Discussion.

Mr. Giles. Mr. ALFRED GILES, President, said the members must all regret that the Author of the able and interesting Paper that had been read was not with them to receive their thanks. It might be, however, agreeable to his representatives to know that the institution had received the Paper with the approval that it deserved. It contained a great deal of useful information, particularly to those gentlemen who were engaged in the construction of tunnels. One remarkable circumstance was the accuracy with which the tunnel, 6,300 yards in length, was set out, and the fact that when the two headings met, they were not above 4½ inches out of the centre-line. Some members present were perhaps old enough to remember that when a tunnel was made at Liverpool, it was stated that the two headings made, instead of meeting in a line, went past one another, and the men working from one end heard those working from the other end behind them. Since that time better methods had been introduced to set out tunnels, and the Mont Cenis and other tunnels through the Alps, though much longer than those mentioned in the Paper, were set out with great accuracy. It showed how necessary it was that, in the setting out of preliminary work of that nature, the greatest possible accuracy should be observed. The Author had not made reference to the use of the compass in setting out the tunnel, and it would be interesting to know from some of those who might take part in the discussion whether any use of the compass in such a situation would be desirable. Another omission from the Paper upon which it would be useful to have some information was as to its cost. The time during which the tunnel was under construction was about five years, and showed a progress of about 3½ yards a day. He would leave it to gentlemen who were interested in the Channel Tunnel to consider this point, because it seemed to him that in two headings with something like 12 miles distance from the entrances, the difficulty would be as great in removing the debris through those 12 miles as it was in the tunnel referred to, which went through hard rock and shale. He would leave it to their imagination how long it would take to complete the Channel Tunnel, involving a length of something like 24 miles. He would ask the Institution to accord to the representatives of the Author its hearty thanks for the very able Paper which he had left for them. Mr. Giles.

Mr. J. C. INGLIS thought the Paper very suggestive, and that must be his excuse for requesting a little more information. In the first place, the geological formation of the ground was varied and peculiar, involving many different conditions. The number of parallel bars built in was always a gauge of the difficulties that were met in driving a tunnel. One case with which he had to deal, which gave a great deal of anxiety, was the Marley tunnel, where was met the peculiar condition of the material expanding when exposed to the air, *i.e.*, the decomposed shale split up into tiny cubes, and of course the volume of material was increased by the fracture, which produced disastrous results on the timber. First of all, in the large headings it frequently broke the cross-trees, and again it had the effect of nipping the parallel bars so much that though 14 inches in diameter, they were frequently bent 6 or 7 inches, and, of course, under those conditions it was impossible to draw them. The length had to be reduced from 16 or 17 feet down to 12, so that many of these parallel bars had to be built in, as also a good deal of timber. He should like to have some statement as to the quantity of timber got out compared with the total amount used in the work. He admired the sections and work of the tunnel, which evidently was a good sample of modern practice. He should also like some information as to the method employed in bonding the bricks. The method he had adopted, and which he had frequently seen employed, was to build the arch ring over ring by successive rings bonding at such points as the joints would allow. In a single tunnel that he had in mind such work gave four bonds between the springing. The plan adopted in this case was superior, viz., building the brickwork in two rings together, and then, in the case of the odd one, bonding it between. He observed that the Author had succeeded in obtaining a frequent bond into the odd ring. Bonding was very important in brickwork. This was a plan which he was sure would be more adopted in ordinary bridge-building than formerly. The difficulty met with, especially in moderate arches, was that they were not flat enough to allow of bonding all through. One thing he noticed in the Paper was the large man-holes for the plate-layers. That was a convenience which some engineers had been rather behindhand in affording. For instance, in the Severn tunnel, the absence of such ample accommodation was disadvantageous to the men. He was Mr. Inglis.

Mr. Inglis. quite sure if large spaces were provided, it would give the men confidence, and more work would be got out of them.

Mr. Galbraith. Mr. W. R. GALBRAITH was struck with the multiplicity of shafts in the Totley tunnel. If it had been possible to drive 5,000 yards without a shaft, he did not understand why five or six shafts were required at the extreme end. It might of course have been done to expedite progress in the headings, but why the expense of making the shafts permanent should have been incurred, he did not understand. It was clear, judging from the section, that for 5,000 yards at least the tunnel was ventilated without a shaft, and he thought it would have been better to close all those shafts up. The Paper was somewhat wanting in details, for instance, there was no statement as to the character of the ground, or as to the weight on the timbers during construction. He judged that the tunnel, on the whole, was not a bad one; that there was not much weight upon it. As he understood, about 700 out of 6,200 yards required an invert, but the rest of the tunnel, except for the quantity of water that seemed to have been met with, was not bad, *i.e.*, having got the headings through, there was not much trouble in building the tunnel. He did not quite understand about the bonding. If the arch was built with "headers," to give the two courses in one, the outer end of the joints must be packed up with mortar, which should be avoided if possible. He differed from Mr. Inglis, and preferred the old fashion of getting the bond in where the courses would allow.

He did not know what material was available for lining the tunnel, but he would strongly recommend engineers where they had the opportunity, especially when they got rid of water, or where the outflow of water was moderate, to make more use of concrete in the lining of tunnels. He had used concrete a good deal in two of the tunnels on the North British lines from the Forth Bridge to Perth. One was lined entirely with concrete, and in the case of a tunnel through rock, concrete was far better than brickwork or masonry, if they had good material, because, if the concrete was properly put together, every inequality was filled up. One of the tunnels on the Glen Farg line was also built of concrete, including the arch, with most satisfactory results. The concrete was made of broken whinstone and some sand, in a mixture of about 6 parts of stone and sand to 1 part of cement. The Government Inspector not having seen a concrete tunnel before, some holes were made for him, and he pronounced the work to be infinitely better than brickwork. All who had experience of tunnels knew the trouble there

Mr. Galbraith. was with tunnel bricklayers and tunnel bricklayers' labourers. In the concrete tunnel, a good foreman was able with ordinary labour to put in the lining. The Cowburn tunnel, about 3,700 yards in length, was driven with only one shaft, which made him wonder why so many shafts were sunk in the Totley tunnel. On the whole, considering the length of the tunnel, and that it was driven entirely from the ends, he thought five years was, perhaps, not a very great length of time for the work. There were certainly plenty of break-ups. Fifty-two break-ups would give about one hundred working faces, and, in his experience, a length of face per fortnight was what might be fairly expected; so that, with a break-up at every 100 yards, the work ought to have been done comfortably in that time. Some contractors were strongly in favour of driving a top-heading. That was entirely a mistake. In tunnel work, to get on quickly, a big bottom-heading should be driven. He was certain that for expedition and getting materials in and the ground out there was nothing like a bottom-heading; and a heading of 10 feet by 9 feet ought to have been quite sufficient to admit a small engine. Mr. Walker, in making the tunnel between Deal and Dover, had engines running in a heading of that size, and found them very useful.

