Discussion.

The Author introduced the Paper with the aid of a series of lantern slides, including some views of Moscow Metro stations. He observed that the work carried out in Moscow had suggested the improvement, if possible, of the degree of space and freedom of circulation in a modern tube station. In Moscow that had been successfully effected by cut-and-cover methods. Perhaps it was rather unfair to have included in the Paper in contrast the rather gaunt photographs of Gants Hill station, because they showed only the bare bones of the constructional work, but the general form aimed at could be appreciated. In the Moscow construction the finish was lavish, but the stations were a notable contribution to progress in underground railway work.

In the Ilford tube compressed air was used at six or eight places. Under Eastern Avenue—one of the big arterial roads leading out of London—in the section leading to Gants Hill station there was a short length of compressed air-work. The air escaping during the work had had a tonic effect on the shrubs in the central reserve, which had flourished exceedingly, and he thought they must have been very sorry when they returned to their ordinary diet of petrol fumes.

The history of the Ilford Tube, an important part of the north-eastern extension scheme, had been rather chequered. Fifteen years ago the London and North Eastern Railway had attempted to get some such scheme under way, but it did not go through. That was a great disappointment for the people of Ilford and other districts, whose travelling facilities had been a byword for many years owing to the sheer lack of accommodation on the railways and to the enormous growth of the dormitory towns. The opening of the first section of the Ilford Tube had been expected in October 1939. The track was being laid and everyone was intensely busy. However, the war had intervened and those who were looking forward so eagerly to the improved facilities were again disappointed.

The Tube had been of considerable use during the war. At various points it provided valuable shelter in air raids, whilst towards the eastern end it had housed a very well-equipped and up-to-date factory for the manufacture of aircraft components.

All that was a thing of the past, and the London Passenger Transport Board were now concerned as to how they could best meet the urgent need of getting the line completed—no easy matter under present conditions. He was confident that when once the Ilford Tube and its related scheme for the electrification of the North-Eastern Railway Company's lines were in being they would constitute one of the most valuable of all the traffic facilities of outer London.

The President observed that before many months had elapsed there would be a new population at Grange Hill—a population very much dependent upon the services described in the Paper. The London County Council had commenced the development of a cottage estate there, and a large number of labourers, chiefly German prisoners, had been working there for some months on the advance preparations. The number of houses would increase rapidly. Could the Author state when the electric trains would be serving that locality?

Sir William Halcrow observed that to describe the design and construction of nearly 10 miles of new tube railway, involving some intricate engineering work, in the compass of a comparatively short Paper was not an easy task, and the Author was to be congratulated on the very successful way in which he had accomplished it. The Paper might be described as a model of its kind, as most of it was devoted to clear and concise descriptions of the unusual and more difficult sections of the work, whilst the general features were disposed of in a few pages.

The major engineering difficulties arose from the fact that the line had to come to the surface at a number of points throughout its length, and the methods adopted for constructing the railway either in tunnel or in subway, through water-bearing and other weak strata were ingenious. An outstanding feature was the effectiveness of the chemical consolidation process, which had been referred to several times as a complete success. There were many instances in underground work where that process provided a ready means of dealing with water-bearing strata, thus ensuring against runs and possible settlement of the ground.

Gants Hill station had been designed to give more circulating space between the bottom of the escalator and the station platforms. The usual construction at the foot of an escalator took the form of three tunnels side by side, the central tunnel forming the bottom chamber for the escalator and those on each side accommodating the station platforms. Openings were formed as required between the bottom chamber and the platforms. That was a simple design and much less costly than that shown in Fig. 15, Plate 2. Did the Author consider that the addition to the circulating area was worth the extra expense? The main purpose of the design was to provide facilities for the easy passage of passengers between the trains and escalators, and Sir William considered that excessive space should be avoided at that point.

In the Introduction to the Paper the Author had given a brief history of the extensions undertaken by the London Passenger Transport Board shortly after it was formed, and the works which were described formed part of what was generally known as the "1935 programme," the Central Line being taken out to the surface both to the east and to the west. Other important works included in that programme should also be recorded, as it was improbable that separate Papers would be written to describe them.

