Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his Paper, remarked that it was a matter for congratulation that this important connection of the two coast-lines of the South American continent had been designed and carried out by British engineers and, he understood, British contractors. The President.

The AUTHOR pointed out that the Paper was almost entirely a record of facts. To give in words an idea of the exceedingly rough nature of the country through which the railway passed was almost impossible; the photographs on the table and some lantern-slides which he had would show this better than any verbal description. He believed that in the original surveys, before mule-tracks were made, the engineers had to be let down by ladders and ropes to various observation-points. He also wished to point out that numerous features of the railway were settled many years ago, when, for instance, the rack-railway was not as well known as it was at present, although even in those days the Abt system was undoubtedly the best. The rack rail, as stated in the Paper, consisted of three plates, but since those days two plates had become what might be termed more fashionable. Whether two plates had any advantages or not was quite open to question. Three plates were adopted in the railway under consideration, but the latest rack-railway under construction used only two plates. There was a natural bridge which was of great interest at a place called Puente del Inca on the Argentine side. The slide which he would exhibit showed that this bridge was in the form of an almost perfect arch. In 1906 a very severe earthquake occurred in Chile, destroying Valparaiso, which was the largest port on the Pacific coast. The path of the earthquake followed the route of the Transandine Railway, but the damage done to the railway was represented by only a few thousand pounds. He believed that those who had had experience of railways in earthquake-countries would confirm his statement that usually earthquakes did not do very much damage to railways. The Author then exhibited several lantern-slides illustrative of the railway and of the country through which it passed. The Author.

Mr. JOHN CARRUTHERS remarked that, while the Paper was very interesting, he thought there was little in it for discussion beyond the question of the main design of the railway and the employment of rack inclines. No one who did not possess a great deal of Mr. Carruthers.

Mr. Carruthers. local knowledge, both as to finance and as to the mechanical arrangements under which the railway had been built, was capable of offering valuable criticism on the subject, and, apart from the Author, there were few present who had that inside knowledge. His own qualifications for discussing the Paper were slender. About 20 years ago he went up by train from Mendoza as far as what was then the rail-head, and up to that point there was no difficulty whatever. The line ran through a broad valley, with gradients that were not at all severe for a mountain railway; but beyond that point he was unacquainted with the line. All engineers knew that, generally speaking, a valley in such a range of mountains as had been shown in the slides did not get better from an engineering point of view as one went up it, and he felt sure the engineer who laid out such a line had only two choices: he must either keep the line in the bed of the valley and adopt whatever gradients the valley required, using special machinery to get up them, or, if he did not like that, and desired a uniform gradient, he must turn into the mountain-side and wind about in cork-screw tunnels so as to get the length necessary for an adhesion line. Mr. Carruthers thought the discussion might profitably be devoted to consideration of the choice between those two methods made by the engineers of the Transandine Railway. He supposed it might be assumed that the engineers were the Author's firm, and that they were responsible for the design of the railway. If the question had come up 30 or 40 years ago, he thought the great majority of those who took part in its discussion would have said that the Author was wrong, and that, instead of adopting special machinery, he ought to have gone into the hillside and developed his line so as to get a suitable gradient for an adhesion line. It was just about 40 years since it fell to Mr. Carruthers's lot to have to choose between those two methods of laying out a railway over a mountain range, and he then chose the same method as the Author, namely, the adoption of a steep incline, which in those days was looked upon as a kind of engineering heresy. He certainly had not recanted that heresy, and he was convinced that the engineers who laid out the Transandine Railway had, by adopting the inclines, served the best interests of the company for whom they were designing the line. There were great drawbacks to all such steep gradients, but it was also a drawback to find a mountain in the way when it was desired to take a railway across country, and the actual question to be decided was, which was the best way of getting over the mountain? The locomotive and permanent-way departments would be unanimous in wishing for a uniform gradient, no matter what it cost.

In his opinion far too much importance had been attached to the views of those departments, and the department whose interests ought to be looked after first was the finance department. In the present instance the question for decision had been, given a certain traffic of goods and passengers to be carried from Mendoza over to Los Andes, which was the cheaper way of doing the work, taking into account both the first costs and the difference in the amounts of interest on capital involved by the two ways of carrying out the work? His experience had not been very extensive, but he had had to make such a choice on two different railways which formed part of important lines, and he had introduced in the one case the Fell system and in the other case the rack. He was decidedly of opinion that on both those lines, leaving out of account altogether the difference in the interest on the original expenditure, the costs of transport were less than they would have been on a uniform-gradient line. It must have been astonishing to nearly all who saw the photographs that had been shown that such a range of mountains as the Andes could be passed with summit tunnels only 2 miles long, and that the aggregate length of the tunnels was only 4 or $4\frac{1}{2}$ miles. If the rack had not been adopted, how much more tunnelling would have been required? The Author suggested that it would perhaps be convenient at some future time to put one engine in front of the train to pull, and another behind to push, but Mr. Carruthers doubted very much whether that would be found practicable. It might be imagined that the two engines would do exactly equal work, and that in the middle of the train there would be a slack coupling, which might even be removed, so that the one train would become two trains following each other very closely. That, however, was a purely mathematical conception, and in practice the two engines would never be in perfect accord, with the result that each would always be running the other out of gear on its own rack, thus intensifying the inherent imperfection of every rack system, namely, want of unison between the pinions and the rack. He thought it would be absolutely impossible to put half a dozen engines on to the same train—that was to say, bring a long train to the foot of the incline, and run it up with half a dozen rack engines. There would be no difficulty in that respect with the Fell engine; in fact, on the Rimutaka incline in New Zealand, on which the Fell engine was used, no difficulty was experienced in attaching three, four, or five engines to one train, whereas he was quite convinced that with the rack system it would be necessary to have a number of trains and one engine to each of them. They could, of course, be worked at low speeds

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Mr. Carruthers. going up-hill, so that they could follow each other like omnibuses in Cheapside; but on a line like the Transandine Railway they would have to follow each other at considerable distances, exactly as on an ordinary line. In his opinion the Fell system was superior to the rack system in being less liable to get out of order through being hit by falling rock; moreover, the plate-layers could put right any damage almost at once, whereas with the rack system the whole line would be blocked for a number of hours. The braking also was dangerous on the rack system. It was mentioned in the Paper that when the brake was put on very suddenly the rack was damaged, and engines had been known to be derailed by injudicious use of the brake. For extremely steep gradients there was no comparison between the two systems, the Abt system being undoubtedly the better; but for flatter gradients, such as those existing over a large part of the Transandine Railway, he thought the Fell system was the better. Where the boundary between the two lay he could not say exactly. As an opinion he would put it at about 8 per cent. (1 in $12\frac{1}{2}$); but if he had to give his reasons for that opinion he would be at a loss to do so. Had it fallen to his lot to design the railway described in the Paper, he would have felt very uncertain as to which system to adopt, but taking it altogether, except for the question of ice and snow, he would have preferred the Fell system. As, however, he had had no practical experience of serious ice and snow and had given no study to that aspect of the subject, he would not presume to say that the Author had not been perfectly right in the system he had adopted.

Mr. Moore. Mr. R. ST. GEORGE MOORE said there were two points in connection with the railway which were of great interest to him. In 1910, before any snow-sheds at all had been constructed on the line, it was his misfortune to be detained in Mendoza, waiting for snow to be cleared from the railway. In travelling along the line he noticed that the snowdrifts appeared to be in positions where they would have been least expected to be. An engineer who built a snow-shed in what he imagined to be the right position would probably find it many yards or many hundred yards away from the correct spot. He was much struck by the fact that there was nothing to indicate to the engineer where drifts would occur, or to show what wind-currents had produced them and what had caused them to assume the particular forms they took. Nearly invariably, when travelling through other countries, such as Siberia, Manchuria, China, Russia, and the Caucasus, it was possible to identify the reason for the position of a snow-drift. He was therefore convinced that great skill and ingenuity had been shown in placing the snow-

sheds that had been built to protect the line. The other point, Mr. Moore, which he hoped the Author would deal with, was the break of gauge at Mendoza and on the Chilian side.