Mr. Shelford. Mr. W. Shelford observed that the Totley tunnel was chiefly remarkable for its length and the quantity of water met with during construction. Apart from that it might be called an ordinary work, for this reason: the lengths in which it was made were mostly 15 feet and 18 feet, and no length was shorter than 9 feet. Having constructed tunnels in lengths of 3 feet, he knew that this work must have been much easier than that he had carried out. It might be considered a light work so far as top weight was concerned, and also because there was no necessity for the rapid building in short lengths to overcome the swelling of material, or slippery material, or mud. It might, he believed, be taken as a fact that the tunnel was in the base of the coal measures, bordering upon the millstone grit, or partly in it. Anyone with experience in mining or tunnelling in such strata knew that difficulties might be expected, and, above all, that large quantities of water might be anticipated. No doubt the tunnel was laid out with that in view. The way in which the water was dealt with was, to his mind, the most interesting part of the Paper; for when it was found that the discharge-pipe was insufficient, and it had to be taken up again and a grip substituted for it, a brickwork dam was built across the heading, with a

Mr. Shelford. horizontal camber, and the water allowed to accumulate behind it to a pressure which ultimately reached 155 lbs. to the square inch. It was successful; but, if the dam or a fissure in the shale had burst, it would have been bad for the men. As it was, there was considerable risk, and it was a very dangerous operation. There was one paragraph in the Paper with which he could not altogether agree. The Author appeared to have arrived at the conclusion that "the best means of drainage during construction was a spacious grip in the centre of the heading, covered with timber, and, therefore, easily accessible." This conclusion had been arrived at after a trial of large pipes which were found inadequate and were choked with sand. In that Mr. Shelford entirely agreed. But the Author went on to say that "the heading should not be carried below the formation unless the tunnel is inverted," and yet he himself had begun the heading at the formation level, and had been obliged to lower it 4 feet. That did not seem in accordance with the Author's experience in that tunnel. It had also to be considered, that in the coal measures it was often necessary to put an invert in the tunnel for a short distance, when the occurrence of good ground might render it unnecessary. Under these circumstances where should the heading be driven? Should it be an *undulating* heading? Unquestionably the proper place to drive the heading was at as low a level as possible in order to get rid of the water. But the Author had advanced another proposition—"that the drainage of the foundation of the length of lining is best obtained in cases where there is much water, by the employment of compressed-air pumps." No reason was given in the Paper from which it could be inferred that the conclusion was a right one. What the Author meant was, where there was no invert there was necessarily at the foot of each wall a trench full of water, and it was impossible to get at the work without getting rid of that water; and he had arrived at the conclusion that it was desirable to use compressed air to pump it up when there was an open grip of sufficient depth to drain the water from these foundations by gravitation. There appeared to be no reason for compressed-air or any other pumps under those circumstances. The handling of so large a quantity of water was certainly materially assisted by the gradients of the tunnel itself, and that accounted for the adoption of the gradients shown on the section. There was a fall from the summit level in the tunnel to the west, of 1 in 1,000 for drainage purposes, and the other gradients were the natural falls required for the traffic.

The junction of the headings took place about 1,000 feet east of the point marked "level," and fortunately in dry material. Mr. Shelford.

The system of grading was the same as that in the Mont Cenis tunnel, and he expected that the same difficulty with regard to ventilation would be found in the present case as was experienced at Mont Cenis. He might say that the same difficulty was found on the Metropolitan Railway at Portland Road, where there was a gradient rising from King's Cross at 1 in 100 to near Portland Road station, and then a slight dip into the station itself. That meant that there was always a cushion of foul air in the tunnel near the station, which was very difficult to get rid of; and he feared that when the traffic began to run in this tunnel, it would be found that the ventilation would be defective at the point marked "level." It had been stated by the Author that in the Act power was obtained to make a shaft, no doubt for ventilation, which did not appear to have been constructed.

With regard to the time occupied there were no complete data given. From the commencement to the finish there were nearly four years occupied, and dividing that time by the number of faces worked, it showed a progress of about half-a-yard per day at each face, which was a very usual rate of progress. That was so, notwithstanding that the progress made by machine-drills was 3 yards per day, the balance of time being of course occupied in preliminary work, headings, and so on. No information was given on the important subject of cost. It was perhaps not reasonable to ask the actual cost, but the relative cost might have been given per yard run for long tunnels as against short tunnels. In this case there was a very long tunnel of 6,000 yards, a short tunnel of 90 yards, and an intermediate length of tunnel of 3,000 yards, all practically in the same material, and giving an excellent opportunity of showing how far the cost of a tunnel depended upon its length. The Italian engineers, who were great tunnel-makers, in estimating for tunnels, reckoned so much per yard in proportion to the length. That information might have been supplied with great advantage. The Institution was greatly indebted to the Author, and much regretted that his promising career had been cut short by death.

Mr. W. R. GALBRAITH, referring to Fig. 32, Plate 5, thought if the rails had been pulled a little more to the left, the question of the "cant" of the rails might have been got over without introducing that very peculiar construction, which must have been rather difficult to build. Mr. Galbraith.

Mr. W. SHELFORD stated that he happened to know the circum- Mr. Shelford.

Mr. Shelford. stances. The tunnel was on a 12-chain junction curve joining the main line of the Midland Railway. The curve followed the contour of the hill. The dip of the strata was across the diagram from right to left, and consequently the tipping over of the tunnel not only accommodated the curve, but also brought the line of resistance of the tunnel more in the direction of the line of pressure.

Mr. Squire. Mr. J. B. SQUIRE, on behalf of Messrs. S. Pearson and Son, the contractors, said the subject was of special interest to them, as they were at the present time engaged in the construction of several tunnels in the neighbourhood of those described for the Lancashire, Derbyshire and East Coast Railway Company, one of which, the Bolsover tunnel, was 2 miles in length. In connection with what had been said about some arrangement being made for the more rapid removal of the debris, he might state that they were at the present time successfully employing locomotives in the headings. The headings were 9 feet square clear of the timbers, and the locomotives, specially designed for the work, were convertible. By a mechanical arrangement, the foot-plate was lowered and the chimney was taken in, and the locomotive could run right up the headings. Alluding to what he should call the indiscriminate sinking of shafts, where the depth of cover seemed to give a favourable opportunity for doing so, he thought that if the persons in charge of the Totley tunnel had wished to tap every spring in the hill, they could not have done it more successfully. He had often found a great deal of mischief arising from sinking shafts with no object beyond getting to a bit of easy work. Two shafts of larger diameter would have done the work, given less trouble, tapped less water, and would, he thought, have made no difference in the ultimate progress of the tunnel.

Mr. Thomas. Mr. W. H. THOMAS observed, in reference to the difficulty Mr. Inglis had found through getting the crown-bars cambered so much by the weight that it was not possible to draw them, that thirty-three years ago he was resident engineer on one of the heaviest clay tunnels ever made in England—that at Sydenham. It was 2,200 yards long, and great difficulty was caused by the pressure of the clay. The crown-bars were bent between 6 and 9 inches. They were drawn very simply, by keeping the leading end up as high as 2 feet 6 inches, so that when they were cambered the leading end of the bar was dropped, and when it straightened, was got out. There was comparatively little weight felt till the work was in and finished, and then, perhaps a month afterwards, Mr. Thomas.

the clay would begin to crack. The section was similar to that used in all heavy clays up to that time:—a high horse-shoe tunnel with a very flat invert. It began to fail by the invert rising; and he had recommended to Mr. Cubitt, the chief engineer, that the invert should be deepened. That was done, but it did not give the desired relief, and he came to the conclusion, which was borne out afterwards by experience, that it was not top weight that was giving the trouble, but compression all round. He then inferred that the circle was the proper form for the tunnel. He had great difficulty in persuading Mr. Cubitt to alter the section; but at last he did so, and from that time they never had a broken length. As to ranging the lines, no doubt meeting within 4½ inches was a satisfactory result. At the same time, he thought that in the manner in which the lines were ranged with the transit at the end of the tunnel with a long back-sight, there ought to be no difficulty in ranging with the greatest exactitude. At Sydenham they had seven shafts, some of them 15 or 16 chains apart, and had no headings at all. All the lines had to be transferred by wires down a shaft which gave about 8 feet clear, and thence ranged through. In all the shafts there was never more than 1½ inch deviation at meeting, and it was far more difficult to range in a short space like that than to set out 2 or 3 miles with the transit theodolite.