The first was an extension of the Bakerloo railway from Baker Street to Finchley Road, where the tube came to the surface at the same level as the Metropolitan Line. New stations with escalators were constructed at St. John's Wood and Swiss Cottage and an additional platform on the southbound line with new escalators was added at Baker Street. The works at Baker Street and where the tubes rose to the surface under Finchley Road were of a complicated nature. At Finchley Road a diversion of the up Metropolitan line in subway was first constructed, to a large extent under property. The diversion left sufficient space for the two tube lines to rise between it and the existing down Metropolitan line. The northbound tube was brought up into the up Metropolitan tunnel and the southbound tube was located in the space between it and the new up Metropolitan line. All of that work was carried out without interrupting the very heavy traffic at Finchley Road. Trains on that line now ran to Stanmore, with a convenient level interchange at the surface between the Metropolitan and Bakerloo lines at Finchley Road.

The other line to be taken to the surface was the Highgate branch of the Northern line, which previously terminated at Archway Road. The tube railway was extended up Archway Road and passed under the Highgate station of the L.N.E.R., at which point a booking hall was constructed under the L.N.E.R. station, and from that level an escalator was built down to the new tube station. That whole extension line rose on a general gradient of 1 in 50 and broke surface a small distance south of East Finchley station on either side of the L.N.E.R. embankment, and eventually crossed over the Great North road at the same level as the L.N.E.R. to the surface station. The Northern line trains on this branch now ran to High Barnet, with a level interchange with the L.N.E.R. at East Finchley. The two northbound branches of the Bakerloo and the two on the Northern line now ran trains to the surface.

In addition to those line extensions a number of stations were provided with escalators to replace the old lifts, and a major work was the extension of all the platforms on the Bakerloo line from Kilburn Park to Elephant and Castle, at which point a new cross-over road and train sidings were constructed. That work was done in compressed air. The platforms now had a length of 377 feet, to accommodate seven-car trains. In most cases the extensions were carried out by the method shown in Fig. 22, Plate 2, but in others some intricate work was involved. The larger contracts were carried out by Charles Brand and Son, Ltd., John Mowlem and Company, Ltd., and Balfour Beatty and Company, Ltd.; the late Sir Harley Dalrymple-Hay, M. Inst. C.E., and Sir William were the consulting engineers for those works. The 1935 programme had not yet been completed. Some schemes started before the war had been held up and others had yet to be commenced.

Dr. David Anderson observed that both the Author and himself had heaved a sigh of relief when some of the work was completed, especially

at Stratford. The Author had called the ground "very bad," but that was a very moderate expression, since it was more like pea soup in places. Congratulations were due to John Cochrane and Sons, Ltd., and especially to their agent and engineer, Mr. George Ford, M. Inst. C.E., for carrying out the work so successfully. Had a disaster of any kind occurred it would have been a major one; but in fact no troubles developed and the work was carried to successful completion. Dr. Anderson considered that engineers did not blow their own trumpets enough. No more difficult work had been done in Great Britain than that at Stratford and he doubted whether a more difficult bit of tunnelling had ever been done in any quarter of the world. He emphasized that because it showed what British contractors could do.

With regard to the Moscow stations, in 1932 Lord Ashfield was approached by the Moscow authorities and asked whether he would be prepared to render technical help. The travelling conditions in Moscow at that time were simply deplorable, and assistance was badly needed. Lord Ashfield had replied that he was prepared to help in any way he could, and without making a charge of any kind. No one wished to take advantage of the desperate traffic situation in Moscow, and Dr. Anderson wished to have that plainly stated, because advantage had been taken in certain directions of the difficulties that were experienced in Russia when equipping herself as an industrial nation. Lord Ashfield agreed to help and in 1932 he sent out three engineers—Mr. E. T. Brooke, Mr. Evan Evans, and Mr. J. C. Martin, M. Inst. C.E., who obtained information as to the conditions prevailing in Moscow and drew up a report on what ought to be done. Dr. Anderson's firm was also asked to make a report and in company with Mr. Martin Dr. Anderson went to Moscow, taking with them a large number of drawings, including one prepared by Mr. Martin, which formed the basis of the work illustrated on the slides shown by the Author. About three years later, at the opening ceremony, the British engineers were interrogated for hours on end as to the working and organization of Tube railways, and Dr. Anderson, as a spectator and listener, had been much impressed by the way in which those engineers from the Underground had answered every conceivable question and by the superb organization that they had explained for the help and guidance of the Russians.