Sir FRANCIS FOX remarked that it was his good fortune some time ago to be out in that part of the world through which the Transandine Railway ran, and looking at the magnificent barrier of ice and snow, and the great mountains of Aconcagua and Tupungato, it really seemed almost impossible to carry a line through the district. It was certainly a very bold undertaking to attempt to do so. The valleys, as had been seen in the photographs, were very narrow, and the engineers suffered from the same trouble that was experienced in the Culebra Cut on the Panama Canal, namely, that whenever a slip occurred it went into the particular place where it was not required. At Panama it went into the canal; on the Transandine Railway it went on to the line, and that seemed to point to the necessity for much longer snow-sheds than were provided at present. Timber was very scarce, of course, and had to be conveyed for a very long distance; but those were difficulties that would probably be solved in the course of time. He was glad to see it stated in the Paper that the main tunnel was lined throughout, but he noticed that the smaller tunnels were not. He ventured to think it would be much better if they were. He remembered the late Sir James Inglis saying—not in that room but in its predecessor—that for nearly 50 years after the Box tunnel on the Great Western Railway was built no trouble was experienced, and then, on one night, such a combination of peculiar circumstances occurred that 700 tons of rock fell in different parts of the tunnel, or was picked down as unsafe.¹ If any of the rock had fallen on or in front of a train the consequences might have been disastrous. He thought it was false economy to make a tunnel even through rock without having it properly lined to prevent the possibility of a fall. With reference to the rack system, with which he had had something to do, he desired to call attention to the fact that many accidents had occurred with it. He thought no rack-railway ought to be used for the carriage of passengers unless it was provided with a proper safeguard. It was easy to render the mounting of the wheels of the rack engine on to the teeth of the rack an impossibility. If the engine mounted the rack the five brakes with which it was provided were rendered useless, and the train became simply a toboggan. The Paper was a valuable one, and the members were much indebted to the Author for having

Sir Francis
Fox.

¹ Minutes of Proceedings Inst. C.E., vol. clxi, p. 141.

Sir Francis Fox. placed it amongst the archives of The Institution as an interesting work of reference. He thought great credit was also due to Messrs. C. H. Walker and Company for the way in which they had carried out the work, in spite of great difficulties. The altitude of 10,000 feet was less than in the case of the Oroya tunnel, but was such as to have disagreeable effects upon the staff, the engineers, and the workmen, who, he was sure, were thankful when their work was finished. The Paper would form a very useful precedent for all engineers to consider when they had to deal with the question of railway-construction in such mountain ranges. As Mr. Carruthers had said, it was necessary to make cork-screw tunnels in the mountains to obtain adhesion lines, and the credit for that device must be given to the engineers of the St. Gothard tunnel, which was not yet 40 years old. That was a splendid example of getting over the steep declivity at the head of a valley which prevented the valley from being mounted unless heavy gradients and long lines were adopted.

Mr. Simson. Mr. DAVID SIMSON said he had waited long to hear a Paper read at the Institution on the Transandine Railway, and it had therefore given him great pleasure to listen to the Author's very interesting description of that work. No one was better qualified than the Author to read a Paper on the subject, because his firm had been connected with the work since its inception, and the Author had been personally connected with it for many years. To Mr. Simson it was one of the most interesting lines in the world. Darwin, who crossed the path of the railway when he made his voyage round the world in the "Beagle," would probably have said that it was absolutely impossible for a railway to make this tremendous climb over the Andes; and in fact the engineers were told by many travellers during the earlier stages of the construction that the task was quite impossible. Mr. Simson joined the line exactly 25 years ago, as chief assistant to Mr. M. Grant-Dalton, M. Inst. C.E. It was to be regretted that that gentleman was not present, as his connection with the railway had covered many more years than Mr. Simson's, and he could have made far more pertinent observations on the subject. To Mr. Simson, as a young engineer who had been engaged under The Institution's worthy Vice-President, Mr. John Strain, on Scotch railway-work, the construction of the Transandine Railway was a revelation. A young engineer could not have gone to a more interesting piece of work on his first foreign engagement. For instance, he had been accustomed to the use of nothing but the level and the theodolite in Scotland, but when he got out to the Andes he found engineers of practically every nationality in Europe working with

their own instruments, very largely the tacheometer and the plane-table with the stadia telescope; and, as the Author had stated, the rodmen often had to be let down with ropes, as it was impossible otherwise to take proper measurements. The financial aspect of the question, to which Mr. Carruthers had referred, was borne very clearly in mind in locating the railway. It was only by liberal use of the minimum radius that the engineers were able to avoid miles of tunnel, because the small tunnels that had been shown in the photographs were only through projecting points of rock. His experience, both on the line under discussion and on the Antofagasta Railway in Bolivia, another Andine railway, was that it was far more a question of curvature than of gradients in getting through mountain ranges. Where the curves could be made sharp enough it was possible to get anywhere economically. He had been connected principally with the Argentine side, where the great difficulty was the river Mendoza. The railway entered a mountain gorge about 20 miles from Mendoza, and then followed the river for about 85 miles. The river was the most tremendous mountain torrent he had ever seen. The sole source of its enormous volume of water was the melting snow on the two great mountain masses of Aconcagua on the north and Tupungato in the south, the highest two mountains in South America. In many places, even in the lower valleys, the river ran in a narrow gorge, occupying the whole of the bed, so that the railway had to be blasted with dynamite out of the sides of precipices—in fact, the first thing the engineers had to do was to blast mule-paths along the precipices, as everything required for the work was carried on mule-back. In order to show the terrible nature of the river he might say that, during the 3 years he was there, forty to fifty men were lost through being drowned in it. If a man fell into the river he never got out again; he was probably killed by the boulders rolling along its bottom. He remembered on one occasion arriving in the evening at the camp of San Ignacio, at kilometre 50. The house was on a level plateau about 2 acres in extent, 15 to 20 feet above the level of the river, and about 100 yards back from it. Just as he was sitting down to dinner a servant rushed in to say that the river was attacking the bank, which consisted of a hard conglomerate of gravel and earth. In 2 hours' time the site of the room where he had been about to dine was in the middle of the river. He discovered next morning that the cause of the trouble was that a moderate-sized boulder had rolled into the river from the mountain on the opposite side of the river about $\frac{1}{4}$ mile above the camp, deflecting the current with the result he had stated. He wished to testify to the correctness of the Author's

Mr. Simson.

Mr. Simson. remarks in regard to earthquakes. Mendoza itself was utterly destroyed in 1861, about 14,000 inhabitants being killed. Not a week passed while he was on the work in which an earth-tremor did not occur. He remembered sleeping one night in a corrugated-iron house about 200 yards from the end of the bridge at kilometre 37, in a direct line with the bridge. The bridge had viaduct approaches 60 or 70 feet high with 30-foot masonry arches. While he was asleep an earthquake occurred of such violence that he was thrown right out of his bed. The next morning he expected to find the arches completely wrecked, as the earthquake-wave came right in the line of the bridge; but there was not a sign of a crack. That was an extraordinary example of what the Author had stated, that earthquakes seemed to do very little harm to railway-work. The rack incline was of the greatest possible use in enabling the engineers to choose their ground, and the Abt system had the great convenience that a normal adhesion engine with rack gearing was used. It could climb up the rack incline, and then run again on an adhesion part of the track, and in that respect it had great advantages so long as the gradient did not exceed 1 in 12. When he was on the work the summit tunnel was intended to be at a level nearly 1,000 feet lower; it would consequently have been much longer than the present tunnel, and there would have been also a spiral tunnel on the Chilian side. But all that had been done away with, and so far as he could see the result seemed satisfactory. He thought the Author was to be heartily congratulated on the design of the rack engines, which he understood to be working exceedingly well.

Mr. Bury. Mr. OLIVER BURY remarked that the Paper was of special interest to him because he was daily concerned with the working and management of various mountain railways, among them one referred to in the Paper—the Central Railway of Peru, better known as the Oroya railway, which ascended to a height of 15,863 feet. That railway was worked entirely by adhesion. It started at about the sea-level, and for 106 miles climbed steadily up on a gradient ranging between 3 per cent. (1 in 33) and 4 per cent. (1 in 25). When it was a question of getting over a summit by rack or by adhesion, not from the locomotive- or the permanent-way engineer's point of view, but from the commercial point of view, he would always say that the rack should be avoided if possible. He was of the opinion that the adhesion principle should be adopted, several extra miles of railway being put in if required, and all the necessary money being spent if it could possibly be obtained. He realized that in the case under discussion there might have been financial