Mr. Greathead.

Mr. J. H. Greathead observed that nearly thirty years ago he had to do with a tunnel on the Midland Railway, constructed with very great care, as anyone who was acquainted with the late Mr. Bernard Baker, the resident engineer on the line, would know. The lining was composed entirely of bricks made of London clay. They were beautiful red bricks, hard and non-absorbent, and anyone looking at them would imagine that they were good for all time. He understood, however, that quite recently the whole of the internal lining of the tunnel had to be taken out and replaced by blue bricks. The brick-lined tunnels referred to in the Paper were faced with brindled bricks, but it was not stated to what thickness that facing was carried. The Figure would lead to the supposition that the thickness was about 4½ inches, and that the inverts were not so faced. He thought it would be better to have 9 inches, because that thickness would lend itself to the bonding together of two rings, as described in the Paper, better than with one ring of the blue bricks and one ring of common bricks. Blue bricks were important for other reasons than their durability, and were coming into general use on railways, not only in tunnels, but in the facework of arches, retaining-

Mr. Greathead. walls, &c., generally. This was on account of their strength to resist pressure; but it was unnecessary that the blue brick should extend further than the internal face, or 9 inches of the face of a tunnel lining, because beyond that the pressure was not nearly so intense. But, however strong the material with which a tunnel was lined might be, it was of little avail where great pressure had to be met, if the shape were not that best adapted for resistance. He noticed that the section of the tunnels which had inverts and which therefore were intended to bear pressure, departed widely from the circular section where great pressure had to be sustained; and he could not help thinking the form adopted might have been much improved by introducing curves of larger radius at the junction of the side walls and the invert. The curves were put in with an internal radius of only 3 feet 6 inches, but a radius of 7 or 8 feet would have been of great advantage in strengthening the side walls and inverts; involving less excavation and giving practically a tunnel of equal usefulness to that which was shown. The width at the rail-level was not so important as the width a few inches higher; and the width at the latter place would not have been thereby affected, whilst the tunnel would have been very much stronger.

Sir Douglas Fox. Sir DOUGLAS FOX remarked that the Institution was much indebted to the deceased Author for the practical way in which he had brought forward details of a most important and excellently carried out work. The Paper was instructive, because the Author had not hesitated to state the difficulties which arose during the construction of the tunnel, and members of the Institution could appreciate how much more was learned from their difficulties, than when everything was going on perfectly smoothly. He agreed to some extent with Mr. Greathead with reference to the small radius of the cross-section of the tunnel beneath the rail-level; but, whilst the circular cross-section was theoretically best to resist pressure, the question to be dealt with was not so simple, because it was necessary to allow for the clearance of the rolling-stock, and in order to do that, if a circle were employed, there resulted a somewhat wasteful section in another way. He thought the section shown on the diagram was excellent for its purpose. He thought Mr. Parry had exercised a wise discretion in enlarging the cross-section, by giving a width of 27 feet, which was economical in maintenance, and also tended very much to assist the permanent ventilation. His experience went to prove that there was nothing better for lining-purposes than brindle-bricks. He did not think that first-quality blue brick was a good material to

Sir Douglas Fox.

use. It had happened in his experience where a very smooth glazed brick had been used, that an invert had been blown up by hydrostatic pressure; whereas the brindle, a less expensive brick, was much rougher on its surface and therefore held the cement much more tightly. In the particular instance referred to, the bricks came away, leaving the face of the cement perfectly smooth; but when brindle-brick was substituted, the actual strength of the invert was much increased, whilst at the same time the cost of the brickwork was greatly reduced. He agreed that a most important point in dealing with long tunnels was at once to put in thoroughly efficient drains. This appeared to have been learned with a little trouble in the case under discussion; but those who had experience in tunnel-work would agree that a very full-sized drain was an economical thing; and, further, it should not be a pipe, but a trench covered with flags so that it could be easily opened if there were a stoppage. It was also important, especially in long tunnels, that no expense should be spared to provide a thoroughly efficient heading, of ample size, so as to be able to run full-sized wagons into it and to allow plenty of room for passing. Nothing would so facilitate speed and ultimate economy of construction as ample size of heading. Shafts were generally a source of weakness, and, in water-bearing strata, should be carefully tubbed. Members would be very much interested if Mr. Parry could give a few facts as to the cost of the work. All who knew anything about this tunnel knew how important a work it was, reflecting great credit upon the Engineer and all who had acted under him; but they would wish to hear something about the cost, seeing that similar tunnels were contemplated in different parts of England. Mention had been made of the excessive use of explosives. It would be well to know the real amount used, and the cost per cubic yard of excavation resulting therefrom. The Paper would form a valuable addition to the archives of the Institution, giving, as it did, a very frank description of a difficult work; explaining not only the way the tunnel was set out, but also the difficulties met with from water, especially from the size of the drain adopted in the first instance. For the information afforded in connection with the works described, thanks were owing not only to the deceased Author, but also to Mr. Edward Parry who was the Engineer of the work.

Mr. Elliott Cooper.

Mr. R. Elliott Cooper was at the present time carrying out four tunnels of various lengths, from 2,387 yards down to 500 yards. There was one point referred to in the Paper, namely, the shafts which specially bore upon the tunnel he was constructing in

Mr. Elliott Cooper.

Derbyshire, at Bolsover. It seemed rather a peculiarity in working, as shown on the section of the Totley tunnel, that there should be seven shafts near the lower end, and that the rest of the tunnel should be driven entirely from the two faces of the heading at each end. It had always appeared to him that if it were possible to avoid having any shafts whatever, there would be a very great gain in point of time in going through strata of that kind, where practically a series of underground reservoirs were tapped. The system adopted at Bolsover, where strata of a somewhat similar character were traversed at the upper part, was to make the shafts as far as possible absolutely water-tight. They were sunk in 50-foot lengths, and were then lined with brick in cement. The space behind the brickwork was well puddled so as to keep back the water as far as possible. Of course in a case of that kind it did not require any great amount of pressure to keep back the water, which would readily find its natural course round the small circumference of the shaft. He noticed, however, that the shafts described by the Author were left unlined until after the tunnel had been advanced a long distance; and it seemed, therefore, that they practically acted as pipes to drain the surrounding country. There might have been special reasons for putting in those shafts, but from the point of view of time, it was manifest that as the distance of the farthest shaft was only 500 feet from the open end, it could not reduce the time occupied in construction, considering that the remainder of the distance was nine times as much. He would have been disposed, if there were shafts at all, to have distributed the money in those shafts by facing the matter a little more boldly, and putting in two shafts at much greater depths, say about 600 feet. About seventeen years ago he had been associated with the earlier stages of a tunnel where there were six shafts of an average depth of 450 feet. The greatest difficulty arose from the water that collected in those shafts. They were, however, carried down, and the tunnel was executed by break-ups from the shafts in a comparatively short time. He would also call attention to the new and peculiar form of locomotive which was being used for working the Duckmanton (Chesterfield) and the Bolsover tunnels. That locomotive was so designed that it could work through a 9-foot heading. Tip-wagons of the ordinary size were used. The trucks could therefore be hauled out in a much shorter time, and with much greater convenience, than by any arrangement with horses or hand-labour. The locomotive drew the wagons right away from the heading to the tip. It was practically the same as the ordinary