At Moscow the stations were comparatively shallow and were carried out by cut-and-cover methods. Almost anything could be done if unlimited labour and money were available. About 70,000 men and women were engaged on the construction of those 5 miles of railway; that seemed an unbelievable figure, but he assumed that it included the workers in the factories making the necessary materials. In London about 1,500 men were employed during the peak period at Ilford. The Russian cost ran into millions of roubles. The value of the rouble was not easy to assess, but undoubtedly a very large sum of money was spent upon that work. The final results were very impressive, and on returning to Great Britain

he had felt that British engineers should try to do something to give similar results, but, of course, without using unlimited supplies of labour and money. Thereupon the type of work illustrated in Fig. 15, Plate 2, was devised, whereby a platform width of 51 feet was obtained. The first estimate of cost was about £25,000 for the length that was done, but it cost somewhat more, because various difficulties were experienced. Nevertheless, he considered that the cost was justifiable, and that when the work was lined and finished off it would provide a type of station much more spacious than anything to which people had been accustomed and of pleasing appearance. He hoped that it was a step forward in the construction of underground tube railways.

In his opinion it was only right that the help which British engineers had given to the sorely tried people of Moscow should be placed on record. Those people were suffering very severely at that time. He had a vivid recollection of the trams going along crammed not only inside but also outside, with people hanging on wherever they could.

Mr. G. C. Brand observed that the Author had mentioned that on two drives a "digger" shield was used. Those two drives were from Bethnal Green to the west. The shield was designed and built for his firm by Messrs. Markham, of Chesterfield, and in principle it was a modernized version of the original Price rotary excavator shield. It had recently been used for two drives on the Highgate Extension but as it was the first excavator shield to have been built for about 15 years, it was rather an experimental tool and was subject to a certain number of mechanical defects. That accounted to a certain degree for the fact that the progress, as given by the Author, was of the order of 100 rings per week, in comparison with 45 rings with the ordinary hand shield.

Another factor which rather retarded the progress which might be expected from a modern excavator shield was the necessity of grouting up every second ring. Mr. Brand admitted that that in itself was a concession from the specification, which called for grouting every ring, but he felt that in the present days inquiry should be made whether it was necessary to grout as frequently as that. At the start of the Liverpool Street extension certain experiments were made to test the degree of settlement that might be expected in the roof of a 12-foot diameter tunnel in the London blue clay, and it was found that at the end of 48 hours—the length of time during which the tunnel was open for experimental purposes—the settlement ranged from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch. In the discussion on the Author's Paper on reinforced-concrete tunnel lining,¹ Mr. A. W. Skempton had given certain figures for experiments on the amount of stress on the tunnel lining in London blue clay. The amount of stress at the end of the third day was very small, but the stress built up between the third and the fourteenth day, and thereafter was more or less constant.

¹ "Tunnel Linings, with special reference to a New Form of Reinforced-Concrete Lining." *J. Instn Civ. Engrs*, vol. 20 (1942-43), p. 29, (Mar. 1943).

It all came back to the question of whether the grouting of tunnel linings should not be put on a time basis—in other words, whether, instead of grouting up after each ring when built, it might be done at the end of, say, 24 hours. That was an experiment worth making, and would have the supreme advantage that it would be possible to grout up a good length of tunnel at a time so that one could make certain that one had the grout where it was wanted, namely, at the circle joints. At present, when one ring at a time had to be grouted, a peculiar mixture of grout, clay “pug,” paper, sacking, and general what-not occurred at the very point where the grout was required. If the question of grouting long sections of tunnel at a time could be adopted considerable advantage would result. The way to a leak-proof tunnel was by grouting rather than by caulking and preferably by pressure grouting over fairly long lengths.