conditions which rendered that course entirely prohibitive. He Mr. Bury. had personal experience of a case where there were three different routes to reach a common point; the adhesion line was longer than the rack line, but the former was always used where possible, the latter being avoided for everything except passengers. He supposed every one would agree with Mr. Simson that the surmounting of a great height in a mountainous region such as the Andes was a question not so much of gradient as of curvature. He desired to ask the Author whether, if he could start afresh with the problem, and having already a 5-foot 6-inch gauge all the way from Buenos Aires to Mendoza, and a 5-foot 6-inch gauge through Chile to Los Andes, he would not somehow or other have put in a line of 5-foot 6-inch gauge to couple the two systems. No one knew better than the Author—who had been over the Oroya railway—the sort of place that could be got round with the 4-foot 8½-inch gauge, and personally Mr. Bury thought it would have been possible to connect these two great countries by means of a railway having no break of gauge. There was certainly nothing more important in connecting two countries than that goods and passengers should be able to get through without transshipment. It was not quite clear at what altitude the Diesel engines were used, but he presumed it was about 10,000 feet. It was useful to have the short cut to accurate calculation that the internal-combustion engine lost about 4 per cent. of its efficiency at sea-level for every 1,000 feet of altitude at which it worked. He found—and he presumed other operators of mountain railways had the same experience—that the locomotive was much harder to fire. The difficulties had been overcome to a large extent by the exclusive use of oil, and it would be of interest if the Author would state whether coal—and, if so, what sort of coal—or oil was used on the Transandine Railway. Did the engines steam freely at that height? The Author was to be congratulated on having designed an excellent rack engine, which would pull 140 tons up an 8½-per-cent. gradient. It would be interesting to know how those engines negotiated the curves, and whether there was not a great deal of friction on them. Before sitting down he wished, having given up engineering himself, to commend one other point to the notice of engineers, namely, the question of rolling stock. He hardly thought that engineers had made their last effort or, if he might say so in the presence of the Author, had made full use of their brains in cutting down the weight of rolling stock for use on mountain railways. There had been rather a tendency to follow the lines of ordinary railway rolling stock, and, when it was borne in mind that on the Oroya railway there was a vertical lift of about

Mr. Bury. 3 miles, it would be seen that it was of the utmost importance commercially that the dead weight of the rolling stock should be reduced to the minimum. He would also like the Author to say whether he had any fault to find, or had experienced any difficulties, with the brakes in use on the Transandine Railway. In England Mr. Bury had always been in favour of the vacuum brake, but the experience obtained in Peru showed that the Westinghouse brake was better than the vacuum brake on mountain railways. It might be of interest to those who were not closely connected with mountain railways if he said, in conclusion, that on the Oroya railway an engine was never allowed to go down-hill in any circumstances whatever without having two wagons attached to it, because, owing to the mist and the consequent slippery condition of the rails, an engine alone, even on a 4-per-cent. gradient, could not stop itself.

Mr. Clark. Mr. MATEO CLARK desired to say first a few words on the selection of the route for the Transandine Railway. Before it was decided to survey the pass from Mendoza to Chile, other surveys were carried out in different parts of the country. He had with him plans showing in detail another route about 30 miles to the north, from San Juan to San Felipe, joining the Government railways in Chile. It was found that that would mean a longer line to Buenos Aires, because it would go farther north and then to the south. It was therefore decided to make the line through the Uspallata Pass. The first idea of the engineers was to avoid any kind of steep incline, and they actually succeeded in obtaining $3\frac{1}{4}$ -per-cent. gradients coming up by the Cuevas valley and going down the Juncal valley. But that was a very long distance, there being 70 kilometres between Puente del Inca and Juncal. When the line was proposed in 1870 the idea was not to make a line to Buenos Aires but solely to unite the Province of Mendoza with Valparaiso on the Pacific, because it was thought that if greater facilities were given trade would improve considerably. As it happened, in the course of time the Argentine Government desired the line to be extended to Buenos Aires. But in passing the law for the construction of the line, which was built under a guarantee from the Argentine and Chilian Governments, the Governments fixed such a low cost that it was impossible to think of building a long tunnel, and the engineers consequently had to seek for the shortest possible pass. Then it was decided to adopt the rack system, which was recommended by a well-known engineer after some studies in the Hartz mountains in Germany, where it worked very successfully. When it was finally decided to construct the line through the Uspallata Pass, great opposition to the proposal was aroused,

because nobody believed it was possible to carry the railway over Mr. Clark. such a difficult pass. No one at that time, however, had made a survey, and when he and his colleagues came to do that they were greatly surprised to find that the Andes had a thickness of only 3,000 metres at the bottom of the valley of Las Cuevas, and that at its summit the mountain was only 40 to 50 yards thick. He was convinced that the Uspallata Pass, although not approved by the generality of the public, was in fact the narrowest in the whole range of the Andes from Panama to Valparaiso, and that at no place in the whole range of the Andes was there a pass better adapted to the construction of a railway. There were a great many lower passes in the south of Chile, but they were so far away from the centres of trade that it was impossible to pay any attention to them. He even went so far as to say it did not matter if there was a lower pass. What was wanted was a line running through the populated parts of the country, and consequently the line that had been planned was adhered to. He had prepared a sketch plan showing that it was possible to get to the summit by a series of side valleys that would allow the engineers to develop the line in any way desired, with tunnels of any particular size; but the carrying out of this plan, involving a much longer tunnel, must be left for another generation. It would require a large amount of money, but it would be practicable to make a tunnel to overcome all the present difficulties. He heard frequently that the northern passes of the Andes were better for the purpose, but travellers who went over the country on horseback never measured distances or elevations. There were many passes to the north that were really easy of access, and in which there was no snow, owing to their proximity to the Equator. The Arica-La Paz railway, for which he obtained a concession for an English company, had just been finished, 300 kilometres of which was above 12,000 feet elevation: no trouble had been experienced on that railway with snow, which was unknown there until an altitude of 15,000 feet was reached. The Oroya railway in Peru reached a height of more than 15,000 feet, but there was no snow there. In order to give an idea of the remarkable features of the Uspallata Pass, compared with the one nearest to it, he had prepared *Fig. 11*, the hatched portion showing the pass by Uspallata and the unhatched the pass by Copiapó. In the first there was a tunnel 10,500 feet in length, in the other, at the same elevation, the distance through the mountain was about 300 kilometres. Similar conditions existed everywhere in the north of Chile. In the south the passes were lower, but the snow was more abundant. The perpetual snow-line in the Uspallata Pass was about 15,000 feet, whereas

Mr. Clark. 300 miles to the south the snow-line was only 6,000 feet, and

consequently a railway built in that region would require more

protection. The difficulties connected with snow never troubled Mr. Clark. his mind while he was preparing the scheme for the Transandine Railway. He studied the influence of the snow for 20 or 30 years before the railway was made, and found that after storms very strong winds blew which swept away any snow that had accumulated. He therefore strongly recommended engineers to avoid cuttings and to build such lines on embankments, and if that were done snow-sheds would not be required. A previous speaker had remarked that the snow-drifts occurred where they would not be expected: those drifts were in cuttings; they never occurred on embankments, and if cuttings had been avoided no drifts would have occurred. He noticed that the first time he crossed after the opening of the tunnel, when, owing to the snow, he paid the penalty of being shut up in the train for two days and nights. But when he crossed into Chile he was very pleased to see that where the line had been built on embankments the rack-rails were clean; the wind had swept away the snow, and there was no necessity at all for the construction of snow-sheds. The Paper said nothing about the bridges, but Mr. Carruthers had remarked that when he went half-way over the railway he did not notice any particular difficulties connected with its construction. When a railway was finished, and it was possible to travel easily over it, the difficulties that had been experienced in constructing it were not seen. He remembered that, before he went through the St. Gothard tunnel, he fortunately studied every detail of the line, and he was therefore able to appreciate the difficulties connected with the construction of the spiral tunnels; but on questioning friends who had gone through the tunnels he found they were unaware that they had passed through spiral tunnels, because they did not know of their existence. It was proposed at one time to put a bridge of 60 metres span near Mendoza, but when the engineers commenced to build the bridge it was found that the floods were so heavy that the length of the bridge had to be doubled, and a considerable sum spent on defences. From kilometre 40 to kilometre 70 the same river had to be crossed ten times with bridges of 45 to 75 metres span, a bridge of the latter size never having been built in South America before. It was a curious feature that, as the work progressed, it became necessary to increase the length of the bridges, and it would be understood that, although so many bridges had been put in, it was impossible to do without them. That alone proved the difficulty of the ground over which the railway had had to be built. No timber was available for staging, etc. It was necessary also to devise special means of launching the girders, and those arrangements were