Mr. Elliott Cooper.

contractors' locomotive, except in the peculiar design of the foot-plate being so low that the driver's head was only about 8 feet above the level of the rails; and the funnel, by a telescopic arrangement, shut up when the locomotive entered the heading. The plan adopted for working those tunnels was to excavate the cutting at the face to within about 20 feet of the formation, and then to form an inclined line with a gradient of 1 in 16 down to the mouth of the tunnel. This had greatly expedited the construction. The headings were driven at the rate of about 10 yards per week from each face. In the Bolsover tunnel, the rate of progress was about 60 yards per week from the six faces. With regard to the Dore tunnel, he was just commencing one with a curve of the same radius, namely, 12 chains. It ran through the Undercliff near Ventnor, but he could not see any advantage in the peculiar tilting-over, as shown on the section of the Dore tunnel, that would induce him to adopt that form for the purpose he had to accomplish. So far as super-elevation of the rail was concerned, which was only a matter of about 2½ inches, he did not think the amount by which the rolling-stock was thrown out of the vertical by that super-elevation really necessitated the tilting of the tunnel; and he could not see that the increased strength paid for the rather curious appearance which would be produced when the tunnel was finished—an appearance which in years to come must give rise to the idea that the tunnel had somehow or other slipped out of its original position. No doubt the engineer had a good reason for having adopted that particular design, but Mr. Cooper did not see that the advantages gained were sufficient, at any rate, to justify him in adopting that rather peculiar form. The question of lining was undoubtedly most important. He was adopting brindled bricks for facing the lining, because it was not the back part of the brickwork which went, but the face, which was exposed to the effect of fumes and the damp of the atmosphere, which deteriorated bricks to the extent observed, not only in tunnels, but in a great many bridges throughout the country. If there had been no water in the tunnels described, the difficulties would have been comparatively small—not greater than would be found in all tunnels, such as the Mont Cenis, the St. Gothard, and other long tunnels. The water undoubtedly had been a serious difficulty, and it had been dealt with in a manner that reflected great credit upon all concerned.

Mr. Baggallay.

Mr. H. C. BAGGALLAY observed that the ventilation of tunnels during construction was a most important matter; but where fuel was cheap, it was not so important as in countries where it was

Mr. Baggallay. impossible to get fuel of any kind or only at a cost that was almost prohibitive. He was connected with some tunnel works under construction in Chili, where there were 10 miles of almost continuous tunnel, *i.e.*, the mouths of any two adjacent tunnels were within 3 or 4 yards of each other, the summit tunnel being about 5,000 metres, and the next tunnel about 4,000 metres long. In arranging how such tunnels should be constructed, the question of ventilation was most important. It was therefore decided to use rock-drills, worked by compressed air. As the summit tunnel was at an elevation of 10,000 feet above the sea, and the approaches were very difficult, the carriage of fuel was almost impossible. The engineer in charge of the work, Mr. Schatzman, a Swiss engineer who had been employed on the St. Gothard tunnel, decided that the only practicable way of conveying power to the tunnels was by electricity. Water-power was obtained in a valley about 3,000 feet below the site, and was utilized through turbines to drive the dynamos. Electricity was transmitted to the tunnels and there motors drove the air-compressors. The horse-power at the first installation was 800. It was calculated that if only two compressors, each giving 9 cubic metres of air per minute, were used in each tunnel, that it would be sufficient for the ventilation necessary for the workmen. There were three important points to be considered with regard to setting-out tunnels: first the direction, secondly the levels, and thirdly the length. Of course, in a case like that of the Totley tunnel, where the gradients were slight, the length was not a matter of great importance. But in the tunnels to which he had been referring, there was an almost continuous gradient of 1 in 12½, and therefore, any slight difference in the length of the tunnel, however straight the line was set out, and however accurately the levels were started at each end, might cause considerable trouble if the gradient from one end did not meet that from the other, owing to the distance being less than that calculated—the maximum gradient permitted being used throughout. In setting out the chief tunnel at an elevation of 10,000 feet above the sea, it was necessary to pass over the top of the mountain 3,000 feet higher. A straight line was set out as nearly as possible over the direction of the tunnel, and another about 2,000 yards from it, that one over the tunnel being about 6,000 yards long. Between those two lines a series of large triangles, as nearly equilateral as possible, was set out, the base-line measured in one valley being about 2,000 metres long. From this the triangles were set out. They were checked by a carefully-measured base-line in the other valley, and the error in length was only 1 metre. He need hardly say that it required very accurate work, and even then such a close approximation could hardly have been attained had it not been that luck to a certain extent corrected the errors; because in setting out five large triangles, having sides of 2,000 metres each, it was almost impossible to get as close as that in 3 miles, especially as all the stations had to be levelled under great difficulties over very rough ground, in places where there were no foot-paths of any kind, and with a difference of level between the several stations of over 3,000 feet. With regard to the building of the observatories described in the Paper, he had found it very useful, instead of having a stone top to any station of that sort, to make the surface of almost neat cement, and then plant the transit instrument into it while it was soft. The instrument could then be taken out and put into the hole again with the greatest accuracy. It saved a good deal of time and trouble when it was necessary to use the same instrument at the same place frequently. With regard to the ventilation of the tunnels during construction, it was arranged that everything should be done by compressed air. The drills adopted were the Ferroux drills, the same as used in the St. Gothard tunnel. Two compressors were capablo of working five of those drills, which were carried on carriages hoisted up to the incline by compressed-air winches. The spoil was carried away down a gradient by gravitation on a double line of rails. It was found much more convenient to put down a double line of rails for small wagons of 2 feet gauge instead of using larger wagons, as the double line could be worked with a wire rope. Last winter he had reduced the length of the longest tunnel alluded to by slightly altering its position. The chief difficulty in setting out the work was, that in order to get the reduced length, he was obliged to introduce another spiral tunnel, of which there were now three almost directly over one other. It would be a delicate operation to drive those tunnels with a radius of 200 metres and an 8 per cent. gradient so that the headings should meet exactly. The entrances to three spiral tunnels could only be approached by pathways cut in the solid rock, where it was practically impossible to measure a single yard horizontally. He was therefore obliged to calculate all distances from observations taken with a theodolite. Mr. Baggallay.

Mr. J. G. FRASER directed attention to the question of the unusual amount of water in the Totley tunnel. Some years ago he had under construction a tunnel, in which the men were so Mr. Fraser.

Mr. Fraser. much disturbed by water that they had to work in quarter-shifts. It was then determined to drive a heading at a higher level so as to tap the water before it reached the tunnel. That proved successful; it left the tunnel comparatively dry and the work went on without further interruption. He did not find any allusion in the Paper to an attempt to divert the water from the tunnel, and no doubt many of the difficulties would have been reduced, or obviated, if such a precaution had been taken. There appeared to be about one million gallons a day yielded at the east end, and at another point, 1,800 or 1,900 yards from the west end, there were something like 500 gallons a minute. That was an enormous quantity of water, and it might have been much reduced if cross-headings had been put into the hill-side at different places, to lead it away from the tunnel. Water would always find its way into the tunnel, which would be constantly damp and would suffer in consequence.

