

## Discussion.

The PRESIDENT, in proposing that the thanks of the Institution The President. should be given to the Author for his Paper, remarked that it was suggested sometimes that in the world romance was dead; but certainly, after hearing the account of the construction of the Simplon tunnel, romance in engineering must be admitted to be as alive as ever. What with the brave fellows engaged on the work finding first a lake of cold water and then a lake of hot water, and the final struggle between the miners and the imprisoned hot water—a struggle which had come so near to being a tragedy—the whole undertaking was apparently as full of romance as it was of energy, perseverance, and skill, from the very beginning. The Institution was greatly indebted to the Author for the very clear and interesting account he had given. A letter had been received from the General Direction of the Swiss Federal Railways, which was really a contribution to the discussion, and he would quote from a translation of it one or two passages which he felt sure the members would be glad to see recorded in the Proceedings. After a few introductory words the letter went on to say—

“As the personality of the Author would have led us to expect, this memoir is one of the most interesting and most complete that we know of on the works connected with the piercing of the Simplon, and we can accord to it nothing but praise and thanks so far as our administration is concerned . . . The only addition to the information which we should like to suggest is that we strongly desire that the members of the Institution should learn from Mr. Fox himself that the ventilation in the tunnel continues to be excellent, thanks chiefly to the electric traction which has been put into operation and now works to general satisfaction. Several newspapers, particularly in England, announce periodically, on the strength of information which has been misunderstood, that the temperature in the tunnel is intolerable and that the arch has given way in places. These statements are erroneous, for they confound tunnel No. 1, through which the trains pass and which is in perfect condition, with tunnel No. 2, which is not finished and which serves exclusively for the escape of water, some of it hot, from the springs met with in the tunnel. The absence of any mention of this in the Paper is due to its having occurred since the Paper was prepared; there has been no omission on the part of Mr. Fox.”

He could only congratulate Mr. Fox and the Institution on the expression of satisfaction which his account of this great enterprise had called forth from the Direction of the Swiss Federal Railways. The Paper raised a number of really difficult points in tunnelling, such as ventilation, dealing with soft rock and enormous quantities

The President. of water, and the best methods of boring, all of which lent themselves to interesting and valuable discussion.

The Author. The AUTHOR mentioned that he had received from the Italian Ambassador and the Swiss Minister in London, expressions of their regret at being unable to attend the discussion. He was sorry, too, that neither Dr. Locher-Freuler, Dr. Brandau, nor Dr. Sulzer-Zeigler could be present, the distance, the time of year, and their numerous engagements preventing them from crossing to England. With regard to the letter from which the President had read extracts, he desired to take this opportunity of asserting, as he had explained in the newspapers, that the statements which were made about the heat and the danger of the tunnel were false; indeed, they were ridiculous. They had led to the erroneous impression that it was necessary to close the windows of the train when passing through the tunnel, whereas the air was perfectly fresh and not unpleasantly warm; and these absurd rumours had even gone so far that it had been reported that the trains were enveloped in blankets on account of the heat! All such incorrect allegations emanated from people who for some reason were antagonistic to the tunnel. One point which he had not referred to in the Paper, but which he now mentioned as it might arise in the discussion, was that the speed of the drilling had been raised to such a point that any further increase was hardly necessary. Where further improvement was now wanted was in the removal of the debris from the face, because that was what occupied the time. Several methods had been tried. In one case, at the moment of explosion, jets of water under a pressure of about 90 atmospheres were directed upon the rock while it was in the act of being removed by the explosion; the water forced the rock back and distributed it over 100 feet of driftway instead of its being piled up in a huge mound in front of the actual explosion. By that means forty men could be put on to pick up the rock instead of the six men who would be working at the actual face. Any engineer who wished to make a fortune in the future had only to hit on some method of getting rid of rock quickly from the face. In the Library he had placed some photographic views which he hoped the members would look at, as the stereoscopic effect gave a vivid representation of the phenomena of tunnel-construction without any of the danger, inconvenience, heat, or fatigue inseparable from the actual work. When the Paper was written, the arrangements of the electric traction had not been finally settled, and that matter had therefore been omitted from the description; but the Federal Railways had put into his hands some books upon the subject, and he would mention briefly the salient points. The