Mr. Clark. prepared with the plans, so that the launching was done with comparative ease. In the erection of the 75-metre (245-foot) bridge a very simple method was adopted. In those latitudes the floods came in the summer when the snow melted, the rivers being more or less dry in the winter. It had been intended originally to build bridges of 10, 15, or 20 metres span on screw-piles, but it was found that that would be a dangerous method. In the case of the bridge to which he referred, embankments of earth were made on which the bridge was built in the dry season, the floods eventually carrying away the earth and leaving the bridge standing. The facts mentioned by Mr. Simson as to the extraordinary floods in the river, and the loss of forty or fifty men in it, emphasized the difficulties encountered in building the bridges. The Author did not express any opinion on the new idea of using only two bars for the rack; but the Chilean Government had consulted Dr. Abt, who had recommended strongly that the three-bar rack should not be used in future, because the two-bar was found to be much better and stronger for mountain railways with sharp curves. Naturally the two-bar rack had to be so proportioned as to have the same strength as the three-bar. On the Arica-La Paz railway there were 40 kilometres of rack on a 6-per-cent. gradient. After crossing the Andes in a snowstorm and observing the rack, he came to the conclusion that two bars would be better suited to the purpose, because it seemed to him that the three-bar rack was rather weak. The Author also stated that the locomotives used on the rack at present weighed 85 or 90 tons. When the line was first proposed it was not contemplated that locomotives weighing more than 45 tons would be used, and that was another important reason why a stronger rack than the one in use should be employed. A German rack system, invented by Mr. Strub, and consisting of a single line of teeth cut in a solid rail, had been introduced lately. It was very highly thought of by the Government of Chile, and personally, if he were making another rack-railway, he would rather use a strong single rack than have two bars. Mention of the Fell system had been made by a previous speaker. Mr. Clark had a long conversation with Mr. Fell on the subject, but he came to the conclusion—as others had done—that the Abt rack system was preferable. He did not wish to say anything against the Fell system, which was very good in its way. On the Oroya railway there was never any snow, and that made a very great difference in the working of the switches, because the zigzags were difficult to work in several feet of snow. He had studied particularly the question of snow-sheds, in con-

nection with the Central Pacific Railway in California, and in his Mr. Clark opinion the Transandine Railway had nothing to fear from snow-falls apart from avalanches. Where the line ran through a plain, all that was requisite was to build it on a high embankment, and the wind would then sweep the snow away. The chief thing the Transandine Railway required was side tunnelling, to protect the line from avalanches. That was the great difficulty that had to be contended with: ordinary snow-falls would never trouble the railway at all. One thing that astonished him very much when he crossed the Andes for the purpose of studying the problem of the snow was that on the very summit he found no snow at all. The wind cleared everything away; not only snow, but even a masonry refuge-hut for travellers had been swept away by the wind, so powerful was it at that elevation. He was sorry the Author had not touched on the very important subject of the cost of the railway, particularly of the tunnel. As it had not been mentioned, he would not deal with it, though it was really the most interesting question for those who desired to make other railways. So far as the cost of long mountain tunnels was concerned, the most costly tunnel ever made was the first, namely, the Mont Cenis, then came in turn the St. Gothard, the Arlberg, and the Simplon. Each in succession had been driven at a cheaper rate than its predecessors, and had been constructed much faster, owing to the new methods and machinery that became available. With regard to labour, he could say that the Chilian miner was second to none in the world; he was a very good hard worker. His firm had built 3,200 metres of tunnel at the summit of the Andes, and the sub-contractors averaged 1 metre a day by hand-labour before the arrival of the machines, the work being carried out by gangs of twenty-two men in 8-hour shifts. So far as the progress of the work was concerned, after the construction company took over the work from his firm, in the first 3 years on the Argentine side 327 metres were done at the average rate of 9 metres per month. Then the contract was taken over by Messrs. Walker, and in 21 months they did 979 metres, or 45 metres per month. On the Chilian side, in 3 years and 8 months the construction company did 853 lineal metres, while Messrs. Walker in 12 months did 871 metres, the average rate by the company being 19·39 metres per month, whereas Messrs. Walker did 72½ metres per month. The work on the Chilian side was considerably cheaper, owing to the greater facilities that existed, so that the construction went on a good deal faster, and this was shown by the fact that 1,724 metres were drilled from Chile against 1,306 metres from Argentina.

Mr. Clark. With regard to the section of the summit tunnel, the section approved by the Chilian Government was 15·84 square metres on straight line and 18·00 square metres on curves. His objections to the enlargement of the original section, as approved by both the Chilian and Argentine Governments, as well as by Mr. Livesey, when the plans and estimates were originally submitted to them by his firm, were based not on personal opinions, but on observations of natural laws that could not be ignored, and he regretted that a decision to alter the approved section, involving much additional expenditure, should have been carried out without giving technical reason for so doing. He and his colleagues had observed for many years the very favourable conditions of the ground for locating the tunnel with every prospect of obtaining good natural ventilation, and they felt very strongly that the approved section was more than ample. They also felt sure that a tunnel with such a cross-sectional area could be driven at a cost within their estimates, which were based on actual experience in the same locality. They had already drilled about 3,200 metres of gallery there in which there were several headings with the very steep upward gradient of 8 per cent. extending for about 100 to 360 metres, and also headings on downward gradients, as well as an adit with a 30-per-cent. gradient; and although no artificial ventilation was provided, no inconvenience whatever was experienced, because the gases given off by the dynamite disappeared very quickly owing to the exceptionally dry and rarefied condition of the atmosphere at such an altitude (10,500 feet above sea-level). Because there were tunnels unfavourably located, with consequent bad ventilation, it did not follow that the same ill effects would arise in a tunnel where the conditions were different. The ventilation of long tunnels was a very difficult problem when the Mont Cenis tunnel was under construction, many engineers being then of opinion that it would be impossible to secure good ventilation or even any ventilation at all in a tunnel 7 miles in length; but since then it had been found that successful ventilation was a matter of observance of natural laws. He was satisfied that in almost every point the situation of the Transandine tunnel was an ideal one for as good ventilation as could reasonably be expected. Comparing it with the Simplon tunnel, in the first place, the latter had a length of 19,700 metres, while the length of the Transandine tunnel, which, as constructed, was of practically the same cross-sectional area, was only 3,030 metres; and given the same conditions the atmosphere in the Transandine tunnel would be entirely renewed in less than one-eighth of the time that the Simplon tunnel would

require; that was to say, if the current of air in the Simplon Mr. Clark. tunnel travelled at such a rate that 64 minutes were required to renew the whole atmosphere, the air in the Transandine would be renewed in less than 8 minutes, so that if trains ran every 10 minutes the atmosphere would always be fresh. But the probable number of trains that would pass through the tunnel every 24 hours should also be considered, and in the case of the Transandine Railway a reasonable allowance for several years to come would have been twelve trains, so that instead of 8 minutes for clearing the tunnel from offensive fumes there would be 2 hours. In a long tunnel the column of air was retarded by the friction on the walls, and it could be easily seen that this was a point in favour of the shorter tunnel. The gradients in both tunnels were nearly the same. The elevation above sea-level of the Simplon tunnel was 700 metres, while that of the Transandine tunnel was 3,200 metres, and at this great elevation there was a very considerable difference in the atmosphere outside the tunnel, which was another point in favour of the Transandine. All Messrs. Clark's observations had convinced them that a tunnel with an area of 18 square metres for a narrow-gauge railway, such as the Transandine was, would prove ample for securing good ventilation. Why had the Transandine tunnel been given the same cross-sectional area as the Simplon tunnel, which was six times as long, was constructed for the normal gauge, and was under less favourable conditions in the matter of ventilation?¹ In the case of the Transandine tunnel he pointed out to the Company that if a tunnel of 18 square metres area did not have good ventilation, the remedy would not be to enlarge the section, leaving all the other conditions unchanged: the ventilation could only be modified by altering the location of the tunnel, in view of the existing atmospheric conditions outside the tunnel on both sides of the mountain, the respective levels of both portals, and the gradients in the tunnel. If there was any doubt as to natural ventilation, the most reasonable thing to have suggested was artificial ventilation, if, after the advance galleries had met, it had been found necessary. The production of noxious fumes by the locomotives while traversing tunnels had been the subject of special research by several eminent continental engineers in dealing with the problem of ventilation. Naturally the effect varied in proportion to the quantity of coal consumed

¹ See Jacquier, "Rapport sur les travaux du tunnel du Simplon." Paris, 1906.