Mr. McDonald. Mr. J. ALLEN McDONALD thought that the number of shafts at the lower end of the tunnel was more than justified. The object the engineers of the Dore and Chinley Railway had in view in putting down the large number of shafts at that end (the only accessible part of the tunnel), was to get an opening as quickly as possible, to enable them to remove the material from the main tunnel, from its central part. The tunnel was pushed forward as quickly as possible, because to render the line available for traffic depended entirely upon the completion of the Totley tunnel. Had the engineers been obliged to take the material from that heading up only one or two shafts, the work would have been much slower than it was. Of course it made a great difference whether a tunnel was 500 or 600 yards long or whether it was 6,200 yards. The object was to obtain the freest possible access to the most central part of the tunnel as quickly as possible, and that was probably attained best by sinking the shafts referred to. With regard to the water, he thought he was right in saying that the shafts sunk at the Totley end brought very little water into the tunnel; and experience showed that, had the shaft been sunk nearer to the centre where the depth would have been over 600 feet, a very large quantity of water would have been brought into the tunnel. That alone proved that the arrangement adopted was probably the best. No doubt the width of the tunnel was unusual; 27 feet was the maximum width at a point 4 or 5 feet above the rail-level. A wise judgment had been exercised in providing this rather unusual width. It was astonishing to find the variety of opinion that existed among engineers with regard to

Mr. McDonald.

the width necessary for a tunnel that had to carry a double line of railway. He had been associated with cases in which tunnels had been constructed only 23 feet in width, then 24 feet wide, and even now some engineers were constructing tunnels only 25 feet wide. His practice was to make them 26 feet at their widest part, which was generally between 4 feet and 6 feet above the rail-level, according to the cross-section of the tunnel, which, of course, had to be designed to suit particular circumstances. When tunnels were 25 feet wide or less, it was with the greatest difficulty that the plate-layers were able to maintain the road in proper condition within the tunnels. Apart altogether from the question of safety, there was a difficulty in storing plant or materials; and of course many tunnels twenty years after they were made were not as straight as the Totley tunnel was that day. He therefore thought that, apart from any question of increased volume of air in the tunnel, which also was important, the engineers had shown a wise judgment in adopting ample dimensions.

Mr. Fitzmaurice.

Mr. M. FITZMAURICE, referring to the driving of the headings, said a comparison could be made from the Tables given by the Author between the rates at which the headings were driven by hand and by machine. In the case of driving through shale, with much water, driving by machines was accomplished at the rate of 18½ yards per week, and by hand 16½ yards. That was in the Totley tunnel. In the Cowburn tunnel the driving by hand with the Elliott hand-drill was rather quicker than by machine. In short tunnels a matter which ought to be kept in view was, that driving in shale could be done at the same rate by hand as by machine where air was not necessary for ventilation. With regard to the rate of progress of the headings, in considering possible improvements, two questions ought to be kept separate, viz., the reduction of cost, and the diminution of time. In the case under consideration there was no turn-out available close to the face; but if there had been it would not have diminished the time in any way; the rate of filling wagons would have been just the same, although the cost would have been reduced owing to fewer men being necessary, and the time would have depended on the number of men that could be put to fill them. The Author had proposed an overhead traveller with running buckets on it. That, of course, might save time, if sufficient men could be put at the face to fill the buckets in addition to the men filling the first wagon, but he thought it unlikely that in a 9-foot heading there would be room for the travelling buckets, and room for additional

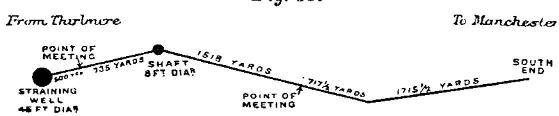
Mr. Fitzmaurice. men to fill these buckets. He thought that a reduction of cost might be obtained in an easier way than that proposed by the Author. In America flat cars with rollers fixed on the cars were used for running out rails quickly. If to those cars was added a light iron movable body, the body of the car nearest the face could be filled and pushed back over the rollers on to the last car. A new movable body would then be placed on the first car, filled and pushed back in a similar way, and so on. These movable bodies could be made very light and with folding sides if necessary. That would relate only to diminution of cost. Saving of time could only be obtained by better picking up of material at the face; and the question was whether that could be done by some special plant designed for the purpose. He thought that in the Totley tunnel there had been an opportunity for designing some special plant which could be worked by air or otherwise. The length of the tunnel would have justified a large expenditure on plant, and he was sorry nothing of the kind had been attempted. The number of shafts had been referred to. Perhaps the fact that the cutting in the front of the tunnel was not taken out when the tunnel was started might account for one or two of the shafts. As far as he could understand, shafts Nos. C and 3 were not used for any purpose when they were driven, but they seemed to have been driven to the formation level and then left until the headings from the adjacent shafts were driven up to them. With regard to machine- *versus* hand-labour, he might give the example of a tunnel with which he had been connected on one of the approach-railways to the Forth Bridge. This tunnel passed under a town and was on a curve of 40 chains radius; and, owing to houses, only one or two points could be fixed on the surface. However, by means of these, the headings being driven from both ends met within one inch. The whole tunnel was in very hard whinstone rock. One face was driven by air-drills, and the other by hand-drills. The progress of the headings was slow, the rock being very hard. With the machines it was about 6 lineal yards per week, and with hand-labour about 5½ yards per week, the headings being about the same size. The cost, however, was very different, that by machine-drilling being 18*s*. per cubic yard of material taken out, and by hand-drilling 13*s*. per cubic yard. Seeing that the progress was nearly the same in each case, that was rather important. He thought, however, that the progress by machine might have been increased, as the holes were only 5 feet deep; and probably better results would have been obtained by making them 6 feet deep. The amount of rock removed per pound of explosive was 1 ton in the heading driven by machines, and 1·3 ton in that driven by hand. The greater progress by hand was probably due to the fact that the holes could be placed to better advantage by hand. He did not in any way wish to depreciate the value of machine-drilling in driving headings; but, considering the excessive time consumed in taking the material from the face, compared with the actual time occupied in drilling, it was evident that the rate of driving could not be much increased by using machines. In short tunnels the time saved by using machines was not great, although it was important in long tunnels. When compressed-air was necessary for ventilation, the value of machine-drills was further increased. With hand-drills the drillers could get to work in a shorter time after a round was fired, and the holes could be placed to better advantage than with machine-drills. Whatever kind of drilling was used in driving headings, every effort ought to be made to remove the blasted material from the face quickly. These remarks would of course only apply to driving headings of the size generally adopted. Although not exactly bearing on the subject of the Paper, he wished to make a few remarks on the subject of drilling in rock cuttings. In large cuttings a great saving in cost and time was obtained by using machine-drills, as there was not the same difficulty in getting away the blasted material as there was in the headings of tunnels. On the railway to which he had already referred, a compressed-air plant was erected for working machine-drills in a large cutting. Four drills were in constant use and one was kept in reserve. Those machines could drill about 80 feet each per day of ten hours in hard whinstone rock, if they had not to be moved much; but, taking an average, owing to changes, lengthening the air-pipes, &c., each machine accomplished 40 feet per day. Over a cutting of 50,000 cubic yards, the total cost was 6*d.* per foot drilled by those machines, making full allowance for plant. That would be about the same cost as drilling by hand, but the rate of progress would be about three times that by hand. In larger cuttings, the price per foot drilled by machines would be less, as the cost of the plant would be spread over a larger quantity of work. Mr. Fitz-maurice.