work had been carried out by Messrs. Brown, Boveri & Co., of The Author. Baden, in Switzerland. The three-phase system was used, the current being generated and supplied to the motors at a pressure of 3,300 volts, with a periodicity of 16 cycles per second. The locomotive was of the bogie type with five axles, of which three were motor-driven, without gearing. The weight on the driving-wheels was 42 tons, and the length of the vehicle was 40 feet 6 inches. The normal power developed was 900 HP., the maximum being 2,300 HP. The copper conductors were placed overhead, fixed to the arching of the tunnel in order to offer no obstruction to the platelayers maintaining the permanent way. They were fixed in duplicate, so that in the event of breakage of one the traffic was not interrupted while the repairs were being effected. At 42 miles per hour the normal drawbar-pull was 7,700 lbs. and the maximum 20,000 lbs.; and at that speed passengers were now taken regularly through the tunnel in 18 minutes. To give some idea of the advantage of the tunnel to travellers he might mention that passengers leaving Victoria Station, London, at 11 o'clock in the morning could, on three days of the week, travel through from Calais to Milan without change of carriage in  $25\frac{1}{2}$  hours, and the only route by which this could be done was that of the Simplon tunnel. On the table were several samples of the rock which would well repay examination, and also a specimen of the lamp used by the miners, which burned olive oil. The lamp could be hung in a variety of ways, and wherever it was suspended it would remain in the right position. He thought that form of lamp might be adopted in England with advantage. The Author then exhibited a series of lantern-slides showing the tunnel in course of construction, the boring-machines and their method of use, the systems of ventilation and water-spraying, etc.

Mr. F. HUDLESTON had been unable to make out from the Paper Mr. Hudleston. whether the haulage had been done by steam-locomotives or not, and if the Author could tell him that it might affect the remarks he wished to make on the subject of the ventilation of the tunnel during construction.

The AUTHOR replied that the haulage had been done by steam- The Author. locomotives which fired up outside the tunnel; they travelled up to within 2 kilometres of the working-face with their fires damped. From this point the traffic was worked by compressed-air locomotives.

Mr. HUDLESTON remarked that 210,000 cubic feet of air per minute Mr. Hudleston. was a very large quantity. With steam-locomotives, even when the fires were damped, there was generally a good deal of steam, and much trouble was caused in a long tunnel. The tunnels with which he had been connected were chiefly "tubes," which, he was sorry to

Mr. Hudleston. see, the Author said were during construction the worst ventilated of all tunnels. A tube was not an easy thing to ventilate while it was under construction, for there was not much room in it. But there were not more than about a dozen men at the face of a tube, and as a rule in London there was no contamination of the air of the tube with the steam from the haulage-engine. Practically what had to be dealt with was the foulness due to the men themselves. No doubt it was better for the men to have fresh air, but the ordinary navvy did not care much about it, and on the few occasions when ventilation to some extent had been tried, the men had generally objected to the draught. As a rule, the ventilation effected by the amount of air given off by the air-driven pumps at the face—pumps which were now almost universally used—was sufficient to cool the face. He admitted that a person who was not used to such conditions generally felt the effect of the bad air, but when a navvy had got used to it he did not mind it much. If a steam-locomotive were put into a tube it was necessary to be very careful, and it might be interesting to mention an occurrence during the construction of the Central London Railway, when for a time steam-locomotives were in use. The tunnel had been driven, the railway was practically completed from end to end as far as the lining went, and it became necessary to lay the permanent way and finish the stations. The tube was constructed under high pressure; he believed no other tube railway of that magnitude had been completed in less time. When the permanent way had been partly laid, it became necessary to use light engines for the haulage of the material, and soon the workmen in the tunnel were affected by the foulness due to both the gases from the coal and the steam. A good deal of trouble was caused, and a method of ventilation was then adopted such as was generally carried out in colliery practice. At every other station a 5-foot Blackman fan was put up, and in one case, where there was an awkward arrangement of intakes, a 6-foot fan. All the passages were blocked at the uptake shafts, except where the fan ran, and doors were made through these bulkheads. The intermediate station-shafts were downcasts, and the fans sucked up all they could. By these means the tunnel had been kept practically free from fumes and steam in spite of the engines running. Trouble had occurred occasionally with the heavier engines afterwards, but still, things had gone on fairly well under steam. He had found that the quantity of air pumped out of the tunnel was about the same as the Author said was pumped out of the Simplon tunnel. The fans were driven by electric motors of about 10 HP., though as a matter of fact they did not need more than 5 HP., and the nominal delivery