Mr. Clark, in the locomotives, which in turn depended on the gradients in the tunnel, the speed of the trains, the length of the tunnel, and the number of trains passing both ways through the tunnel; also, the rate at which the column of air passed through the tunnel had to be considered, in order to find the time required to renew the atmosphere in the tunnel. He had pointed out that in the case of the Transandine tunnel trains would have been able to pass through in an entirely fresh atmosphere at intervals of less than 10 minutes; but if any doubt had existed it would have been easy to arrange that, before entering the tunnel from the Argentine side, trains should stop for a few minutes for the driver to stoke the fire, so that no fresh coal need be put into the fire-box while traversing the tunnel. A similar few minutes' stoppage before entering from the Chilian side, to get up steam and bank the fire, could also be made, so that no fresh coal need be used until the train had passed at least the $\frac{3}{4}$ -per-cent. gradient, in which case the fumes left behind would be considerably diminished. A narrower tunnel could have been finished for less than one-half the cost of the larger one, in view of the friable nature of the rock, which required not only stronger timbering but also considerably heavier lining in the larger tunnel. It would also have been possible to a considerable extent in a narrower tunnel to limit the lining to the roof. The cost of this tunnel had been more than twice the amount of Messrs. Clark's estimates, which were based on the actual cost of constructing upwards of 3,500 metres of tunnel on the same railway. Those estimates were checked by two independent engineers who went out specially to the Andes to verify them, and were finally certified by a firm of eminent consulting engineers in London; and Mr. Clark attributed the very disappointing result principally to the excessive cost of this section of the railway.

Mr. Waring. Mr. F. J. WARING remarked that it might seem almost a truism to say that before designing any railway the conditions should be taken into account. Before the connecting link constituting the Transandine Railway was built, Chile and Argentina were practically separated by land, inasmuch as a pass at an altitude of 12,521 feet, in latitude 33° S., must have been unavailable for general traffic purposes. The only connection, therefore, between the important ports of Valparaíso and Buenos Aires was by sea, a journey of 3,150 miles by the Straits of Magellan, and about 500 miles longer via Cape Horn. By the construction of this short link of railway, only 155 miles in length, the journey had been reduced to one of 895 miles. The population of Valparaíso was, he believed, up-

wards of 200,000, and that of Buenos Aires 1,300,000; and the city of Santiago, the capital of Chile, the population of which he believed was at the present time 340,000, was also placed in communication with Buenos Aires. No information was given in the Paper as to the amount of traffic on the railway, or the working-expenses, nor even as to the cost of the line, in regard to all of which it would be of great advantage if figures were placed on record; but even if the traffic were not very large at present, he thought there was little doubt that, the two countries of Chile and Argentina, inhabited by people of the same race, being now connected together, a very important traffic would soon be developed. Of the total length of railway from Valparaiso to Buenos Aires (895 miles), all, with the exception of the 155 miles of the Transandine Railway, was on the 5-foot 6-inch gauge, and it seemed to him exceedingly unfortunate that a metre gauge should have been adopted for that short length, which, of course, involved two breaks of gauge. He deemed it equally unfortunate that for passing over the summit of the Andes it had been considered necessary to adopt gradients too steep to be worked by ordinary adhesion engines. Further, the distance between the first point on the Argentine side where the rack occurred and the last point on the Chilean side where the rack occurred was, he gathered from the Paper, $77\frac{1}{4}$ kilometres, that was, the distance from the first point to the last point of the rack. But the rack was not used throughout the whole of that distance, the total length of rack being only $35\frac{1}{2}$ kilometres. There were therefore 42 kilometres, in various detached sections, where the line could have been worked by adhesion engines. Admitting that the rack was necessary to pass the summit, it appeared to him it would have been a very great advantage indeed if it had been concentrated in one section, instead of being in numerous detached sections on each side of the summit. It might be argued by the advocates of the railway as built that the curves it was necessary to adopt for the sake of economy would have been too sharp for traffic to be worked on the 5-foot 6-inch gauge. As a matter of fact, that was not the case, although no person recognized more than he did the difficulties attendant upon the construction of such a railway. On the Ceylon railways curves of 5 chains radius had been worked for the last 29 years on the 5-foot 6-inch gauge. The curves on the adhesion portion of the Transandine Railway were 6 chains in radius, and according to his calculations the engines now in use in Ceylon would have been capable of taking trains, in addition to their own weight and that of the tender, of 250 tons up gradients 1 in 40 at the rate of 12 miles

Mr. Waring. per hour. He believed he was correct in stating that the capacity of any railway could be properly gauged by the maximum weight of train multiplied by the speed at which it could be drawn; and, if so, the comparative figure in the case of the Ceylon railways was 3,000, that was 250 tons multiplied by 12, whereas on the rack portion of the Transandine Railway it was 1,120, that was, 140 multiplied by 8. Therefore the capacity of a railway on the 5-foot 6-inch gauge, had it been possible to eliminate the rack portion and to work it as an adhesion line throughout, would have been nearly three times as great as that of the system adopted. Whilst fully recognizing the excessive difficulties encountered in the construction of this railway, he was not sure that, even if spiral tunnels as used on the St. Gothard inclines were out of the question owing to the cost, there might not have been branch valleys which would have enabled developments to have been obtained; or failing that, as a last resort, the system of zigzags, which was used on the Bhore and Thul Ghauts in India, could have been adopted. These were also used on the Darjeeling railway and, he believed, for the ascent of the Blue Mountains in New South Wales. He was much disposed to agree with Mr. Oliver Bury's remarks in regard to the Oroya railway, namely, that anything was preferable to wire-drawing the traffic as had been done in effect by the adoption of the combined rack and narrower gauge on the Transandine Railway.

Mr. Shelford. Mr. F. SHELFORD said that it was with considerable hesitation, after hearing the remarks of Mr. Mateo Clark, who had shown such remarkable local knowledge and such acquaintance with the history of the undertaking, that he ventured to join in the discussion; but as a railway-engineer he wished to emphasize strongly what Mr. Waring had just said as to concentrating the rack into one section of the railway. The Author stated that the rack could not be concentrated into one section on each side of the Andes, but it was of the utmost importance that it should be concentrated if it was at all possible. It would be noticed that in both the Kitson engine and the Esslingen engine (Figs. 7 and 8, Plate 4) only four driving-axles were used out of the seven when the engine was working adhesively. An express engine on a level road was of the type 2-6-2; he believed that on the Mont Cenis railway, where the engine was working up very heavy gradients, an eight-coupled engine was used, that was, an engine of the type 0-8-0; but the engines on the Transandine Railway, when working adhesively, were of the type 0-8-6—a very extravagant method of working. That meant that between the rack portions,

where the engine had to work adhesively, only one-half of the Mr. Shelford. engine was working at a time—a thing that should be avoided, if possible. It was much better to work adhesively up to a certain point, and then change the engine to a rack-engine and work on the rack up to the top of the gradient. Not having seen the line, he did not say that it could have been done; but as one who had located many hundred miles of railway, he thought some better result might have been obtained than having thirteen sections of rack, seven on the one side and six on the other. He might be wrong, but as a railway-surveyor he would have worked at 1 in 40 up either side as far as he could get, then used a rack—perhaps steeper than the rack actually used—and then started again. He was sure the rack could have been concentrated in that way into less than thirteen sections. He was not sure whether the tachometer was invented when the surveys of the Transandine Railway were made, but the survey of such a line, running up a gorge to a mountain range and down the other side, presented a very good opportunity for using the tachometer. It was an excellent instrument, by the use of which the engineer, sitting or standing still, and sending other people climbing about the mountains, could make a contoured plan of a large area in a short time. He was rather curious to know whether the Author would be able to give a reason for the break of gauge in the present case. Engineers made breaks of gauge all over the world, and there was always an excuse of some kind for them. Sometimes strategical reasons were put forward; e.g., possibly war might break out between Argentina and Chile in the future, and it would be dangerous to have a line between the two countries of the same gauge throughout. If there was anything in that argument, it applied to a tunnel between England and France. Perhaps the reason was that the country could not afford to build a line of 5-foot 6-inch gauge throughout. But if a man had work which could only be done by a motor-car, and he could not afford a motor-car, it was no use buying a horse. The right course was to save sufficient money to provide what was required. The weight of the rail was given as 50 lbs. per yard, and on the rack sections 55 lbs. per yard. He would like to know why that heavier rail was used on the rack sections. The engine was no heavier on those sections; the work done on the running-rails was less rather than more, because the rack was doing part of the work. Why, therefore, a heavier rail? That, however, was a minor point; the important question he wished to raise was whether the capacity of the railway had not been greatly limited by adopting a 50-lb. rail, with gradients