Mr. J. V. W. AMOR stated, with regard to bonding the brickwork in the arch, whenever he had had his own way, he had always bonded the consecutive rings together by putting in a course of headers whenever the joints came into the same plane. He had been lately told that was quite wrong, and that it was far better to build arches in independent rings; the reason given being that Mr. Amor.

Mr. Amor. the headers were frequently broken by the settlement of the arch when the centres were removed or struck. He should like very much to know if that was the general experience of engineers who had built arches with rings bonded together. He had built arches in Mexico with very bad bricks, but he never remembered noticing any headers broken through. Mr. Amor exhibited a photograph of the engine for working in the headings which had been referred to by Mr. Squire and Mr. Cooper.

Mr. Hill. Mr. E. P. Hill alluded to the alignment of the Totley tunnel. Apparently one plumb-line was hung down the B shaft, and one down No. 4 shaft. Those shafts were about 190 yards apart, and a distance of about 3,700 yards was driven from them. That was only 20 times the length of the base, which seemed to be a convenient length of base to drive from. With regard to the sighting-objects used, the Author, for long distances, had used a lamp. Mr. Hill had found by experience that a lamp was much

Fig. 33.



5,186 yards long, 8 feet 6 inches by 7 feet.

Plan of Dunmail Raise Tunnel.

too large; there was too much room for variation in giving the line, and a very little error in giving the line accumulated in long lengths to a serious quantity. He used nothing larger than a carriage-candle, hung on gimbal bearings, and carrying a plummet for centering, which he had specially made. He had put on the wall a plan, *Fig. 33*, of the Dunmail Raise tunnel on the line of aqueduct from Thirlmere to Manchester, as he thought it would be of interest; it was nearly 3 miles long—5,186 yards—and 8 feet 6 inches wide by 7 feet high. It began in a straining-well 66 feet deep; it had a shaft at a distance of 1,235 yards and then had no shaft for the remainder of the length, about $2\frac{1}{4}$ miles. At the shaft, which was only 8 feet in diameter, he could only get the lines 6 feet 9 inches apart clear of the timbering. The length driven from the shaft was 1,518 yards, which was 675 times the base. From the south end they drove nearly a mile—1,715 yards—and then had to turn an angle and go something under half a mile beyond that to meet the heading coming from the shaft. In order to fix the position of the angle in the tunnel, it was necessary to measure the 1,715 yards on the surface of the ground, which fell 250 feet; that was done with rods 10 feet long (set horizontal with a hand-level), and a plumb-rule such as that used by masons, specially made for the purpose. The error where the headings met was $8\frac{1}{2}$ inches in line and $2\frac{1}{4}$ inches in level. An error of $\frac{1}{80}$ inch in the base was enough to account for the error of $8\frac{1}{2}$ inches at the point of meeting. It was rather difficult to deal with lines at a shaft which were only 6 feet 9 inches apart; he hardly knew how to transfer them. He could not fix a point at the bottom and set the theodolite over it. The only way seemed to be to set the theodolite about 30 yards off, put a bright light behind the lines and set the theodolite in line with the two plumb-lines. The first contractors began the work with a machine-drill similar to that used in the St. Gothard tunnel, mounted on a similar carriage. There were six machines on the carriage, and of course as the tunnel was only 8 feet 6 inches by 7 feet, it was pretty well filled by the carriage. After about 500 yards had been driven, the work was transferred to Messrs. Morrison and Mason, of Glasgow, and although they became possessors of the very expensive plant, they never used it; but instead set up an entirely new and smaller plant and used the Larmuth drill. With that they drove the tunnel through, one pair of machines being placed at the shaft and the other at the south end. The average progress was 13 yards a week, and the maximum 19 yards, the tunnel being driven through the lower silurian formation, which was extremely hard. The McKean drills did as much as 29 yards a week and averaged 23 yards, so that the progress was very much faster with the McKean, but it was much more expensive, experience showing that the carriage was too large, and there were too many drills. Too large a face was thus excavated, and large sidings required. The drills were efficient, but the weight of the carriage and the drills was about 2 tons. With the Larmuth plant, there were only two drills and a very light carriage, very handy, very adjustable, and capable of standing a great deal of rough work. The compressed air was conveyed in 6-inch pipes all the way, about 2,433 yards. The diameter of the pipes mentioned in the Paper was $2\frac{1}{2}$ inches, so that there was a great deal of difference between the two. Of course they did not lose much pressure with 6-inch pipes. Mr. Hill.

Mr. Ernest Benedict asked why there were so many changes of gradient at the east end of the Totley tunnel; why should not one through gradient have been put in from the entrance to the summit? Would it have been possible to have cut a small grip Mr. Benedict.

Mr. Benedict. at the east end, and to have established a boning-sight or point at that end? He presumed that No. 4 shaft acted as a boning-point as well as for direction. He should also like to ask how the levelling and measuring in the tunnel was done. As far as setting out the line went, it seemed to him there was no particular difficulty; but in such a long tunnel and for such long distances the measurement and the levelling were difficult and troublesome. He had had a good deal of experience in that work, and it seemed to him that it might be possible to do the levelling with water by a pipe. With regard to bonding the bricks, he had used in India tapered bricks; and on one work, where there were many buildings containing a large number of arches of all kinds, he had used those tapered bricks with great advantage. Of course where Portland cement was used the mortar was harder than the bricks, and a thick joint was, therefore, not so objectionable, but the saving in mortar and in expense would be considerable. He believed in this case that lias lime was used, and though the saving would not have been so much had radial bricks been used instead of the ordinary rectangular ones, the strength of the work would have been very much increased.

Mr. Moir. Mr. E. W. Moir, referring to the pumping, found it stated in the Paper that the best form of pump to use was one driven by compressed air. At the Blackwall tunnel there had been a considerable amount of water and, working down-grade, the water all ran to the face. There was no power other than compressed-air for pumping it out. It was found excessively expensive, as also at the Hudson tunnel, where compressed-air was used for similar reasons. In the first place, the air did not seem to be cooled as much as it ought to be by the water-jacket, and they lost from the heating of the air during compression about 25 per cent. of the work done, which was a very serious matter to a contractor. It was consequently being arranged to put water-jets into the cylinders so that the air might be cooled while it was being compressed. He would be glad to know if there was anything done in the way of injection of water into the air-cylinders of the air-compressors used on the works described. Their air-compressing machines were made by Messrs. Walker, of Wigan, who were not in the habit of injecting water at all. It was an important matter where power had to be used. One speaker had said that on a tunnel abroad electricity was generated by means of turbines, and that electricity was employed to compress air. It seemed to him it would have been considerably more efficient to have used

Mr. Moir. the electricity for pumping direct, as could be done, because electricity was transmitted with less loss than air-pressure. He believed that in Paris, where the Popp system was in use, the loss in a quarter of a mile was about 50 per cent., and that was very great when the losses in the pump where taken into account. There was a great want of a direct-acting expansive pump which could be run at low speeds—all small direct-acting pumps now made did not cut off during the stroke. There was one thing which struck him in connection with the section of the Totley tunnel. It was a very fine one, but there seemed to be a considerable portion of the tunnel in rock. He should have thought economy would have been effected by reducing the vertical diameter in the rock. Of course that elongated vertical axis was very important in soft ground, but it might have been flattened considerably where the rock was; and he saw there was a special section of brickwork of reduced thickness where the rock occurred. It was stated in the Paper that the material was not removed as fast as was desirable, but the speed of driving the heading seemed to have been much above the average. He found in an account of the Vosburg tunnel on the Lehigh Valley Railway, in the United States, that about 6 feet a day had been driven; whereas in the tunnels described 9 feet per day had been accomplished in the headings.