of all six fans was about 285,000 cubic feet per minute. He Mr. Hudleston. did not suppose that delivery had been obtained, because the passages were constricted; but it was a very large amount, and the tunnel was ventilated fairly well. The draught was not appreciable because there were in reality six separate installations. One thing about the Simplon tunnel that struck him was that an enormous amount of air had to be taken through a single heading, which, according to one of the illustrations of the Paper, was about 70 square feet, though he thought the Author had said it was about 60 feet. If it were 60 square feet the velocity of the air would be about 60 feet per second through that small heading, and if it was the larger size,  $7\frac{1}{2}$  feet by 11 feet, which one of the illustrations of the Paper scaled, the velocity of the air would be 40 feet per second. No man could work in that hurricane with comfort. Although most of the work would be done in the break-ups, where the area was much larger and the velocity less, still it did seem a very large amount of air to pass through. Of course, if the 210,000 cubic feet was the total supply to both ends of the tunnel, these velocities would be approximately halved, but even then were extremely high. At the face they did not get the full quantity. The very ingenious arrangement whereby a current was induced up to the face gave a good deal of air, but how much he did not know: he supposed it could easily have been measured, but it could have been nothing like 210,000 cubic feet per minute, for no man working hard and perspiring freely could stand a gale of that sort; he would quickly be in the doctor's hands. The changing of clothing, etc., on the part of the men was of course practically a necessity in a long tunnel. The same precautions were taken in England in all compressed-air tunnels, where they were more necessary than in a free-air tunnel like the Simplon. In compressed air men perspired much more profusely than in the open air, and became practically drenched, and in the Simplon and other Alpine tunnels he supposed the men working at the face were in much the same condition; but the worker in compressed air had to face the chilling effect of the air-lock when leaving his work. Some attention was paid to those matters in England, but it was not possible to treat the men in the same fatherly way they were treated in Italy and elsewhere, for the ordinary English navvy did not care to be nursed. The Paper stated that for every foot of air blown into the St. Gothard tunnel, 25 feet were supplied to the workmen in the Simplon. In the Arlberg tunnel the supply was said to have been about 8,000 feet per minute, but he did not think any very special ventilating-arrangements were provided there. The temperatures mentioned in the Paper were

Mr. Hudleston. extraordinary, and were never met with in ordinary tunnelling. In tube work the temperature seldom rose much above  $75^{\circ}$  F.: in compressed air it might reach  $80^{\circ}$ , but hardly beyond that. It was only in compressed air that the higher temperature was reached, generally at the top of the working-face, where, owing to the extraordinary quantity of heat given out by the grouting lime put in at the back of the iron lining, the iron was often too hot to put the hand upon. In the lower parts of the tunnel that temperature was seldom reached; even  $80^{\circ}$  was quite high enough, and necessitated special precautions in cooling down. It would be interesting to know how long the men had worked in such temperatures as  $129^{\circ}$  to  $134^{\circ}$  F., and whether they had found it very trying; also approximately how much air per man had reached the face. He would be glad if the Author could state also the total number of men working in the tunnel, because that would give an idea of what air-supply the 210,000 cubic feet represented.

Mr. Hodson. Mr. C. W. Hodson thought it would be agreed that the Paper was a very interesting account of a piece of work of unprecedented difficulty, and that the wonderful manner in which the difficulties had been met and finally overcome was worthy of the highest praise. Some of those difficulties were very like those experienced in 1890, during the driving of the Khojak tunnel, on the railway from Quetta towards Kandahar, which, though only about  $2\frac{1}{2}$  miles long, or about one-fifth the length of the Simplon tunnel, was still a very notable work. There, however, there were no hot springs. Like the Simplon, the Khojak tunnel was laid out with gradients ascending from each end to the middle, where it was intended that the headings should meet, and, as at the Simplon, the headings did not meet at the middle after all. One was unduly delayed, and the other had to be driven for a considerable distance down-hill, in spite of great difficulties, due to the large amount of water in the heading. The rather peculiar position of that tunnel had made it necessary for the western mouth to be about 150 feet lower than the eastern mouth, and as a consequence the gradient on the eastern side was only 1 in 1,000, while that on the western side was the rather heavy one of 1 in 40. The western heading was driven at the rate of about 60 feet per week until it had passed the summit and was on the downward gradient, where it struck very heavy springs of water. The western heading at that time was about 500 feet away, and was itself in great difficulties owing to rotten ground and torrents of water, against which the men could hardly stand up, though here the gradient helped a great deal, as it enabled the water to get away quickly. Time being the main consideration, the engineers decided to go on with the eastern heading

in spite of difficulties. They adopted the same expedient as that Mr. Hodson. used in the Simplon, driving the heading upwards at intervals until it was 15 feet above its proper level; but finally they had, owing to the water, to retire and to build a wall across the heading. In the west heading also an expedient very similar to that described in the Paper was adopted; a side heading was driven from a point about 100 feet back from the face so as to try to get behind the springs of water, and to relieve the pressure to a certain extent. When the west heading was approaching the drowned heading it was driven up to the level of the other, instead of adhering to the gradient of the tunnel; and the engineers kept a long drill-hole ahead until they struck the eastern heading, which was drowned, and allowed the water to drain away gradually, thereby avoiding the great rush of water, which would have been attended with some risk.<sup>1</sup>

