Discussion

The President, when proposing the vote of thanks to the Authors, said he had gained the impression, when reading, that the work had been carried out with an unusually small number of Europeans. The Authors must have trained their Indian subordinates extremely well to have been able to give them so much responsible work to do. The site had clearly been extremely difficult of access, necessitating much improvization. No attempt had been made to get a highly finished temporary works but everything had been done in a way very suitable for the work.

Mr A. P. Lambert observed that the main value of the Paper lay in its straightforward and honest description of the work which the Authors had carried out. It was particularly valuable because the Authors had described some of their problems, how they had tried to solve those problems, and how in some instances they would do things a little differently another time ; for instance, the ventilating ducts had not been quite large enough and the fog at the tunnel face might have been reduced if there had been after-coolers and separators to get rid of the moisture before the air went into the tunnel. The relationship of the size of the wagon to the rocker-shovel had also been mentioned. A Paper in which the Authors frankly stated their difficulties and confessed that they had not quite overcome them was very much more valuable than a Paper where there seemed to have been a magician in the background, where no problems ever occurred, and where any difficulties were solved before anybody knew anything about them.

He thought that the Paper was lacking in information in one or two places, and it would be of interest if those gaps could be filled in. He could not find any statement about the thickness of lining which had been asked for. There was given in *Figs 1* (*b*) a cross-section of the tunnel, and the dotted line inside the face of the tunnel looked as though it might be 6 inches from the face and that might be the line in question. The information, if it could be given, would make it possible to compare the thickness of the lining in this case with the thickness used elsewhere. It was also a matter of great importance to the contractor, because the influence of the concrete in the over-break was affected by the thickness of lining ; if the contractor had already to provide a thick lining, the concrete which he lost in the over-break was relatively less important, and he might take a slightly different line when blowing his tunnel ; it might pay him to insure against the possibility of having to undertake expensive trimming by cutting the rock a little wide. On p. 136 reference was made to the final cross-section of the tunnel ; what was the average thickness provided compared with the minimum thickness asked for ?

Referring to the statement on p. 128 that "Consequently, a 40-foot-long

travelling steel shutter " had been sent out from the United Kingdom, Mr Lambert asked the reason for the word " consequently." Why had a length of 40 feet been chosen ? He believed that a contractor planning the lining of a tunnel would find that the calculation of the economic length of shutter was very interesting, and also extremely important to him so far as the economic results of his contract were concerned. It was probably almost the most important decision which the contractor had to make. If one shutter were twice as long as another, it could be agreed that it would cost nearly twice as much ; but, having accepted that, there seemed to be many benefits which devolved from the longer shutter. For instance, the stop ends, which were troublesome in any case, would occur only half as often. If the tunnel was to be lined with a pneumatic placer it was the common experience that difficulties with that technique, if they occurred at all, occurred at the start of the pour ; once the concrete had reached the crown of the arch and the end of the discharge pipe could be buried, everything went much more simply. If the shutter were twice as long that troublesome period occurred only half as often.

In the case described, the " waiting time " had been 16 hours after filling the shutter, and the Authors had obtained an average of 5 moves per week. That meant a total of 80 hours, and there were only 168 hours in a week, including the week-end, which probably had not been worked, so that rather more than half the effective working time had been occupied in waiting for the concrete to go off. It would still be 16 hours with a shutter twice as long, so that the effective lost time would be halved. Mr Lambert did not want to suggest that in the case in question the shutter should have been twice as long, but perhaps the Authors would say a little more about their calculations, and their reasons for deciding on a length of 40 feet, which on the face of it seemed to be rather short.

Would the Authors state the cement content of the mix, so that it would be possible to compare the richness of that concrete with concrete in other tunnels. Mr Lambert thought that those in charge of the work on the site had been under a very great disadvantage with the concrete which they had had to use, in the first place because only a very small proportion of natural sand had been available, and crusher-produced sand was a very unsympathetic material ; with crusher-run aggregate, particularly of hard igneous rock, the aggregate was very liable to segregation in the handling. Those factors meant that it was desirable to have better-than-average facilities to split the aggregate into sizes and re-blend it correctly for the concreting, but the Authors had had considerably less than the average facilities for doing that. Those who had used concrete in any situation which was a little unusual, and where they were trying to follow a rather special technique, would have found that there was a mix and a grading, which would suit their requirements, and, having found that grading it was of the utmost importance to be able to preserve it. He did not believe that the Authors had had the necessary facilities

to preserve it, and a good many of their difficulties in the concreting might have devolved from that lack of adequate control.