With regard to the drives of the excavator shield, on the particular lengths in question there was not a great deal in it economically from the contractor's point of view, because the drives were comparatively short, and there was the expense of erecting the shield and getting it going for a comparatively short run. In addition to that a 12-foot 3-inch diameter tunnel was given for the same cost as for a 12-foot tunnel. The principal reason for that was that the shield had been built for a diameter of 12 feet 3 inches and it was not very practicable to alter it. But to anybody who was thinking of driving tube railway tunnels with a “digger” shield, Mr. Brand would suggest that it was worth while to make the tunnel 3 inches larger in diameter than was called for. An excavator shield was not easy to steer; when it started going off line or level it was difficult to correct it quickly. Yet under their present specification the Board would not accept any ring of iron which was out of shape or out of position to the extent of more than 1 inch. With a larger shield, with 3 inches or 4 inches of diameter to play with, one could make progress without having, at the end of the drive, to go back and change many rings of iron.

In the new 1935 programme the Board had stipulated a very high standard of accuracy and it would be interesting if the Author would state approximately how many rings had had to be changed. From Mr. Brand's own knowledge, he believed that it was not more than 1·5 or 2 per cent.; and when it was remembered that the tolerance allowed was only 1 inch, that was extremely good. The people to whom tribute was due were not so much the main setting-out engineers—although their accuracy was proverbial—as the junior engineers, the leading tunnel miners, and even that much maligned figure, the inspector. It was due to their care and trouble that the very high standard of accuracy required by the Board was obtained on that new programme.

Mr. R. Glossop observed that an interesting feature of the work described in the paper was the ingenious use made of a number of specialized devices and processes such as bored piles, of which most effective use was made at Mile End Road station and at Carpenter's

Road bridge; ground water lowering by well points and shallow wells; and chemical consolidation which was employed where the tunnels passed beneath the several branches of the river Lee and at other points where excavation or tunnelling was carried out beneath existing foundations.

The Author had referred to sand and gravel treated by the chemical consolidation process as a weak concrete. Actual strengths were shown in *Fig. 30*, and it would be seen that a compressive strength of about 400 lb. per square inch was obtained immediately. There was then a gradual increase over several weeks to 500 lb. or 600 lb. per square inch, and that was retained indefinitely.

Mr. H. J. B. Harding observed that the section east and west of Stratford Junction, known as the Bow-to-Leyton section, consisted of more than 10,000 rings of compressed-air tunnelling, and was probably one of the longest of its kind in Great Britain. It was fitting, as well as fortunate,

Fig. 30.

COMPRESSION TESTS ON CHEMICALLY CONSOLIDATED LEIGHTON BUZZARD SAND.

that the contract should have been under the direction of Mr. I. J. Jones, M. Inst. C.E., whose Paper¹ on the enlargement of the City and South London Railway tunnels (jointly with Mr. Gerald Curry, M. Inst. C.E.), should be studied in connexion with the present Paper. Mr. Jones would be described by Americans as the "dean" of the London tunnel world, and during his 50 years' experience most London tunnel engineers had come under his influence. The value of that experience had been shown in the choice of plant and methods of working adopted. Rotary compressors of varying capacities proved well adapted to the changing conditions.

Hooded shields had often been used, but trapped shields were less frequent. Prior to the introduction of the hooded shield and clay pocket method by Sir Harley Dalrymple-Hay it was the custom in bad ground to excavate a length ahead of the shield supported on close timbering and to push the shield into it. When the hooded shield was first introduced it

¹ Min. Proc. Instn. Civ. Engrs, vol. 224 (1926-27, Part 2), p. 176.

met with the massed opposition appropriate to any innovation. In order to prove his principle Sir Harley himself worked in the shield, taking out a length of pocketing, and he had acknowledged the help he received in demonstrating the use of the shield on the Bakerloo Line from one particular miner, a Mr. Treleven.¹ On the Bow-to-Leyton section the very able and active general foreman was the same Mr. Treleven, whose experience was utilized in training enough miners to man the ten shields with three gangs per day.