Mr. MAURICE FITZMAURICE observed that everyone connected with tunnelling in rock knew that the removal of debris from the face of the heading was a most important matter, as it took up practically half the time. The Tables at the end of the Paper—one of which he understood related to the time when the work was going on very favourably, and the other to the time when it was being carried on under great difficulties—showed that the time spent in drilling and the time spent in getting rid of the debris were about equal. When the work was proceeding quickly, drilling occupied  $11\frac{1}{2}$  hours, and getting rid of the debris  $12\frac{1}{2}$  hours, in the 24; when the work was going on under difficulties, the drilling took  $13\frac{3}{4}$  hours, and getting rid of the debris  $10\frac{1}{4}$  hours. He had dealt with this question rather fully some years ago, when a Paper on the Totley tunnel<sup>2</sup> was read before the Institution. It was pointed out in that Paper that the improvements in drills and explosives had been so great that the only chance of getting any further increase in the rate of progress in the headings would be by devising some method for dealing quickly with the debris at the face. The Author of the present Paper had suggested that that matter might well be studied by engineers, but as the Author had been exploring the field for a long time under very favourable circumstances, Mr. Fitzmaurice was quite sure he would be able to give some further information as to what had been tried in connection with the important matter of removing debris at the Simplon tunnel. It would be of great interest

Mr. Maurice  
Fitzmaurice.

<sup>1</sup> G. P. Rose, "Report on the Chaman Extension Railway." Technical Papers of the Government of India, No. 35. (In the Library of the Institution.)

<sup>2</sup> P. Rickard, "Tunnels on the Dore and Chinley Railway." Minutes of Proceedings Inst. C.E., vol. cxvi, p. 159.

Mr. Maurice  
Fitzmaurice.

if he would state whether any experiments had been made, and whether any improvement in the speed had been achieved as the work went on. It was not very encouraging to those who had to deal with that class of work not to know what had been done before. Mr. Fitzmaurice had looked back to the Paper written by the Author's son in the earlier stages of the work, and the only method of dealing specially with the matter which he could see mentioned there was the adoption of a steel plate which was put down on the floor of the heading, so that the shovelling up of the debris might be more expeditious. Of course, it was not a question of getting rid of all the debris; the important thing was to get rid of the portion in the middle of the floor of the heading, so that the drilling-machines could be brought up to the face again. In that connection he noticed that the heading was a particularly wide one in relation to the height, and he would like to know whether it had been purposely made so with the object of getting the debris quickly to the sides of the heading so as to give room for the drilling-machines to be brought up to the face as quickly as possible. He noticed that the length of the holes drilled was very short; they appeared to average 1.2 metre, say 3 feet 6 inches to 4 feet. He did not quite know why such short holes had been adopted. Short holes meant more attacks on the face during the 24 hours, and consequently a larger number of times when the drilling-machines had to be taken away from the face and brought back again. At first sight that would appear to be rather a waste of time, but he was quite sure there was some good reason for what had been done. In Table I there were nine attacks on the face during the 24 hours when the work was going on quickly, and in Table II five attacks when the work was going on slowly. Consequently, considerable time must have been occupied in taking away the machines and bringing them back again. Under those conditions it did not seem to be of such vital importance for the men to relieve each other at the machines without a moment's pause. With the machines being so often brought back from the face, the gangs might frequently have relieved each other during the time when the machine was not at the face, which would have saved the men's time. He also noticed that a very large quantity of explosives had been used per cubic yard of rock, and he desired to know whether that had been done with a view to greater shattering of the rock so as to render removal of debris easier, or on account of the particular class of rock met with. With regard to the rate of progress, the rapidity attained had not been reached in any other tunnel that he was aware of. In the Totley tunnel the progress on some occasions had very nearly reached the average rate for the Simplon tunnel, but



the average all through the work had never been anything like what had been attained at the Simplon. On the other hand, the heading adopted at the Totley tunnel was nearly double the size of the heading in the Simplon, the latter being 55 square feet, whereas the Totley heading was 10 feet by 10 feet. In the case of the Totley tunnel the large heading had been adopted in order to enable larger trucks to be brought in to deal with the rock. If the Author could give a little further information on the points Mr. Fitzmaurice had mentioned, it would add still further to the high value of the Paper.