That led Mr Lambert to question the conclusion on p. 133, that the method of using the pneumatic placer was unsuitable for tunnels more than 15 feet diameter. That might be so, but he thought that that conclusion must be accepted with a reservation until the equipment could be tried out under conditions more favourable for concreting.

An important aspect of lining a tunnel with the pneumatic placer was the actual rate of concreting. Whatever the size of the tunnel, the concrete had to be put in at such a pace that the wet end of the concrete was kept moving forward at a satisfactory rate, and that satisfactory rate must be such that the concrete—any concrete—was completely submerged and compacted and buried by other concrete before it started to go off. It followed from this that, as the size of the tunnel increased, so the rate of placing must increase in order to preserve that uniform movement along the tunnel, and it might be that with a 15-foot tunnel the rate of placing by the one placer was not adequate.

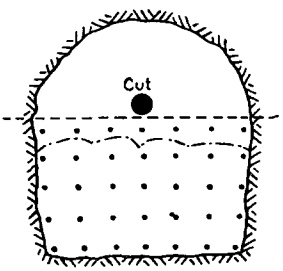
Could the Authors give further data about the rate of placing? Mr Lambert had calculated from the figures given in the Paper that each pour had been between 105 and 110 yards of concrete, but the Authors had not stated whether it was a 3-hour or a 6-hour job; he felt that with the placer equipment which had been used, the quicker the rate of emplacement, the better would be the concrete. A state of affairs might be arrived at where, in a very big tunnel, it was desirable to double the equipment, but to arrive at the conclusion that it was necessary to use one type of apparatus to do the crown and a different sort of apparatus to do the walls was one which he did not think could be accepted without exploring the alternatives more fully.

Mr W. B. Tozer remarked upon the fundamental advantage of overlapped drilling and mucking. In a normal cycle, in which drilling, blasting, and mucking succeeded each other, the drilling time was regulated not by the maximum number of machines which could be crowded into the face but by the minimum number of holes which one machine must deal with, and the cut-hole pattern usually decided that, particularly if it was a burn cut, such as was used in the tunnel in question.

In the case described, he thought that six cut holes had been shown in the film with which the Authors had introduced the Paper, and in addition the driller putting in those six cut holes would probably also have to put in the easer holes immediately above and below, which meant eight. The drilling time, therefore, if a normal cycle was used, would depend on how long it took to put in those eight holes (the six cut holes and the two easers) or possibly more. It would be useless to reduce the task of the other drills to less than eight holes. It was stated in the Paper that only 40–45 per cent of the holes had remained to be drilled after the mucking had been completed. The chain-dotted line in *Fig. 18* was

supposed to represent the top of the muck pile, and it was only the holes below that which had to be drilled, and which of course added to the length of the cycle, the other holes being drilled while mucking was going on. The Authors had also stated that a total of sixty-five holes had been drilled, which left twenty-eight to be drilled with seven machines. That reduced the total task per machine to four holes or sometimes five in a vertical row. In other words, what Mr Tozer suggested was that the potential drilling time had probably been halved in the present case by using the overlapping system compared with the normal cycle.

Fig. 18



He noticed that the Authors had made some criticism of the design of the platform and he could imagine that it had given a certain amount of trouble in bad ground. Some experimental work had been done recently in an endeavour to overcome the more obvious snags in that respect. A much simplified platform structure, which was lighter, cheaper, and much easier to erect, had now been evolved. Tests had been made on a model which spanned an 18-foot tunnel and required only one wall hole at the end of each beam. It would comfortably carry a live load at the centre of at least $\frac{1}{2}$-ton, which corresponded to about five drillers and machines. The beam was simply a piece of pipe about 4 inches in internal diameter, with a $1\frac{1}{2}$-inch sprag in high-tensile steel and a split conical clamp which clamped the sprag when inserted in the hole and centred the pipe on the sprag. It allowed considerable misalignment of the support holes and therefore overcame many of the difficulties. Another advantage was that pieces of pipe were readily obtainable, and in the event of overbreakage it was a fairly simple matter to provide a few slightly longer pieces of extra pipe somewhere near the face and then pick out the size required.