Mr. Harding exhibited a lantern slide illustrating the 12-foot diameter shield used during erection in its 15-foot diameter shield-chamber. The seal, trap, or pulpit filled with water if a run occurred, and so permitted the air-pressure to build up again in the tunnel. The Author had stated that safety screens were erected in the 7-foot pilot tunnels under the water-works river. Actually the method adopted was rather more ingenious, and was shown in *Fig. 31*. Safety shields had been called for, as the 7-foot shield was not large enough to carry a trap, but, as those would have entailed double handling of excavation, a semicircular steel curtain top was assembled and fitted with the lower half of the usual timber grouting rib, and was bolted to the convenient holes in the cross-heads of the shield jacks. That diaphragm moved forward as the jacks were withdrawn. A small steel plate was used to close the upper half of the doorway, and thus a trap was provided which had an advantage over the trap on the 12-foot shields; the labourer shovelling out the muck had more posterior space.

A simple device adopted on the Bow-Leyton shields, and since used, Mr. Harding believed, by Messrs. Markham on one of their newer shields, was the Treleven plough, one of the few new contributions to shield design for many years. It was fixed to the second pilot shield after trouble had been experienced with the first. A steel block machined to fit the hood and sloping upwards was secured by studs to the stiffeners at axis-level. A slot was cut in the hood at each side of the shield, with the bottom of the slot flush with that block. The ploughs, consisting of a flat plate of steel, lay on these blocks and were held in position by studs through holes in the plough and in the blocks. The plough could then be driven out through the slot and held in position by studs dropped into the outer row of holes on the blocks. One plough could be used to correct a roll, and both ploughs to correct diving, and they could be pushed out or withdrawn at will. The difference in performance of the second pilot shield fitted with those ploughs when driven by the same gang through the same ground as the first pilot tunnel was so marked that the ploughs were fitted to a number of 12-foot shields for the remainder of their drives.

Lieut.-Col. C. M. Norrie observed he was sure that Mr. George Ford would wish to thank Dr. Anderson for the very kind remarks he had made

¹ "The Waterloo and City Railway," Min. Proc. Instn Civ. Engrs, vol. cxxxix (1899-1900), Part 1, p. 25.

about the work at Stratford, which had caused many moments of anxiety to him and also to Col. Norrie. With regard to the compressed air working, on the Ilford tube the pressures were quite low, but Col. Norrie wished to appeal to all engineers who might have to carry out compressed-air work in the future, at pressures of from 25 lb. per square inch upwards, that they should carry out some experiments. Everybody was aware that the long

Fig. 31.

BOW-TO-LEYTON SECTION. CENTRE LINE EXTENSION.

Diagram of 7' 0" Diameter Hooded Shield Showing Treleven Ploughs and improvised water trap.

periods required for decompression were a great handicap and expense. If anything could be done by research or otherwise to reduce the times of decompression a great deal would be achieved. It was well known that during decompression the likelihood of "bends" was much less if men would only take exercise, but it was difficult to get men to carry out exercises during decompression after having done a shift's work. He would like to see artificial vibration tried on the men. Engineers might devise some means of vibrating the men with a compressed-air machine or by some other means fitted over the vulnerable parts of the body. Naturally, co-operation by the medical profession would be necessary.

The Author, in reply, observed that the discussion had not raised many points requiring an answer. He could not give the date when the new facility of the North-Eastern extension would be in operation; it was the concern of the Transport Board and of the North-Eastern Railway Company to equip the lines in readiness for traffic.