Mr. Shelford. of 1 in 40 on either side. An 80-lb. rail, to which the circumstances pointed, would have allowed 16 tons per axle on the rail instead of the 10 or 11 tons used at present, that was, 5 tons per axle more, which, with four axles, meant 20 tons extra adhesive weight, 4 tons extra draw-bar pull, and 160 tons more load behind the tender. Yet here was a connecting railway between two important countries limited by a 50-lb. rail. He did not know that it was quite fair to say so, but in the Argentine the Author was employing a 1-in-40 gradient and a 50-lb. rail, whereas in British East Africa he had adopted a 1-in-50 gradient and an 80-lb. rail. Those two things were not quite consistent. With regard to the snow-sheds, some of them could be dismissed from consideration, as he thought they were meant to deal with avalanches of snow. He imagined, however, that type D was meant not for dealing with avalanches but for keeping snow off the railway. If the Author had ever been in Russia in mid-winter he would have seen there a much more economical way of dealing with snow than that adopted on the Transandine Railway. All along the railways hurdles were put about 50 yards distant on either side of the line, and not more than 5 feet high. The snow drove against the hurdles, eddied in the wind behind them, was caught in the lee of the fence, and fell clear of the railway. When the hurdles were buried by the snow, that was, when the drift was about 5 feet high, the hurdles were pulled out and put on the top of the drift. Another storm produced a further drift; the hurdles were lifted again and put on the top; and every time this was done the snowdrifts formed under the lee of the hurdles, keeping clear of the railway. That seemed to be a much cheaper method than the one adopted by the Author. The engines, apparently, must keep the water over the fire-box; therefore the funnel had to be up-hill. Were the engines changed or turned at the summit? And was any trouble experienced at the steam-joints of the articulated locomotives? He recently asked at Messrs. Kitson's works whether the engines gave any trouble at the steam-joints, and received a negative reply; but he would like to put that question to an independent person. In regard to the question of brakes, he noticed the Author was using the Westinghouse brake on a very steep line, and he would like to know whether any trouble was ever experienced through the exhaustion of that brake. On the Uganda railway there were hundreds of miles of falling gradient: he thought he was right in saying that the brakes were constantly being applied, and that it was found necessary to take them off occasionally to allow the

cylinders to replenish their supply of compressed air. He would like to ask whether the Author had found the same thing on the Transandine Railway. He earnestly asked also whether the Author could give the cost of the railway per mile, because that was always a matter of interest to railway-engineers. Many laymen thought that the cost of a mile of railway was always the same. He remembered being told on one occasion that he was very extravagant because a railway he had made had cost £11,000 per mile, whereas one in the West Indies had been made for £2,000 per mile. There was one other question he wished to ask in connection with the subject of finance. Given certain rates prevailing on the Argentine railways, which worked more or less on the level, what were the comparative rates found necessary to make a line like the Transandine Railway, which had cost so much money, pay? In other words, if first-class passengers were carried in the Argentine for, say, a penny a mile, what was it necessary to charge on the Transandine line?

Mr. R. H. BURNETT remarked that, as a representative of the firm that made the pioneer rack-engines for the Transandine Railway, he noted with pleasure the Author's appreciative remarks on those engines. The Author said that the locomotives made by the Maschinenfabrik Esslingen and by Messrs. Kitson and Company were probably as powerful as any that had been "designed" for a rack railway. If "designed" was to be understood to mean "constructed and put to work" it was no doubt correct; but if it was to be taken in its wider sense, he wished to say that he held in his hand a design for an articulated engine which would be far more powerful than either of the two described in the Paper. It was not his intention to criticize the engines described in the Paper, because he did not think that was the place for doing so, but he desired to point out that an articulated engine did exist which was remarkably easily adaptable to the work of a railway where there was a combination of adhesion and rack working. Further, owing to its flexibility, the articulated engine in question, the Garratt engine, was particularly adaptable to all railways, whether level lines or mountain lines, which had unusually sharp curves. The main feature of that engine was that the boiler was carried upon side frames, the ends of which rested on and were pivoted to bogies at each end. Those bogies were fitted with cylinders; the engines were complete in themselves, and they were fed with steam from a common boiler of the simplest construction; they also carried water- and fuel-tanks. The arrangement was such that, if it were desired, the most powerful engine could be made to go at full power

Mr. Shelford.

Mr. Burnett.

Mr. Burnett. round any London street-corner. Another important feature of the engine was that, owing to the absence of wheels at the sides of the boiler, the barrel could be made of any diameter required, and also the fire-box could be made of any width that the loading-gauge of the railway would permit, without relation to the gauge of the railway; with the result that a very wide box could be obtained, and a relatively short one, for any particular grate-area that might be required. It could also be carried down as near to the rail-level as the ash-pan would permit. The grate in the design he was referring to was 6 feet 9 inches wide inside, which was very wide for a metre-gauge railway. Again, when going round sharp curves, the boiler and frame centre formed a chord between the pivot on the bogies, and the weight came inward instead of being thrown outward, as was the case in some articulated engines. He hoped he would be pardoned if he mentioned briefly the relative power of the design of the engine, particulars of which he would hand in. The design had been got out for adhesion working, but it had been modified to render it suitable for a combination of adhesion and rack, by making one bogie of the engine into a rack-engine. The adhesion engines had two cylinders 17 inches in diameter by 19 inches stroke, working on eight coupled wheels of 3 feet diameter. The rack-engine had four cylinders, two outside of the same diameter as those he had mentioned, and two inside 12 inches in diameter by 16 inches stroke, together working upon three rack pinions. In power the design exceeded the engines described by the Author in the following respects. It had 42 square feet of grate-area, which was 20 per cent. more than the Esslingen and 23 per cent. more than the Kitson engine. It had 2,662 square feet of heating-surface, which was 22 per cent. more than the Esslingen and 30 per cent. more than the Kitson engine. Of that area, 175 square feet were in the fire-box, being 52 per cent. more than the Esslingen and 25 per cent. more than the Kitson engine. The adhesion engine could develop, with 75 per cent. of the boiler-pressure, 22,800 lbs. tractive effort, which was 14 per cent. more than in either of the other two engines. The rack-engine, assuming an average pressure in the cylinders of 80 per cent. of the boiler-pressure, was 50,000 lbs. against 47,000 lbs. in the one case and 34,000 lbs. in the other, or $6\frac{1}{2}$ per cent. more in one case and 47 per cent. more in the other. The total tractive power of the two engines combined was 9 per cent. more than that of the Esslingen and 35 per cent. more than that of the Kitson engine. The Garratt engine, assuming the same quantities of water and fuel, weighed 13 tons more, being 100 tons as against 87 tons. With regard to the net train-load that the

two engines would take up the steepest incline, his calculations Mr. Burnett showed that, although the Garratt engine was 13 tons heavier, it would take 7 tons more than the 140 tons taken by the engines mentioned. It might be said that that was a poor performance for an engine weighing 13 tons more. It had to be remembered, however, that, owing to the boiler of the Garratt engine being at least 20 per cent. larger than that of either of the other engines, it would take those 140 tons 20 per cent. faster over the line; so that any distance that the present engines would take 5 hours to travel over would be done by the Garratt engine in 4 hours, with the result that the line would be cleared sooner for trains in the opposite direction, which was a very important matter in a single line of railway such as the Transandine. Comparing the design with the Kitson engine, the result was that the Garratt engine would take 64 tons more than the 140 tons mentioned, equal to 45 per cent. He was convinced that in practice an engine of this design would hold its own in regard to ease of running—not only on the straight but round curves—and in regard to low cost of maintenance, with any design of articulated or other engine in the world.