Mr William Brown said that as a contractor he was very interested in the rate of progress, but he could find no reference in the text to the sizes of the tunnels, by means of which he would make comparisons. It would appear from *Figs 1* (*b*) that the tunnels were of about 16 feet equivalent diameter, whilst the maximum progress was given as 130 feet per

week. In Appendix I an average time-cycle of about 14 hours was given and, assuming the usual 136-hour working week, that showed a weekly progress of about 80 feet, which he thought was very creditable. In the report of the North of Scotland Hydro-Electric Board it was stated that their rate of progress in 16-foot tunnels driven in Scotland had improved from about 40 feet per week in 1949 to a little more than 90 feet per week in 1952. The Board had also stated that in their 10-foot tunnels the rate of progress had gone up from about 70 feet per week in 1949 to about 135 feet per week in 1952. The majority of those tunnels had all been driven by the modern technique described in the Paper, with light-weight drills mounted on air-legs and " Eimco "-type loaders filling 2-yard skips on 2-foot-gauge track, hauled out by Diesel or battery locomotives.

It was generally agreed that 2-yard skips on 2-foot-gauge track represented an economical proposition for tunnels of the size in question and it was no surprise, therefore, to read the Authors' conclusion that their 1-yard skips had been too light.

Mr Brown had been surprised to read that the Authors had had no trouble from exhaust fumes with Diesel locomotives, particularly since the methods of dealing with ventilation had not been all that they might have been. Even though poisonous fumes might be avoided, there was still the characteristic Diesel smell, and in the United Kingdom there was a temptation on that account for labour to invoke the clause dealing with obnoxious conditions. Mr Brown would advocate where possible using battery locomotives in a tunnel.

Referring to the concrete lining, he had been interested in the Authors' decision to use a placer for easier handling by native labour and because it was less likely to choke the pipes than a concrete-pump. He agreed that there was nothing more frustrating and aggravating than a choked pipe-line, particularly where a length of 400 or 500 feet was concerned, but he still thought that the concrete-pump had much to be said for it as a means of placing concrete for tunnel lining. The merits of the placer, he understood, lay largely in the rate at which it was possible to shoot the concrete into a shutter, but he thought that undoubtedly a certain amount of segregation occurred and that there was not very good control of compaction and the consistency of the concrete. Vibration might also be a difficulty. He understood that with a concrete placer it was not possible to have men using internal vibrators when concrete was being shot in at an air pressure of 100 lb. per square inch, and the Authors had resorted to external vibrators fitted to the ribs. In the United Kingdom some engineers frowned on that, and Mr Brown thought that external vibration was very local in its effect. He knew that comparison between concrete-pumps and concrete-placers was a question of some delicacy, but he personally believed that the concrete-pump was a very much better tool for pressing concrete into the roof. Especially in a steel-lined tunnel with steel ribs and packing and plenty of voids it was possible to get a pressure

on a concrete-pump and a consistency in pumping which he did not think was practicable with a placer.

The Authors had concluded that difficulties in controlling the flow and the problem of segregation increased rapidly with larger tunnel-diameters. They believed that a diameter of about 15 feet was approaching the limit at which a placer could be successfully used for placing the whole arch and sidewall lining in one operation. Mr Brown thought that that was probably correct with a placer, although he admitted that he had not used one. Recently, however, in the Woodhead tunnels, a combined arch and sidewall shutter had been successfully used in a tunnel of about 28 feet finished diameter ; the concrete had been placed by means of four pumps, and the output had reached the maximum of about 3,000 cubic yards per week, the average over many months being about 2,000 cubic yards.

He suggested that just as in tunnel excavation the rate of driving depended very largely on the rate at which it was possible to get rid of the muck, so in tunnel lining probably the speed of lining would depend mainly on the rate at which it was possible to supply aggregates, sand and cement to the tunnel.

Brigadier S. A. Westrop explained that he was in a rather fortunate position compared with previous speakers, because he knew the works described intimately and had examined them during the course of progress at various stages.

Certain items of plant, such as the light capacity tip trucks, had been criticized, and he wished to explain that the contract had been of the target type ; and the Madras Government had already supplied a good deal of plant for the job, including tip trucks and crushers, which the contractors had had to take over ; in some respects, therefore, the choice had been limited.