Sir Frederick Bramwell. Sir FREDERICK J. BRAMWELL, Past President, said, with regard to the subject of air-compressing cylinders alluded to by the last speaker, that many years ago the engineer to whom he was apprenticed was the inventor of a mode of transmitting power to long distances, not by compressed air, but by exhaustion, working the engines at the ends of the main at about half an atmosphere of pressure. In the exhaust-pump precisely the same thing occurred with regard to generation of heat as in the compressor-pump, *i.e.*, the air in passing through the mains became heated practically to the temperature of the earth; it then came into the pump, and was exhausted, then the piston returned, and had to compress the air to atmospheric pressure to open the head-valve and get out; and in doing that heat was generated just in the same way as in the compressor-pump. He thought he might claim to have introduced water-jets into those pumps as long as 50 or 55 years ago. In those days they had very few indicators or instruments of that kind. He remembered putting up a water-lifting apparatus in a coal-pit in the Forest of Dean; the water was lifted, not by pumps, but by the exhaustion of boxes placed at intervals in the shaft, the water going from

Sir Frederick Bramwell. box to box; and there a steam-engine worked the exhaust-pump. It was found the engine would make so many revolutions a minute if there were no water-jets. Directly he introduced the water-jet, the engine made a very considerable number more revolutions per minute. It might be said it was rather a rude test, but it was the test of those days, and was a practical one. More work was done with the same coal and the same engine.

Mr. Parry. Mr. EDWARD PARRY much regretted that the sad death of his late friend and assistant, the Author of the Paper, should have prevented any proper reply from being given upon the discussion. The Author had been very much interested in the preparation of this Paper, and everything connected with it, and having been upon the works from the commencement, he knew all the details and would have been better able than anyone else to have replied. His early death had deprived the Institution of a talented engineer. Some questions had been asked about the timbering of the tunnel, and Mr. Parry had prepared drawings which would furnish the information. *Figs. 34* and *35* showed the timbering of the Totley tunnel. In the section five drawing-bars were shown. The usual number was either four or five. In some places, where the ground was good, three only were used; at other places there were five or six, chiefly at the open ends. *Fig. 36* represented the general section of the lining with the centering used during construction. The leading ribs were composed of three elm planks bolted together, and the intermediate ribs of two planks. The *Fig.* also showed the sheet iron which was put outside the brickwork to protect it from the water during construction, and that had been very successful; for when it was remembered that at both ends of the tunnel there were flowing two large streams of water, amounting to 2,000,000 or 3,000,000 gallons a day, while from the crown of the tunnel there would probably not drip enough to fill a 1½-inch pipe, he thought it would be agreed that the method employed for bringing out water behind the work and into the drain had been very satisfactory. The inspectors were each supplied with a printed book in which they entered the thickness of the side-walls, the number of miners excavating, and all other particulars, and that was afterwards handed in to the Resident Engineer and posted up in the usual way. When the Paper was written, the tunnel was not completed, and of course it was not possible at that time to give any statement of cost, and even at the present time, as the final accounts had not been settled, it could not be stated definitely. Approximately, however, the

Mr. Parry.

Fig. 34.

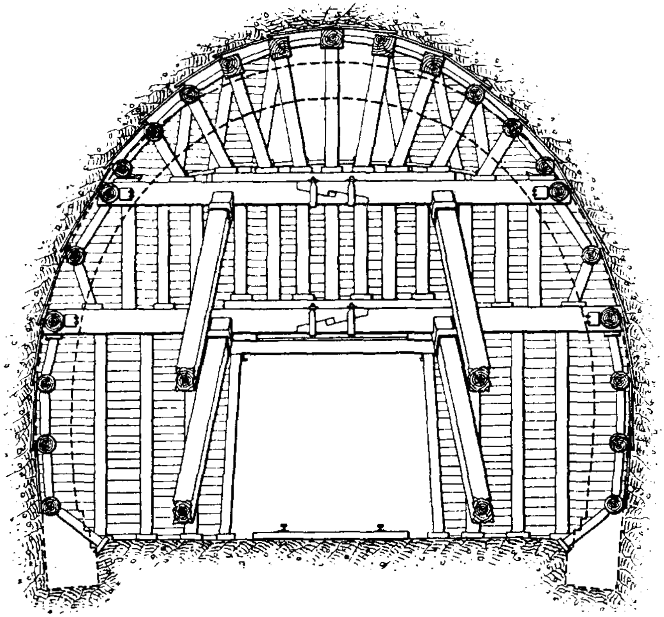
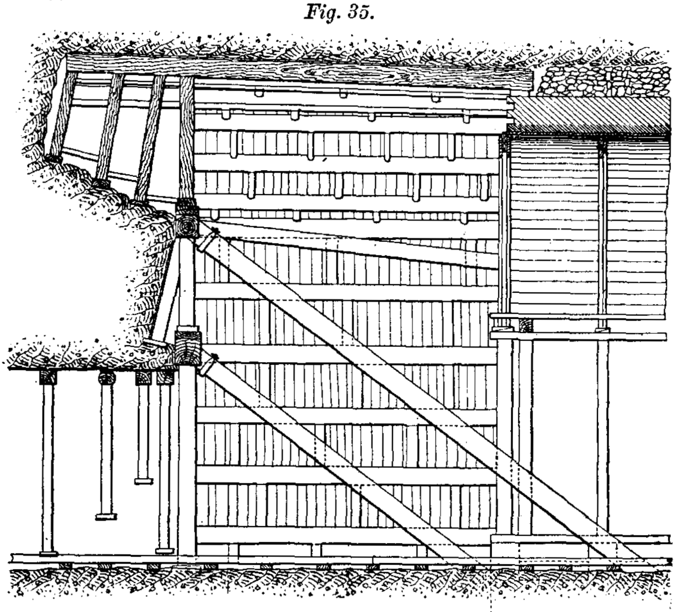


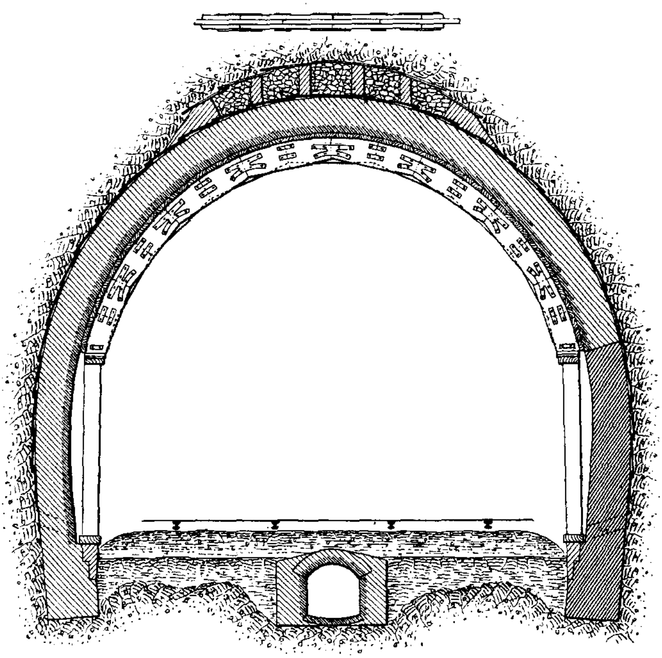
Fig. 35.