Sir William Halcrow had questioned whether the extra space provided by the special construction he had described was worth the extra cost. That could not be answered by the civil engineer, who merely gave effect to certain methods of construction to satisfy the requirements or suggestions of his client, and the matter had been influenced to some extent by what the Board considered desirable from points of view other than those of civil engineers. There was expenditure on many things in connexion with the design of tube railways that to the outside observer would hardly seem justified. For instance, the Board insisted on saving—often at considerable cost—every foot of depth from road-level to booking-hall because any unnecessary depth was likely to have its reaction on the popularity of that particular station and therefore on the revenue-producing capacity of the railway. Thus there were psychological features in such a construction as that at Gants Hill which were perhaps imponderable; and their value could be proved only in actual practice and in the use of the station. It was to be hoped that the novelty of the construction at Gants Hill would eventually prove its worth in terms of money.

He was sorry Sir William Halcrow thought that no Paper describing the other operations under the Board's 1935 programme would be presented, and it would be unfortunate if they were not put on record in more detail, as he knew that some of them were very interesting from the civil engineering point of view.

Dr. Anderson had paid a well-deserved tribute to the contractors. All who were engaged in the work had had an anxious time, and the unremitting care that they had bestowed upon it was very much to the credit of the contractors as well as their own engineering staff.

Mr. Brand had referred to the use of the "digger" shields in one of the two contracts for which his firm was responsible, and had made some rather provocative suggestions in regard to grouting and the length of time that might be allowed to elapse between grouting operations. Also it seemed that it would be necessary to extend specifications and prohibit the use of "what nots" in grouting!

A consideration of some importance arose in connexion with grouting. Engineers and contractors tended to pull in opposite directions. Engineers were seriously concerned not to allow the interval between successive groutings to be so long in time or distance as to endanger structures above the tunnel. The contractor naturally wanted to improve progress, especially when he had a "digger" shield, of which he wanted to make the best possible use. Perhaps the engineers, on their side, were rather conservative, but in the particular length to which Mr. Brand had referred they were

driving under one of the most important L.C.C. sewers in London. No harm had, in fact, happened to that sewer, but perhaps some might have occurred with twice or three times the interval between grouting operations. With a length of ungrouted tunnel—six, eight, ten, or even twelve rings—surrounded eventually with a material which took, perhaps, 12 or 15 hours to harden, there was obviously some risk to overlying structures, and there must be a strict limit to what the engineer could allow. So far as they could they would like to meet the contractors, because they were all for progress, but progress should not involve too great risk. Members would be amazed at the extraordinary claims that were put forward to the Board in connexion with minor defects in buildings alleged to be caused by tunnelling operations. In London great care had to be taken to avoid damage. By comparison, he understood that a recent shield drive in Chicago had resulted in cellar floors along the line of route being pushed upwards.

He did not know what percentage of rings had had to be rebuilt, but it was remarkably small, and he could endorse Mr. Brand's remarks as to the accuracy of the driving and erection. The credit was shared by all concerned, including the tunnel gangs.

The chemical consolidation process had been found to be of immense use again and again, particularly in its application under the river Lee and its tributaries and under the river Roding, a comparatively small river, but one where a break-in would have been a very serious matter. A sense of security was felt in driving in the consolidated material, which had a consistency preventing any chance of running.

He welcomed Mr. Harding's reference to the work of Mr. I. J. Jones. He had felt happy that a man with such a great wealth of experience and tunnel wisdom should have been behind the organization of Messrs. Mowlem's work, which covered some of the difficult and anxious tunnel operations.

Colonel Norrie had opened up an interesting field for discussion; but no high air-pressures had been involved in the Ilford Tube work and no special precautions were necessary in regard to it.

Colonel Norrie's idea of applying vibration to the miners was novel and stimulating. The Author was always prepared to try out anything new, and he would consider that suggestion. If Colonel Norrie should join forces with him in some future work involving high air-pressures, would he devise a suitable vibration apparatus for use in connexion with it? If so, the Author would stipulate that Colonel Norrie should indemnify his clients against damage by riot which might occur when the men emerged from the air-lock!