Mr. F. W. BACH remarked that Mr. Carruthers seemed to have Mr. Bach. rightly indicated what the main question in the discussion of the Paper would be, namely, whether it was preferable to construct a rack railway and have a short line, or to attempt an adhesion railway without a rack. He had gone farther, and had expressed the opinion that, in considering that question, far too much stress was laid by engineers upon the locomotive problem of dealing with the railway after it was made. So far as the gradient of the line was concerned, in Mr. Bach's opinion that problem was not considered anything like sufficiently by consulting engineers. The problem of the working of lines such as the Transandine Railway should be taken into consideration in the fullest possible manner when considering the type of railway that should be adopted. Mr. Clark had shown by his remarks that he was of the same opinion, and he had given the key to the reason why the railway was ever made in its present form, in the fact that the Argentine Government were so short-sighted that they would not find the money for the construction of a better line. As made, with a 1-in-12½ gradient, the line was said to be worked by engines with a train-load of 140 tons, that was, a gross train of about 225 tons. If it could have been made with a gradient, not, as had been suggested, of 1 in 40, which was out of the question, but 1 in 25 (such as the Oroya railway had), which was a perfectly practical problem, it would have been found that the same engine would work two-and-a-half times

Mr. Bach. as much load up 1 in 25 as it would on a gradient of 1 in $12\frac{1}{2}$. The difference in cost of working per ton-mile was not entirely covered by that, because, as everybody with experience in working mountain railways knew, it was impossible to work a train-mile on an 8-per-cent. gradient for the same cost that it could be worked on a 4-per-cent. gradient. He had come to the conclusion, after investigating in Peru the relative costs of different gradients, that there was at least 20 per cent. difference in the cost per train-mile. When those two things were taken into account, it would be found that the cost of working on a railway of that description was about $17\frac{1}{2}$ to 30 per cent. in favour of the 4-per-cent. gradient. If the assumption were made that the gradient was 4 per cent., that the racks were done away with, and that the line was made about 40 per cent. longer, it would not mean an addition of 40 per cent. to the initial cost, because the stations and many other things would be the same. He believed that, for 25 per cent. increase in the cost, the railway could have been made with a 4-per-cent. gradient. Even with 25 per cent. increase in cost and 40 per cent. increase in length, the conditions would still be largely in favour of working this longer line and paying interest on the larger capital. He estimated that for every 3 per cent. of interest that could be paid on a line of 8-per-cent. gradient, 5 per cent. of interest on the larger capital could be paid with the same engines working on a 4-per-cent. gradient. Although not the only factor, speed was certainly the most important factor of the capacity of a line. The safe speed on an 8-per-cent. gradient was only two-fifths of that on a 4-per-cent. gradient, so that in respect of speed also it was found that the capacity was about two-and-a-half times as much with the flatter gradient. Taking into consideration the heavier train-load and the higher speed, the capacity of the line on a 4-per-cent. gradient, working by adhesion only, would be more than six times its present capacity. He did not say the making of this rack railway was not justified, but he did say that only the most serious considerations could have justified putting it where it was, on what was, and always would be, the trunk line from ocean to ocean in South America. As to the break of gauge, having worked on mountain railways and on level railways in the Argentine, he knew well what the conditions were for each gauge, and he was able to say confidently that rolling stock which was suitable for a mountain railway was utterly unsuited to the plains of Buenos Aires. The chief thing to be aimed at in a mountain railway was as low an axle-load as possible. That load was a function of the gradient; and for economical working

on the level it was essential to get wagons of very large capacity. But those wagons would be absolutely out of place on a mountain line, and anybody who attempted to run them up from Mendoza across the Andes and down to the coast would make a grave mistake economically. With regard to brakes, great trouble was experienced in using the vacuum brake at such high altitudes. On the Oroya railway the vacuum brake was useless, as in practice it only gave 6 inches of vacuum at 12,000 feet, and it had to be superseded altogether. It had been mentioned that on the Oroya railway the engines could not run by themselves. That was true in a measure, but not entirely so. He had come down from the summit of that railway using no brake but the repression brake. The fact was that the axle-load was the determining factor, and the brake-blocks could only go on absorbing 300 foot-tons per minute per pair of blocks. In handling engines on those 4-per-cent. gradients, if the train consisted of an engine and tender only it would have an average axle-load of about $12\frac{1}{4}$ tons, and a safe working-speed of $7\frac{1}{2}$ miles per hour; but if two wagons were added, the axle-load dropped to an average of $7\frac{1}{4}$ tons, and the safe speed immediately rose to 13 miles per hour; so that everything was not trusted to the driver. The Author spoke of Diesel engines giving only 70 per cent. of their power at an altitude of 12,500 feet, and Mr. Bach had had to deal with a very similar difficulty in La Paz. In that case the engines were not Diesel engines but ordinary internal-combustion engines, which he found were giving at 12,000 feet only about 50 per cent. of their normal power—a loss agreeing fairly closely with the 4 per cent. per 1,000 feet which had been mentioned by Mr. Bury. He suggested that if the Diesel engine had been supplied with compressed air it would have developed its full power. A specially light compressor could be fitted quite easily. He also wished to ask whether the consumption of the Diesel engine had been found to be inordinate, because he had found at La Paz that a gas-engine which was supposed to consume a little over 1 lb. of coal per brake horse-power-hour, was consuming about $4\frac{1}{2}$ lbs. He would like to know whether the Diesel engine acted in a similar way. It was hopeless to attempt to run the first motor-car that came to La Paz, for the same reason: the makers had not considered the loss of power that occurred at high altitudes. The two types of locomotives used on the Transandine Railway were stated to be of the same haulage-capacity, namely, 140 tons. That statement showed the fallacy of leaving out the boiler-power in considering the question of locomotive-

Mr. Bach. design. The fact that the two engines were in practice of equal haulage-capacity naturally resulted from giving them equal boilers and equal heating-surface. If the engine that Mr. Burnett had described were ever used, the same thing would be proved, namely, that it was useless to work out the tractive force if the boiler-power was insufficient to supply the steam for that tractive force. The ratio of the heating-surface in square feet to the tractive force in pounds should be about 1 : 15 or 1 : 16 for good practice. In the Esslingen engine it was 1 : 22; in the Kitson engine it was much nearer the proper ratio: but if it were not for the fact that the engine-power was always limited by the boiler, very different figures would be obtained for the loads. On working out some figures for those engines he had come to the conclusion that they would not take a train-load of 140 tons, in addition to themselves, up 1 in 12½, looking at the matter from the point of view of the boiler. On looking at the section of the line (Fig. 3, Plate 3) he could not find a gradient of 1 in 12½. He presumed that the 1-in-12½ sections were so short that they could not well be shown on a diagram of that sort. The fact was that no gradient of more than 1 in 14 was of such a length as to make a full demand on the boiler, and the work that the engines were doing would be more correctly considered as applied to a long gradient of 1 in 14 than of 1 in 12½. That conclusion, under the circumstances, fitted in very well with the figures which he had given for the relationship between heating-surface and tractive power. There was a further question he desired to ask the Author, in regard to the rack-engine and the adhesion engine. He did not know whether he was right in assuming that the two engines never worked together. [The AUTHOR said they did work together.] When working together the two engines had a much greater cylinder-power and tractive force than the boiler could possibly meet, and he ventured to suggest that if a differential arrangement were fitted, similar to that which the late Mr. F. W. Webb used on his three-cylinder compound engines, and if a 33-per-cent. cut-off in the adhesion engine and a 50-per-cent. cut-off in the rack-engine were adopted, all the boiler-power obtainable could be used with duplicate engines for adhesion and rack, which would enable all the cylinders of the engines to be made of the same size, namely, 16½ inches in diameter by 19 inches stroke. The engines would be lighter, cheaper in first cost, more powerful in proportion to the weight, and much less severe on the permanent way. In conclusion, why were the locomotives on the Transandine Railway still burning coal? The Oroya railway and practically all the railways up the

east coast of South America were now using oil fuel, and he suggested there would have been no difficulty in fitting the engines illustrated in the Paper to burn it. That would have been of very great advantage in hauling up to the summit, because although it was stated that the engine carried only $3\frac{1}{2}$ tons of coal, he assumed that it would burn about 7 tons on the trip up and down. Therefore 5 tons of the train might be deducted as virtually tender service. If the engine burned only what it could carry it would have less to take up, and every ton by which the train could be lightened on its upward journey was of importance. Another important consideration was that the labour involved in dealing with the oil, both on the engine and at the coast, was much less.

The AUTHOR, in reply, remarked that several speakers had decided that the best thing to do in the case of the Transandine Railway would have been to construct a railway on the adhesion and not on the rack system; and no doubt everybody would construct an adhesion railway in preference to a rack railway if circumstances allowed. Long before he had any connection with the railway the matter was looked into by his partner, Mr. James Livesey, who had surveys of an adhesion railway laid before him, and, after much consideration, came to the conclusion that an adhesion railway was practically impossible. Through the kindness of Mr. Clark he had been able, in the last few days, to inspect the survey plan made for that adhesion railway. He found that the length of the adhesion line was more than double that of the rack line; and if the members could only see the country in the winter, as he had seen it, they would realize that to go wandering about those mountains for twice the necessary distance was a task that no engineer would face. The difficulty of location had been not only one of gradients and curves, but also of avoiding snow-slides, casual avalanches, permanent avalanches, and all sorts of difficulties that were not met with in mountain railways under ordinary circumstances. The alternative would have been to go through the hills by means of a tunnel, the cost of which would have been prohibitive; and he was quite certain that if an adhesion system had been insisted upon, instead of combined rack and adhesion, the railway would not have existed at the present time, and the two countries would have been still unconnected by railway. It was a question of estimated cost. He estimated that an adhesion railway of 5-foot 6-inch gauge, which had been advocated by some members who, he must presume, were ignorant of the nature of the country, would have cost at least three times as much as the present line, and probably more. In stating that the

Mr. Bach.