Mr. ERNEST BENEDICT wished to know what had been the hygro-metric condition of the air in the tunnel. It was absolutely impossible for Europeans to do hard manual labour in a temperature of 80° F. in Bombay or Calcutta, whereas in a dry atmosphere, as in Egypt or the Punjab, that temperature did not prevent work from being carried on. Personally, although he had had some experience in India, he had never known any large body of Europeans working for any length of time in such temperatures as those mentioned by the Author, though there were records of English soldiers having done wonderful feats in great heat during the Mutiny. He would also like to have some information as to the sanitary arrangements, which appeared to have been perfect, as he understood that the miners' illness was due entirely to neglect to promptly get rid of the dejecta of the workmen. With reference to the levels, it seemed extraordinary to a man who had had to do a little tunnelling work, that under the circumstances such accuracy should have been attained. The curvature of the earth must have made it very difficult to get a sight through: the Author said that he had got a sight of 5 miles, but that must have been almost accidental. The Author also said that an error of about 3 feet was anticipated in the length; probably that was arrived at by halving an extreme difference of 6 feet in the observations. It was an extraordinary result considering the difficulties of working in such huge mountain masses. It would seem almost impossible, under the circumstances, to get within a few inches of the level, as had been done. It had often seemed to him that in such cases a rough but easy check might be put on the levels by means of water, though of course in long tubes time would have to be allowed for the water to get to the level.

Mr. OSCAR GUTTMANN recollected seeing, 32 years ago, Mr. Brandt's first drill. He remembered, too, the excellent impression Mr. Brandt had made upon everybody as an engineer and a gentleman, and he would have been glad to see, in the Paper, some stronger recognition of Mr. Brandt's work. Mr. Brandt's rock-drill had probably done more than anything else for the progress of modern tunnelling.

Mr. Maurice  
Fitzmaurice.

Mr. Benedict.

Mr. Guttman.

Mr. Guttman. In conjunction with high explosives it had undoubtedly made progress in that kind of work extremely easy. The work of the first Brandt drill on the Sonnstein tunnel in Austria was undoubtedly much slower than anything at the Simplon, and it would be interesting to have a comparison of the rate of progress made in the various tunnels from the Sonnstein tunnel down to the Simplon. The consumption of explosives was not given in the Paper per cubic yard of rock, but calculation showed that 2·84 lbs. of dynamite was used per cubic yard of rock. That was about 25 per cent. less than at the St. Gothard, where, he believed, the same kind of rock was met with. As it was very important for engineers who had to undertake tunnelling work to know exactly what they could get from the explosives used, he thought a little supplementary information would be much appreciated. He had been very interested in seeing the familiar miner's lamp, a lamp which his own antiquarian researches had shown him existed 500 or 600 years ago in Hungarian and German mines, and which no Italian miner would be without. From the remarks of the Author it would seem that he thought the lamp was unknown in England, but Mr. Guttman believed he had seen it—or a very similar lamp—in Cornish mines. He did not think anything simpler or better calculated to withstand rough usage could be invented, and he fully endorsed what the Author had said as to the ease with which the lamp was manipulated; it would stick almost anywhere. The nozzle used for producing spray was different from any he had yet seen, although it was like some others in having inside a spiral which caused a jet of water to revolve and come out in fine spray. Nozzles were largely used for producing a fine spray of water in sulphuric-acid chambers; such nozzles were smaller than those used at the Simplon tunnel, and the spray produced was so fine as to be really a fine mist. The disease of anchylostomiasis, caused by the presence of a small worm, the *Anchylostoma duodenale*, in the intestines, had been met with in the St. Gothard and many other tunnels, and was first studied in the lead and silver mines of Příbram in Austria by a medical man, Dr. H. Goldmann. A Paper<sup>1</sup> on the subject had appeared in the Journal of the Austrian Society of Engineers and Architects, and it would be found in the library of the Institution with an enlarged picture of the worm. That was long before so-called miners' phthisis in this country troubled the minds of officials.

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<sup>1</sup> L. Jehle, "Die Anchylostomiasis, eine Berufskrankheit der Tunnelarbeiter." Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, vol. liv (1902), p. 542.

Mr. BERTRAM BLOUNT mentioned that the analysis given on p. 76 Mr. Blount. had been made by his assistant, Mr. Levy, in his laboratory. Its interest lay in the entire absence of chlorine, and in that respect it was water of a kind new to all chemists and water-engineers. He did not suppose that a case of that kind had ever been met with before, and the conclusion was irresistible that the water had never been on the surface of the globe—that it was, as the Author said, plutonic. To explain how such plutonic water could occur, and why it should be brought to the surface of the earth at that very moderate depth, was a matter for the geologists, and he understood they were somewhat exercised about it. It might be useful if an opinion upon that point could be elicited from geologists.

