus the question of steep gradients was introduced. Reverting to the above-named Passes, it would be found that above the elevation of 4,000 feet, the average distance over the mountain by following the natural sinuities of the ground and a mean gradient, was from 15 to 20 miles.

The mean elevation (over the 4,000 feet) was about 3,300 feet.

The mean gradient „ 1 in 12 to 1 in 16.

With an average gradient of 1 in 12, or a maximum gradient of 1 in 10, and from 15 to 20 miles of covered ways, the difficult part of these Alpine Passes might be crossed by railways passing over their summits. After studying various systems on steep inclines, such as the locomotive system, the rope system, and the old atmospheric tube system, he was driven to the conclusion that none of them avoided the necessity of the covered ways mentioned. He therefore thought that the wisest plan to take, was to make use of them for transmitting the water power by means of compressed air on the pneumatic system (as it was now called), and propel the train from the bottom to the top of this difficult part of the mountain.

Having mentioned this idea to the Minister of Public Works of

Italy, he had been invited to submit to a committee a memoir¹ developing this subject; a copy of which unpublished pamphlet, in French, he had now the pleasure to present to the library of this Institution.

March 12, 19, & 26, 1867.

JOHN FOWLER, President,
in the Chair.

THE discussion upon the Paper No. 1,160, "On the Working of Steep Gradients and Sharp Curves on Railways," was continued throughout these meetings, to the exclusion of any other subject.

¹ "Système de Chemin de Fer Hydro-Pneumatique pour le Passage des Hautes Montagnes." 4to. Turin, Octobre, 1865.