Turning to the question of ventilation, the Authors had referred to the use of a 10-horse-power fan and a 15-inch-diameter duct. Brigadier Westrop thought that 15-inch-diameter ducts were common because steel or aluminium sheets were usually rolled not more than 4 feet wide, but from what he knew of some of the Scottish tunnels he would say that for a tunnel of the size and length in question—the maximum headings, he understood, were at about 2,000 feet—that was about the correct capacity, and the question arose of whether the Authors had used the equipment correctly. They mentioned that they only sucked. If the pipe was brought in up to 200 feet from the face and suction was applied at the same time as quantities of good fresh air were being produced from the tools on the face, that was rather like " eating one's own tail," because the fresh air was being drawn out, and the remainder of the tunnel was being cleared only by the inflow from the back. There was sure to be a great deal of experience available in that connexion, and it would be interesting to hear opinions on the desirability of using the equipment in the way in which it had originally been intended that it should be used, namely, to blow

after having first cleared the tunnel by suction. When that was done the air released from the face assisted the air blown from outside in pushing the bad air out of the tunnel. The Authors had used a booster fan to get sufficient air when the line exceeded a certain length. That booster fan, apparently, had not been reversible, and that might be the reason why, having set it one way, they did not change ; but what experiments had they carried out on blowing as well as sucking to improve their ventilation ?

Brigadier Westrop's third point had already been referred to by Mr Lambert and Mr Brown, namely, the use of the placer. Brigadier Westrop had used a placer on a smaller tunnel farther south in India, and the walls had been so solid that no grouting had been found necessary. He did not believe that the pump would give such a solid effect. Once the placer pipe was buried the concrete was thrown through the pipe with enormous force and everything was filled up, so that no places could be found to grout if the equipment was handled properly.

Brigadier Westrop fully agreed with Mr Lambert that 15 feet could not be accepted as the limiting diameter of the tunnel in which a single shutter could be filled. He had just had a report of some work carried out in America with two placers, where apparently two nozzles, 2 feet 6 inches apart, had been used in the roof of a 40-foot-diameter tunnel, placing about 150 cubic yards an hour. It seemed that the essential point was the speed with which the work was done. With the placer it was necessary to work at great speed, and the arrangements made to supply the concrete to it had to be adequate. If they were, he thought that all the troubles would disappear. The method was fairly new to Great Britain and so was apt to be treated with reserve, but in his view it should become standard practice for almost all tunnel linings. He had used the method and had seen what it could do.

It was possible in India to train men to carry out any operation as efficiently as it could be carried out by British workmen. It was only a question of time. The present Paper, and the film which the Authors had shown when introducing it, indicated what could be done by training. The Indian workman tended to have rather a one-track mind, and it was undesirable to take a man off one job and suddenly put him on another. He was very painstaking and loyal, and would climb into all sorts of dangerous places, seemingly without regard for personal risks.

*** **Mr P. O. Wolf** asked the Authors to provide additional information which he thought would be required if full advantage was to be taken in future of the many interesting facts and opinions recorded in the Paper.

So far as he knew, this was the first mention in the Proceedings of the Machkund hydro-electric project. Although the main object of the Paper

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*** This and the following contribution were submitted in writing upon the closure of the oral discussion.—SEC. I.C.E.

was to deal with a limited number of constructional problems, it would be of interest to have a more complete description of the whole scheme, including possibly some cross-sections of the diversion dam, of the flume channel and aqueduct, of the power station, and of the surge shaft and its gates. The dimensions of some of the works and the final electrical capacity were of the same order as those of some Scottish schemes, for example, Loch Sloy, and engineers would be interested in data enabling them to study the similarities and the differences of treatment.

The value of a record such as the present one lay, to a great extent, in the use which could be made of the information in it by engineers faced with similar problems in future. For that reason the critical observations in the Paper were particularly stimulating. Could the Authors add to them more complete details of the dates of the work and of the conditions under which their contract had to be operated, so that some unusual features might be more fully understood ?

Mr C. M. Roberts observed that it was essential that the concrete lining of a tunnel connected directly to a hydro-electric power station should be absolutely sound throughout its thickness. It was not sufficient merely to show a smooth face backed by inferior concrete. Most highland waters had properties which attacked concrete and, in the course of time, any weakness in the concrete resulted in distintegration at the point of weakness. It was inevitable that cracks should form in any continuous concrete lining and such cracks admitted water to the heart of the lining. Any method of placing concrete in the lining which was likely to give rise to weakness in the concrete was not therefore acceptable.