Mr. WM. R. GALBRAITH, Vice-President, remarked that the Paper Mr. Galbraith. described a great work, admirably planned and carried through with the utmost perseverance, and it might be that the members were a little reluctant to discuss trivial matters in connection with so elaborate an undertaking. Long as the Simplon tunnel was, probably a greater aggregate length of "tube" tunnelling had been carried out in London in the last few years, and there also he had been astonished at the accuracy of driving. Of course, there was no single tube 12 miles in length; but in the Simplon tunnel the alignment was straight, and this, with the use of very powerful and fine instruments, had made for accuracy. In constructing the Baker Street and Waterloo Railway, it had been impossible to work on straight lines. For instance, lines were laid down in the shaft in the River Thames, and from there the tunnel was driven towards Piccadilly. There was no straight drive from the Piccadilly shaft, because the tunnel had first to be driven across into the Haymarket and also round a curve at the bottom of the Haymarket; and yet, with all that, there was not an error of more than  $\frac{1}{2}$  inch in the lines when they met. In the levels there was really no error at all in some cases: it was a fluke, of course, but it came out all right. He was also astonished at the rate of progress of the work in the Simplon tunnel—about 17 feet per day at each heading. He thought that for tube-tunnelling a record had been established on some of the works that had been carried out lately. On the Charing Cross, Euston and Hampstead line, 22 feet of tunnel per day had been completed. Mr. Price, the contractor, had used his rotary digger, and the lines had been driven very accurately on the whole. He believed Mr. Ross had established a further record on the line to the Strand. The difficulty of driving 17 feet per day in a tunnel of the length of the Simplon tunnel made that great work wonderful. There was not such good ventilation in some of the tunnels in London, because such scientific and careful

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Mr. Galbraith. arrangements were not made for the work. For instance, one of the contractors did not use electric engines to draw the spoil from the face to the shaft; he used ponies, and when Mr. Galbraith ventured to tell him that that method was quite out of date he was somewhat offended. The work was done quickly, however. The idea of granite arches 5 feet thick made an engineer's blood run cold; but the Author did not say how much there was of such work, or what the general lining of the tunnel was. No doubt arches, particularly arches of such dimensions, had been used only in very exceptional situations. Government inspectors required that all tunnels should be lined, because with an unlined tunnel there was likelihood of the fall of rock. With regard to the speed of tunnelling, for the old-fashioned method of driving tunnels in ordinary ground the rule of thumb, "a length per face per fortnight," meant about two lengths of 12 or 13 feet per month at a face, or 24 feet per month. When that was compared with 17 feet per day the latter could only be said to be marvellous.

Mr. Colson. Mr. C. H. COLSON asked whether the Author could add to the Paper a plan and a few more details showing the setting-out. A plan showing the lines of triangulation had been exhibited on the screen, but there was nothing in the Paper. He himself had never had to do with large tunnels, and he would very much like to know the basis on which arches 5 feet thick had been worked out: on what grounds had their thickness been decided?

Sir Douglas Fox. Sir DOUGLAS FOX, Past-President, desired to confirm what Mr. Galbraith had said as to the great accuracy with which the assistants of tunnel-engineers had been able to set out tunnels under difficult circumstances. In the case of the Mersey tunnel<sup>1</sup> the difficulties were very considerable, because, as in London, it was impossible to place the shafts on the line of the tunnel, and there were curved headings leading from one of the shafts to the tunnel, consequently the setting-out was complicated. It was rendered still more difficult by the fact that the lines were set out in a drainage-heading which was a continuous shower-bath. It was exceedingly difficult even to walk along the heading, and still harder to perform any delicate operation in it. In that case, when the two headings were about to meet it was decided that the Mayors of the two towns should come and shake hands in the middle. He ventured to suggest to the resident engineer that a bore-hole should be put in before the Mayors came, at which he was offended, saying that it was unnecessary, as he was quite certain where he was.

<sup>1</sup> See Minutes of Proceedings Inst. C.E., vol. clxii, p. 344.

However, Sir James Brunlees and himself insisted upon having it, with the result that a bore-hole was put through from one side in the centre-line, and the edge of the bore-hole struck the centre-line on the other side. On the Charing Cross, Euston and Hampstead Railway, with which Mr. Galbraith and his own firm were connected, there were six closures, and five of them had come within  $\frac{1}{4}$  inch. In the sixth case the resident engineer telegraphed to say he was very sorry to have to report that the difference was  $\frac{1}{2}$  inch, and he could not account for it! That showed extreme care on the part of the resident engineers and great credit was due to them. There was quite as much difficulty in dealing with such matters, which were complicated by the traffic in the streets overhead, by the curves in the streets, and by the want of anything like a really good base for the work, as there was in longer tunnels. The Author had said very little about his own part in the matter, and, being his brother, Sir Douglas did not wish to say much about it either, but he would like to emphasize the fact that if there had been good ventilation-arrangements they had been the outcome of exertion on the part of the Author to have proper conditions inserted in the specification. He only wished it were possible to get similar clauses into some English contracts. It did not matter to him as an elderly man, but for the sake of some of the younger engineers it would be very desirable, because very often the air at the face of tunnel-works in England was very trying, not merely to the workmen, who did not seem to mind it, but to the engineers, who did. When the result attained in the Simplon case was considered, he thought the Commissioners who laid down the rules on which the work had to be carried out had every reason to congratulate themselves. The contrast between the St. Gothard tunnel, with its sad history, and the Simplon tunnel, with its empty hospital, spoke volumes for what could be done by care; and he thought engineers ought as far as possible to insist that the working man to whom they owed so much should in all large undertakings be looked after, even if he would not look after himself, and should be protected, even against his will.