The Author.

The Author. capacity of a railway was to be judged by multiplying the weight of the train by the speed, Mr. Waring had surely not considered the fact that a railway with an adhesion gradient of 1 in 40 was 3·2 times as long as a railway with a gradient of 1 in $12\frac{1}{2}$ and that his speed of 12 miles per hour on the adhesion railway would, therefore, have to be diminished very considerably to make the comparison correct. With regard to the Fell system, personally he had very little knowledge of it, except on a railway among the hills in Brazil, which had been built by a native company and eventually taken over by an English company. He had been sent out to report on it, and although it was a main-line railway, a section of it had been equipped with the Fell system at one period of its history. When he inspected the line he found they had given up working by the Fell system that particular section—which was about $7\frac{1}{2}$ miles in length, with a maximum gradient of 1 in $11\frac{1}{2}$ and very sharp curves of 88 feet radius—and used ordinary adhesion locomotives weighing 45 tons, and hauling up only 34 tons. The central Fell rail, however, continued to be used, for the purpose of enabling heavy trains to be brought down-hill, a very powerful scissors brake having been fitted on the engine, which enabled trains of about 150 tons to be let down the steep gradients. It was an interesting fact that every journey consumed one set of brake-blocks. That was the only experience, if it could be called an experience, he had had of the Fell system, but he was certain it would be useless in a country where ice and snow were met with, because, as was well known, it depended on adhesion. A suggestion he had made in the Paper, that possibly the proper way of working the line would be by an engine at the back and another at the front of the train, had been commented upon unfavourably, and probably the comment was quite correct. With one engine in front and another behind, nothing like the full duty was obtained from either engine. The difficulty in working a line like that described in the Paper was that the engine was required at the low end of the train for safety's sake, and for the same reason a heavy vehicle was required in front. That difficulty had not yet been properly solved on any rack railway; when it was solved, it would enable mountain railways to be worked with more safety. With reference to the use of the Westinghouse brake on long gradients, the difficulty Mr. Shelford had referred to could be overcome by employing a control-pipe. The gauge of the Argentine railways generally was 5 feet 6 inches, and that of most of the railways in Chile was the same; but a more unsuitable gauge for the Transandine line it would be hard to imagine. Mr. Simson had pointed out that the problem of getting up such a

valley as the one in question was more a matter of curves than The Author. anything else. In the Argentine Republic the Government prohibited, and wisely so, curves of less than 250 metres radius. Personally he would be very sorry to employ any curve of less than 200 metres radius, although it had been stated in the discussion that that was often done. The law prohibiting the use of any curve of less than 250 metres radius on a 5-foot 6-inch gauge rendered the use of that gauge for the Transandine Railway out of the question. Even if a wider gauge had been adopted and a sharp curve permitted, it would have cost a great deal more money, which, in those days, was not available. It must be borne in mind that the line had been under construction since 1887, and in those early days money was not so plentiful in South America. Financial people in Europe were not then very willing to find money for the Argentine, and every economy had to be practised. Mr. Shelford seemed to think that, by better surveying, a more satisfactory line could have been found, and that antiquated methods of survey had been adopted. The contrary was the case: the most able surveyors in Europe were employed, and the tachometer was used freely. Engineers from Switzerland, accustomed to mountain railways, spent years studying the route; and during a very long period Mr. M. Grant-Dalton, M. Inst. C.E., who was the resident engineer in Mendoza, had the country surveyed and resurveyed in order to ascertain the best position for the line. A railway must be built to meet the probable requirements of the traffic, and the Transandine Railway as constructed did this; but as the traffic increased and capital became available, it might be advisable to endeavour to eliminate some of the rack gradients, though the cost would be heavy. It was obvious that the concentration of the rack section into one length was advisable, as was stated in the Paper, but when it was impossible there did not seem to be much objection, having once split the rack into, say, six sections, to having ten or twelve sections. The reason why the rail on the rack section was heavier than that on the adhesion section was that extra work was thrown on the rail on the steep inclines where the rack was situated, particularly by the action of the brakes, and, if money had allowed it, the weight of the rail would have been considerably heavier than that adopted. As to the fuel used, on the Chilian side it was "Crown" fuel in briquettes, and on the Argentine side Welsh coal. There was no reason why oil should not be burnt in the locomotives as soon as a cheap and reliable supply could be obtained. The statement had been made that engineers had not exercised their intelligence fully in reducing the ratio of the tare

The Author. of wagons to the load carried. He disagreed with that view, because that was just one point to which engineers had given the greatest possible attention, the result being that on the railways in Argentina bogie wagons were carrying up to 45 tons load with a tare of 1 to 3. It would be a long time before anything much better was obtained, although no doubt everybody was trying to get still better results. The question of the summit tunnel was of historical, if not of engineering, interest, and he might recall some facts about the line before he had anything to do with it. When Mr. James Livesey was dealing with the matter the question of the cross-sectional area of the summit tunnel was discussed, the concessionaires and contractors desiring naturally that the tunnel should be of the most economical form possible. Mr. Livesey travelled in those days over most of the mountain railways in Europe, chiefly on the locomotive, in order to ascertain the effect area had on ventilation; and he judged, after studying the question, that a tunnel of about 25 square metres, or 269 square feet, was the proper size. The tunnel was not proceeded with, owing to financial reasons; the construction of the railway was stopped for many years, and when the Author came to deal with the matter the same question was still prominent, namely, what was the proper cross section for the summit tunnel? He went into it and found that, without there being any particular magic in the figure of 25 square metres, that was just about the right size. The contractors, however, were not entirely satisfied, as they thought something smaller would do. The matter was thereupon referred to Sir Francis Fox, who was asked to suggest a cross-sectional area, and he, without having heard what had been suggested previously, recommended 25·2 square metres. The Author believed the contractors still thought that a smaller tunnel would have answered, but against that he must point out that in the smaller tunnels—smaller because they were much shorter—the atmosphere was far from agreeable. He thought, therefore, that no great mistake had been made in deciding upon a tunnel of that area. In his opinion it was very questionable whether the high elevation of the summit tunnel was, as Mr. Clark claimed, in favour of good ventilation. Mr. Clark's observations upon this matter appeared to be based upon the assumption that the final location of the summit tunnel was exactly the same as his original location, but that was not the case. Mr. Clark had made the valuable suggestion that on mountain railways, where snow fell as heavily as it did in the case of the Transandine Railway, the line should be constructed, as far as possible, on banks. Moreover, in locating

a railway such as that described, it was necessary not only to study the hills, rivers, etc., in the usual fashion, but also, and more carefully than usual, the climatic conditions. The wind, as Mr. Clark had said, had a powerful effect in keeping the rail clear of snow, which was of great importance, particularly where there was a rack. The method of protection by hurdles mentioned by Mr. Shelford had been tried on the Transandine Railway. In conclusion, he would like to point out that a rack railway should be employed only where an adhesion railway was impossible, owing to high cost or other causes, and that a rack railway was a very useful method of overcoming difficulties which in many cases would otherwise be insuperable.

Correspondence.

Dr. ROMAN ABT, of Lucerne, observed that the Paper brought out, in addition to its numerous points of interest, a feature which was also to be observed in innumerable cases of railways constructed in the ordinary manner. A line would be built upon certain assumptions, and then one day it would be found that these were no longer correct, the most usual cause being a very large increase in the traffic. The Transandine Railway had been laid out with a maximum gradient of 8 per cent., up which rack locomotives 45 tons in weight hauled 70-ton trains at the rate of 5 miles per hour, corresponding with a tractive effort of about 10·5 tons, and an output of about 300 HP. According to the Paper, however, trains 140 tons in weight had now to be hauled at a speed of 8 miles per hour, and in order to do this locomotives of 87 tons had been provided, representing a threefold increase on the original power. The factor determining the capacity of a railway was its gradient. Where this exceeded a certain limit, well-considered auxiliary methods became necessary whenever an unusually heavy train-load had to be hauled. An 8-per-cent. gradient lay beyond the limit to be recommended in principle, not only on account of the capacity of the line but also having regard to safety in working. The latter depended upon the braking-appliances, and, so far as ordinary rolling stock was concerned, upon the adhesion between wheel and rail. In certain places an adhesion coefficient of $\frac{1}{5}$ could be calculated upon, but in the majority of cases, especially in moun-