There were three points mentioned in the Paper which seemed to Mr Roberts inevitably to give rise to possible weakness, however efficiently the method was applied :—

(1) The trailing end of the shutter had to be filled from the open-ended delivery pipe, giving distinct possibilities of segregation.
(2) At the trailing end, concrete had to slide over the shutter and then drop freely over a considerable height giving further possibilities of segregation.
(3) When delay occurred during placing with a long sloping surface, it was difficult to reinstate the proper action of the placer without having a run of concrete over the surface of that previously placed and that would inevitably lead to weakness.

For the proper action of the pneumatic placer to be developed it was essential that the end of the delivery pipe should be buried. The sooner that condition could be achieved the better and that was one reason why the pneumatic placer was more suited to small tunnels.

The Authors had stated that honey-combing at the trailing end of the shutter could apparently be eliminated by placing six batches of mortar before placing concrete. Mr Roberts wondered if there was any evidence

to show that, although the concrete surface was good, honey-combing did not exist behind. The extent of honey-combing appeared to be related to the distance which the concrete had to fall, for in tunnels of 9 feet diameter and less the fault was not generally apparent.

The difficulties mentioned above arising from the " intermittent " system of placing could largely be met by placing concrete in the sidewalls in horizontal layers. That could be done by hand placing, the concrete being conveyed to the upper levels of the sidewalls in skips elevated by hoists or ramps and being fed into the shutter direct by hand or through chutes. Alternatively, two small pneumatic placers could be used with shooting " heads " at the ends of the delivery pipes to break the velocity of the concrete. Both placers would travel to and fro to fill the shutter in horizontal layers. Such a method allowed the proper preparation of the upper surface of concrete to receive fresh concrete on top of it. All laitance could be removed and, if a hold-up occurred during placing, there was no question of fresh concrete flowing over the top of the concrete below. When the sidewalls were complete the arch could be placed, using the pneumatic placer with a reduced drop for the concrete, and the end of the delivery pipe could be buried quickly.

The proper action of the pneumatic placer demanded the highest possible rate of delivery of concrete consistent with the capacity of the placer. The highest rates of delivery could usually be obtained by mixing concrete outside the tunnel and conveying it by means of transit mixers.

Figs 4 showed that a small splay was formed in the sidewall above the kerb. Mr Roberts had found that such a splay tended to break off, apparently because of shutter movement and sometimes because of weak concrete in the splay, and that better results were obtained by casting a haunch to the finished profile extending about 12 inches into invert and sidewall before the sidewall was placed.

Could the Authors give details of the size and position of the inspection panels provided in the shutter ? They had an influence upon the amount which could be done on the concrete after placing behind the shutters.

Although it would seem that the Authors concluded that vertical sidewalls would improve the finished surface when pneumatic placers were used, such a design could not always be accepted, since it would decrease the hydraulic efficiency of the tunnel and impair the structural value of the lining.

The minimum clearance between rock and the finished concrete surface scaled, from *Fig. 1* (*b*), about 6 inches. That appeared to be the minimum thickness of lining which should be used when mechanical placing was adopted, since a smaller clearance would seriously interfere with the flow of concrete. Mr Roberts asked if the Authors considered that a larger clearance would have been of assistance in obtaining a good quality of concrete in the lining.

The Authors, in reply to Mr Lambert, said that the thickness of the

concrete lining had been specified as 6 inches minimum. In the first tunnel, where the rock had been fairly good, they believed that the final average thickness had been of the order of 20 inches. For the flume tunnel no figure could be given which was in any sense accurate, because in a number of places they had run into difficult ground, as mentioned in the Paper, and there had been one hole in the roof 40 feet high, which naturally had an effect on the average figure!

Mr Lambert had raised the question of the choice of the length of shutter. At that time the Authors believed that the 40-foot length represented all the steel which they were allowed, and that had settled the matter, but they believed that 40 feet was about right. It would have been nice to have had it 80 feet long, but the capital cost of the equipment would have been excessive, since the first shutter had to have a good many additional bits and pieces to convert it for use in the second tunnel. The length of 40 feet made it possible to pour in a reasonable time, but it had had the disadvantage of repeated joints, and they believed that the best answer would be a telescopic form of shutter with continuous placing with a pump or placer. That, however, was a very expensive proposition and would need a very long length of tunnel to justify it.

The concrete had been volumetrically batched on a 1 : 2 : 4 mix.