Mr. WALTER HUNTER mentioned that about 4 years ago he visited the Simplon tunnel, and was greatly struck with the care taken for the comfort and health of the men employed there. The machinery outside was very interesting, and had he known he was going to be detained in the country, he would have asked for a letter of introduction in order to examine the work thoroughly. As it was, he went into the tunnel as far as the casual visitor was allowed to go, and what he saw of the arrangements for the health and

Sir Douglas  
Fox.

Mr. Hunter.

Mr. Hunter. comfort of the men made him wish that they could be provided for the workers at home. No doubt the tunnel would be an important means of communication between the two countries which it joined, but he strongly advised people after going through the tunnel in one direction to come back over the pass, for, probably, a finer piece of scenery could not be found anywhere in the world.

Mr. Coath. MR. D. D. COATH had visited the Simplon tunnel shortly after the galleries were pierced, and he could only say it was a very remarkable piece of work. The whole construction of the tunnel had been a question of ventilation, because without efficient ventilation the tunnel would never have been completed. From the temperatures which he had heard of before he went into the tunnel, he expected to find something very terrible. The temperature certainly was as reported, but there was no great discomfort, simply on account of the excellent ventilation which existed. In fact, during the 4 hours he was there he was much more comfortable than he had been on the underground railway in London before it was electrified. The arrangements for the men had been about as perfect as they could be. As one speaker had observed, they probably would not do in England, because the British navy might object to being nursed; but the Simplon workmen had certainly been nursed to their own benefit. One advantage the Simplon tunnel had over the other two Alpine tunnels was the ease of access. An ordinary engine took the train from Lausanne to Brigue. That was very different from the St. Gothard line, where two or three engines were used, and the trains twisted about for hours on all sorts of curves and through spiral tunnels before getting to the tunnel itself—a fine work from a purely engineering point of view, but very slow and expensive to work. A curious coincidence about the Simplon tunnel was that it was finished and opened just 100 years after the Simplon road, which was regarded as the greatest work Napoleon ever constructed. That was a work undertaken solely in the interests of war and destruction, while the Simplon tunnel had been constructed wholly in the interests of peace and civilization.

The Author. THE AUTHOR, in reply to Mr. Hudleston's questions, pointed out that No. 1 tunnel had been kept about 1 kilometre behind the excavation, and had been arched quickly, as shown in *Fig. 11*, so that there was a full area of about 250 square feet along which the current passed, and it was in that the men travelled. The air was blown in along No. 2 gallery, and at every 200 metres (656 feet) there was a transverse gallery with doors. The current of air naturally took the shortest route, and went through the last cross cut which was open, returning by the larger section, where the velocity was low. The

men worked in the advance gallery, where only a comparatively small volume was required, amounting probably to about 2,000 cubic feet per minute. The speed of the current was not by any means excessive where work was proceeding, and by keeping open the doors in the different galleries it was possible to regulate the current to any point desired. The 210,000 cubic feet per minute mentioned in the Paper was the total supply of air to both ends of the tunnel. Mr. Hudleston had also spoken about the nursing of the English navy. It might be quite true that he did not want it, but in most jobs he certainly did not get it. With some noble exceptions, the English navy was not properly considered, and the question of ventilation of tunnels for his welfare was not sufficiently attended to. When future tunnels were driven in England, he trusted the question of ventilation would be given a much more prominent place. It was difficult to give the number of men that had worked in the tunnel, because it had varied; but he thought it might be taken that with the works in full operation the total number of men had been rather more than 3,000, that was, 1,500 to 1,600 on each side. Of that number probably one-third had been out in the open air or in the workshops, and the other two-thirds had been either in the advance heading, or engaged in enlarging the gallery into the tunnel, or on the arching. The trains used to go in three times a day, at 6 a.m., 2 p.m. and 10 p.m., with about 200 to 300 men each, who were dropped at different points in the tunnel for the carrying on of the work. With regard to Mr. Fitzmaurice's question as to what had been done in the matter of clearing away the debris, in his son's Paper some description was given of that, but he only hinted at the question of *marinage*. One method was to lay plates on the floor, so that when the explosion took place there was a smooth surface for the rock to slide over, and it travelled some distance along the heading: the men shovelling up the debris thus had something smooth for their shovels to work upon. The question of *marinage* had not yet been solved, although a good many experiments had been made. In one of these a high-pressure pipe was taken up as near to the face as was safe; it was then covered with old timber, sleepers, etc., and jets of water were fixed near the end of the gallery, with the jet blowing away from the face, so that the moment the explosion took place the water could be turned on and directed upon the flying rock, forcing it away from the face and distributing it many metres along the passage, instead of its being heaped up in a mound in front. That was a subject well worthy of consideration and further development. The heading had been made 10 feet wide in order that three drills might be at work at a time,