Scale, 1 inch = 10 feet.

Mr. Parry. Totley tunnel had cost something like £75 or £76 per yard, the Cowburn tunnel £2 or £3 less, and the Dore tunnel, excluding the fronts, which in a short tunnel came to a considerable portion of the cost, amounted to something like £53 or £54 per yard. With regard to the time occupied, it was true that progress of the work averaged 3 yards or 4 yards per day, but that scarcely represented the exact fact. At the early part of the time there were considerable difficulties with water and with the men and other

Fig. 36.



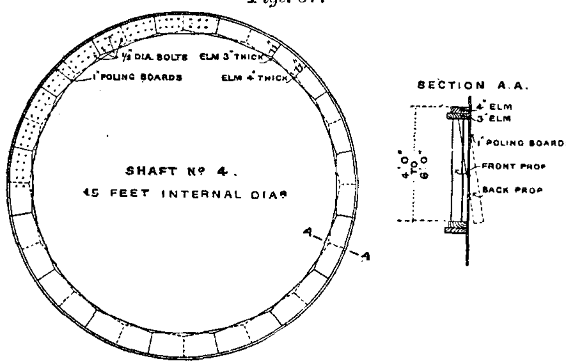
Scale, 1 inch = 10 feet.

things, so that progress was not so rapid, but latterly very rapid progress had been made. From July 1889 to July 1890 the rate of progress was only 16½ yards per week; but from July 1892 to July 1893 it was 48 yards per week. That would compare favourably with the progress in any similar tunnel worked from the open ends as the Totley tunnel practically was. The geological formation from the Totley end to near No. 4 shaft, was the lower coal measures; at the Padley end it was millstone grit and shale. Very few bars were built in except at the junction-lengths. There was no great weight upon the timber anywhere, and as a result nearly the whole of the bars were got out. The compass was scarcely sufficiently accurate to use in setting-out the line, and he did not think anything better than the large transit instrument could have been desired for that operation. The levelling was done with an ordinary spirit-level, in the usual way. A question had been asked as to the time it would have taken to excavate the heading of the Channel tunnel, if what was done at Totley were taken as a guide. He did not think the two things were at all comparable. The promoters of the Channel tunnel would, no doubt, wish to make sure before they commenced, or did much of lining, that the tunnel was feasible, and they would naturally wish to see the heading completed before they did much work. If so, there would not be the same difficulty that had arisen in the present case in putting in lay-byes for the wagons to pass one another as they were brought up to the face. With regard to bonding, one speaker referred to the trouble there was with tunnel bricklayers, and suggested that there was not such trouble in putting in a concrete lining. If anybody wanted to scamp work he could do it with either brickwork or other lining, and, probably, more easily with concrete than with brickwork. Neither was he at all certain what effect would result from steam and smoke impinging upon concrete lining. It was known that brindled or blue bricks stood well, but he did not think there had been as yet sufficient experience of concrete lining in railway tunnels to warrant confidence in its use. With regard to top- and bottom-headings, contractors always liked to avoid driving bottom-headings if possible; but if there was any question of water in a tunnel, the formation-level seemed to be the proper place to drive the heading. If, on the other hand, the work was in soft sandstone, or some material where there was no danger of water, then a top-heading might be convenient. Mr. McDonald had already pointed out that the number of shafts at the Totley end of the tunnel were wanted in order to expedite the progress. It was desirable that the tunnel, from the entrance to No. 4 shaft, should be completed as quickly as possible, in order to get the material from the open end to the portion of the tunnel between No. 4 shaft and Padley. *Figs. 37* showed the curb employed in sinking No. 4 shaft. These shafts were for the time left open until the question of ventilating the tunnel was finally decided. As had been said, powers had been taken for putting down a ventilating-shaft to be near the summit in the deepest part of the hill; but when it was found that there was so much

Mr. Parry.

Mr. Parry. water, it was determined to let the ventilating-shaft remain in abeyance until the tunnel was completed. A large ventilating-shaft was now being sunk. A bore-hole had been made to drain the shaft during construction into the tunnel-drain and so get rid of the water. With regard to the use of air-pumps, the Author had not been quite understood. What he meant was this: the gradient of the tunnel at the Padley end of the tunnel was very flat, and a great deal of water collected in the heading there, and ran out in a sluggish stream. In order to drain the foundations of the footings and side-walls it would have been necessary to put down that drain below the foundations of the footings; in fact, he doubted whether, if the drain had been put 2 or 3 feet below the bottom of the footings, it would have been possible to drain them without a cross-drain from each length into the grip.

Figs. 37.



Scale, 1 inch = 10 feet.

Instead of doing that, as there was already the compressed-air passing on its way to the face of the heading, the contractors naturally used that for the purpose of pumping the water from each length of foundation into the grip, and so got rid of it, having tried first of all hand-pumps and finding them insufficient. In reply to Mr. Greathead the brindled-brick lining was laid in alternate courses of 4½ inches and 9 inches, so as to bond the work properly together. The work was not built in single 4½-inch rings, but, as explained by the Author, the 1-foot 10½-inch work was built in two 9-inch rings with 4½ inches in the centre, bonded where they came together. With regard to the form of the tunnel, there was no great weight except at the open ends, and consequently the consideration of space was more important than any question of weight upon the lining. As to the suggestion of the shafts bringing in the water, as a matter of fact there was not so much water at the Totley end of the tunnel as there was between No. 4 shaft and Padley. The great difficulty was the large quantity found some 200 or 300 yards west of No. 4 shaft, which stopped the work for some time, while the dam was being put in to enable a drain to be laid through to carry the water away. He would not conclude without saying how admirably the work had been executed by the contractor, who had, under great difficulties, succeeded in carrying it out, and must be heartily congratulated upon its completion. Mr. Parry.

Mr. ALFRED GILES, President, said the Institution was to be congratulated upon the profitable discussion on the great work that had been described; and thanks were specially due to Mr. Parry for having afforded information upon the points as to which the original communication was not sufficiently explicit. Mr. Giles.

Correspondence.

Mr. BENNETT H. BROUGH remarked that, as there were but few published records of surveys of tunnels, the information given in the Paper could not fail to be of value to all interested in underground surveying. The results obtained when the two headings met were very satisfactory and compared favourably with others recorded elsewhere, as was shown by the following tabulated statement:— Mr. Brough.

Tunnel.	Length.	Error at Junction.	
		In Alignment.	In Level.
	Feet.	Inches.	Inches.
St. Gothard	48,872	12·99	1·97
Mont Cenis	40,081	Nil.	12·00
Hoosac, Massachusetts	25,031	0·03	0·23
Ernst-August adit, Hartz (Division 2)	23,760	1·20	0·09
Totley	18,687	4·50	2·25
Cowburn	11,106	1·00	
Croton aqueduct, New York (Division 1)	6,400	0·09	0·01
Nepean, New South Wales (Division 2)	4,341	0·42	0·25

It was possible that the Author might have obtained even better results if he had adopted more precise objects for sighting