Several speakers had commented on the pump *versus* placer problem and Mr Brown had remarked that one was on delicate ground in dealing with it. Both machines had many good points and inevitably some bad ones, and the Authors had had to be very careful about what they had said in the Paper to avoid undue bias either way. The operating conditions had to be taken into account. One of the best points about the placer, of course, was the complete (so far as they were concerned) absence of mechanical trouble. The rate of placing was limited only by the rate at which one could put concrete into it and by the compressor-capacity available to pump the concrete out. But the cost of operation was quite considerable if the cost of the compressed air was high, and that was also a factor to be taken into account. They thought that in the conditions in which they had been working a concrete-pump might have suffered serious mechanical trouble and it would have been impossible for them to manufacture spare parts at site for a machine of that kind, and it was doubtful if spares could have been stocked to meet every contingency.

They had been glad to learn from Mr Tozer that a new form of platform had been introduced. There was no denying the advantage of simultaneous drilling and mucking in reducing the cycle time, and the whole of the equipment was much lighter and less costly than that required in the older techniques, so that the new technique seemed to be the answer. Particularly in the second tunnel, if it had been possible to take a piece of pipe which was a little longer than the standard length to bridge a gap, that seemed to be a very effective way of dealing with the difficulty where excessive overbreak had occurred.

Mr Brown had suggested that the size of the tunnel was not clear. It was true that the Authors had not given the thickness of concrete, but the internal size of the linings were given in *Figs 1 (b)*. The concrete thickness had, as mentioned above, been designed as a minimum of 6 inches. Mr Brown's conclusion that the average progress figure had been about 80 feet per week was correct, but that was an average figure obtained after the men had been reasonably trained; it had taken a long time to get them up to that figure. Their best week, when everything went right, was 130 feet, but figures of 80 or 90 feet in a week were regularly obtained in the second tunnel, the week being the same as that normally worked in Britain. Only maintenance work was done on Sundays; sometimes the Saturday shift worked on a little to finish a round, but normally on Saturday night and Sunday no actual tunnelling work had been in progress.

Mr Brown had expressed interest in the fact that the 1-yard skips had been found to be too light, and Brigadier Westrop had explained that for certain items of plant there had been no choice. The skips had been one of them. They were Indian-made wagons, similar to those used in the United Kingdom, but using a somewhat lighter gauge of metal and lacking some of the stiffening. The Authors agreed that a 2-yard skip would have been much better if sufficiently strong to stand the rough treatment and rough loading from a rocker-shovel.

They had had little or no trouble with the Diesel locomotives. They had referred to the care taken in the maintenance of those machines, and one man alone had been responsible for filling them with fuel, to make sure that it was clean. The atomizers and fuel pumps had been kept in first-class condition. In those circumstances the smoke was nil and the smell negligible. In those relatively large tunnels it had not been anything like so serious as the smell of explosives, which had worried them at times.

Mr Brown had also raised the question of the use of internal vibrators. There had been time between the actual shootings of the concrete for men to use internal vibrators; they had kept the inspection panels open and a certain amount of hand punning had been done in the intervals between shots; but the ordinary pencil type of vibrator had tended to bore its way down the shutter and form a very local point of vibration. That had tended to draw the "fat" from the concrete to make a circle round the vibrator, and the effect had not spread throughout the shutter. Better results had been obtained with heavy insertion-type vibrators used externally by mounting them in suitable clamps fitted to the main ribs of the shutter, moving them from one position to another following the freshly poured concrete.

Brigadier Westrop had raised the question of experiments in ventilation. In the earlier stages, when they had been working with only the external fans which had reversing ducts, they had carried out experi-

ments, but the time had come when with the use of the external fan only on a long length of pipe, something of the order of 750 feet in, its effectiveness had been very much reduced and it had been necessary to install booster fans. The only fans available were one-way axial propeller-type and it was obviously impracticable to change them round after each blast to either blowing or sucking. The final conclusion reached on the basis of experiment had been that they were better placed on suction. It had been found that when blowing fresh air into the face (it did not matter much whether it came from the compressed air main or the blower duct) it tended to churn up with the existing fumes, and they had obtained a weaker and weaker mixture, not a pocket of clean air. By blowing compressed air at the face the same effect had occurred but gradually, with the suction duct working 200 feet away, the face had tended to clear and the " mixture " had been gradually drawn away. They agreed that they had been " eating their own tail " to a certain extent, but the method had ultimately cleared the atmosphere 200 feet from the face, which enabled the men to work. The fumes remained down the tunnel, and the loco drivers had to pass through them, but the period involved was short and it seemed to be the best way of dealing with the problem in that particular case.