**The Author.** and it also gave two narrow roads, an up and a down, for the wagons. With regard to changing the shifts, he need hardly point out to Mr. Fitzmaurice that to arrange for that to take place when the machines were withdrawn into the cross galleries out of the way of the explosion would have been impracticable, because it was never known at what hour the blast was going to be made; it depended entirely upon the speed of the drills. Mr. Benedict had asked about the sanitary arrangements, and how the excreta had been removed. There had been a custodian to each latrine, whose business it had been to keep everything sweet and clean. The Author had never been able to discern, when in the tunnel, the proximity of the latrines. With regard to the calculation of possible error, a volume had been written by Dr. Rosenmund on the matter, and it was to him and his assistants that the wonderful accuracy of the line was due. Mr. Guttman had asked for something more to be said about Mr. Brandt. The Author had not said much in the Paper because he had often said it before, but he could assure Mr. Guttman that it was not from want of regard or respect for that good man's memory. The way in which Mr. Brandt had carried out his work, and the many improvements he had introduced from his experience at the St. Gothard, were beyond all praise. He had endeavoured to do justice to all the gentlemen in charge of the work. Messrs. Brandau, Sulzer, and Locher were three men—had Mr. Brandt lived there would have been four—who formed a wonderful combination of dogged determination, of financial and mechanical skill, and of a frame of mind that would absolutely refuse to acknowledge defeat. Over and over again it had been said the tunnel was impossible and could not be made, and Dr. Sulzer had replied, “‘Impossible’ is not in my dictionary; the tunnel must go through.” The credit of that was due to the gentlemen, German, Swiss, Austrian, and Hungarian, who had carried out that wonderful work. Mr. Blount had asked a question which the Author was afraid he could not answer, about the definition of plutonic water. He had had a very interesting letter from Dr. Locher, who said he believed that the real explanation of the peculiar phenomenon encountered in the tunnel, namely, two springs of water within a metre of one another differing by many degrees in temperature, was that one of them was plutonic water from below, water that had never seen daylight, and the other was surface water, heated by the rock and containing chlorine. With reference to the accuracy of lines and levels, Mr. Galbraith had given some very remarkable examples, and the Author desired to supplement them with some account of work in the tube railways of London, in which Sir Douglas Fox and he had had the pleasure of being associated with Mr.



Galbraith and the late Mr. Greathead. When he said that there had been numerous cases in which two shields had been put down two shafts 1,000 or 1,200 yards apart—shafts which were off the centre-line—that a drift had been made from the shaft to the centre-line in the middle of the road, that the line was on curves and gradients, and that notwithstanding all this those two shields had met edge to edge and had actually been left in as portions of the lining of the tunnel, it would be seen how high a degree of accuracy had been attained. As to the progress, 17 feet per day had been the average. There had been days on which as much as 32 feet had been driven through granite, which was quite a record. The arching 5 feet 6 inches thick had been used only in those difficult places where the timbers had been crushed. The average thickness of the lining from end to end might not exceed 2 feet 3 inches or 2 feet 6 inches. In many places, of course, an invert had to be provided to allow for the side pressure. In conclusion, he thanked the members for the attention they had given to the Paper, and he trusted it might be a useful record in the Proceedings of the Institution. The Author.

### Correspondence.

Dr. KARL BRANDAU expressed his pleasure at the excellent grasp of the subject displayed by the Author. Whilst those responsible were contending, in the heart of the mountain, with difficulties which they had been able to conquer only by severe and protracted toil, they much dreaded the criticism of engineering experts. This fear had fortunately proved to be unfounded, and on all sides they had met with unprejudiced and hearty approval. This was shown also by the friendly sentiments of the Author. With regard to deductions of scientific and practical importance made during the execution of the tunnel, besides the observations already recorded—concerning the distribution of the temperature at great depths below the surface, and with respect to the nature of the water encountered—knowledge had been increased by the observations made on the stratified construction of the Simplon range. Thus the transfer of great mountain masses from considerable distances was a new fact, as was also the penetration deep into the earth of distortions of the mountain strata. Below a depth of 6,500 feet were found beds of recent formations, underlying those of the