It was very interesting to learn that placers were being used in America on a tunnel 40 feet in diameter. Perhaps Mr Lambert had put his finger on the real point, which was that the materials which the Authors had had to use, with the lack of sufficient good river sand and the limited facilities for getting the various grades screened out from the crushers and then correctly re-proportioned, had been the cause of the difficulty. In other words, if it were possible to get the concrete correctly graded for the placer it would, apparently, be possible to use a placer on any size of tunnel, but, considering the materials and equipment which the Authors had had to use, the Paper had given their conclusions quite correctly so far as the Machkund Tunnels were concerned.

The Authors agreed with Brigadier Westrop's remarks about the training of Indians. They could not have wished for men who were more willing and more responsive to training or who took a greater pride in their job. The only fundamental difference between India and Great Britain, once one had got the right group together, was that one needed more men, but that was entirely a question of physique and not a lack of willingness.

In reply to Mr Lambert's request for further data about the rate of placing, that had been limited in the Machkund tunnels, not by the capacity of the placer, but by the output of concrete from the mixer. A 1-cubic-yard mixer had been used and from that they had averaged twenty mixes per hour but not a full cubic yard per mix. They had found that they had to cut down the volume of each mix slightly, both to suit the size of the trucks they had had available for bringing in the aggregate

and also because they had found that it did not pay to try and fill the placer too full. The result was that the mixer had turned out an average of 15 cubic yards per hour, which was well within the capacity of the placer.

The average amount of concrete per length of shutter was about 100–110 cubic yards, as Mr Lambert had calculated, so the pouring time was 7 to 8 hours. They had found it was possible to start concreting 4 hours after the start of moving the shutter, which gave roughly 12 hours from the end of setting time to completing a length of concrete. The cycle was, therefore, 28 hours, including a 16-hour setting time, and so five lengths a week thus fitted very nicely into the 6-day working week.

Mr Tozer, the Authors thought, had made a very interesting point about the use of the platform having cut down the effective drilling time from that required for one man to drill eight holes to that required to drill four holes only. It would be interesting to take it a stage further and see if it was possible, by speeding up the mucking, which had been slow in relation to the size of the tunnels, to eliminate the mucking time from the effective time-cycle. The cycle time would then consist essentially only of the total times for fume clearance, drilling (being the time taken for one man to drill eight holes), and loading and blasting; the mucking and drilling of the bottom holes would be done whilst the cut and easers were being drilled. In view of the possibilities of that overlapping technique, it was, therefore, very interesting to hear that experiments were being made with the object of producing a simpler and more adaptable platform, which would answer the criticisms put forward.

In reply to Mr Wolf, the Authors regretted that it had not been possible to include a full description of the whole project; they were hardly qualified to do so since their activities had been confined to the construction of the two tunnels. If Mr Wolf was very anxious to have details of the other works, the Authors were sure that they would gladly be supplied on request by the Chief Engineer to the Electricity Department, Madras.

The conclusions reached by Mr Roberts in regard to the use of the pneumatic placer were clearly similar to those of the Authors. At several places, subsequent examination had disclosed concealed honeycomb in the lining, but that had been an exception rather than the rule. The discussion had emphasized the importance of correctly graded aggregates and rapid placing, conditions which had not been fully realized at Machkund, and the Authors were prepared to accept the evidence put forward that, given the right conditions, satisfactory linings could be placed in large tunnels with a pneumatic placer.

The Authors fully agreed with Mr Roberts's comments regarding the splay at the foot of the sidewall shutters and had referred to the matter on p. 135.

Inspection panels were provided in the shutter throughout its full length at two levels on both sides. The first line was about half-way up the sidewall and the second about half-way between the springing and crown of the arch.

The Authors had not intended to convey the impression that they would prefer to design tunnels with vertical sidewalls in the interests of an improved finish. The trouble experienced with " water marks " was described in the Paper and the Authors merely justified their theory as to the cause by the fact that they had rarely occurred in the second tunnel, where the sidewalls were vertical. The defect may have been peculiar to the conditions obtaining at Machkund.

The Authors agreed with Mr Roberts that small clearances seriously interfered with the flow of concrete when mechanical placing was being used but that could be offset by increased punning in the areas affected. In those tunnels, closely supervised hand punning had been used, and it had been found that the tendency to produce segregation or honeycombing had not been noticeably greater where the lining was relatively thin.