Discussion

The Author, in introducing the Paper, said that the complications introduced by the need to keep the cables clear of air passages would be a peculiarity of the Ilford Tube, since he understood that in future tube lines it was proposed to rely entirely on the air circulation produced by the main extract fans, and not to have intake fans at stations. He also hoped that in the case of future lines it would be possible to incorporate in the original design most of the requirements for services and cable runs; the omission of such details, or major departures from the original scheme, might involve considerable work during subsequent equipment operations.

With regard to fire precautions, he hoped that a more satisfactory method than the use of " water fog " would be devised for dealing with smouldering in escalator tunnels ; a spray of water could have an adverse effect on the escalator mechanism. Perhaps some form of carbon-dioxide installation would meet the case.

It might be asked why equipment which was quite capable of standing up to all weathers above ground should have to be protected against dripping water underground ; but he thought that it would be agreed that incessant dripping in an air current constituted the more serious condition. Moreover, certain items of equipment, including conductor rails (which were of lighter section underground than above ground), the noise-reduction paxtiles, and the tunnel lighting cables, were designed on the assumption that the tunnels would be reasonably dry.

Part of the description in the Paper of the high-tension equipment might require some clarification. The transformers were protected by overload relays of the " instantaneous " pattern. Each feeder was fitted with a translay relay at each end, these translay relays being interconnected by the pilot cable. If a fault developed in the length of a feeder, so that the input and the output became unbalanced, the translay relays operated and the circuit-breakers opened, isolating the feeder.

It was a statutory requirement that at least 25 per cent. of the lighting load should be provided by an independent supply. From the section of the Paper headed " Power-Supply " the impression might have been gathered that the emergency lighting-supply was derived from the same source as the normal lighting but, in fact, the emergency lights were fed from emergency lighting batteries, which were maintained in a charged condition by the 60-kilowatt charging rectifier, as shown in Fig. 18, Plate 2.

The way in which control of works of the nature described in the Paper could best be organized was a matter upon which he would like to hear other views. In the confines of the tunnels, staff responsible to no fewer than six officers had been working at one time, and a strictly limited amount of rolling stock had been required to meet the needs of several departments. In the analogous case of public works, the agent of the main contractor should have direct control over all the sub-contractors working on the site, whilst in an Army division the various arms took their orders not from the headquarters of their corps or regiment but from the divisional commander. Were those fair comparisons ? Was there a case for the counterpart of an agent or a divisional commander on the site of railway new works, or would the best results be produced by an inter-departmental committee with one member responsible for liaison ?

The Author showed a number of slides illustrating some aspects of the Paper.

Mr H. A. Wickham said that he wished to confine his remarks to the installation of the 300-foot flash-butt-welded rails in the tunnel. From the Paper it would be seen that the tunnel was lined with 20-inch cast-iron and reinforced-concrete segments, and he wished to point out that it was not always an easy matter to accommodate the sleepers in the 17-inch space between the vertical segment ribs. If there was a horizontal joint in the rib at sleeper-level it was practically impossible to install a sleeper in that segment; he begged all tunnel engineers to try to avoid that state of affairs. An 18-inch fishplate situated by one of the segment ribs should have the joint located almost precisely on the centre-line of the vertical rib. If it were more than 1 inch out in either direction the fishplate would bear against the chairs, which would cause trouble when the trains began to run and there was movement of the rails. Also, the flash-butt-welds in the rails should be located clear of any chairs, to avoid uneven surfaces resting in the chairs.

A very careful survey was therefore made of the tunnels, with 300-foot steel tapes, before any rail-making was attempted. One such tape was kept in the welding station and one in the tunnel, and they were carefully calibrated to ensure that their measurements agreed. Special rail-sheets were also prepared, and had to be made out with extreme care to ensure that no errors were made in reading them; an error of more than $\frac{1}{2}$ inch in the length of a rail would render it incapable of being used in the tunnel.

On the London Transport system, an allowance of $\frac{11}{16}$ inch was generally made for loss of metal in the welds, but it seemed that that figure actually varied from day to day according to the weather conditions. Mr Wickham would like to hear other observations on the loss of metal in flash-butt-welds.

The whole object of flash-butt-welding was to avoid joints. With the type of signalling used on the London Transport system, it was necessary to install a number of block joints, and an effort was always made to locate them to coincide with ordinary fishplate joints. Standard rail lengths could not be used, because the joints had to be located precisely, and it was necessary for the manufacturers to hold a stock of sub-standard lengths. Those were generally multiples of the segment width plus the caulking in the joint (about $20\frac{3}{8}$ inches). It was necessary also to accumulate rails with blank ends and rails with the specially machined fishplated end, and also a small stock of rails with normal fishplated ends for block-joint work. It was generally found, in any event, that in a 300-foot rail it was necessary to cut one of the component rails to make a finished rail of the precise length required.

Welding was generally done by day in the Drapers Field depot, and laying was done by night, ensuring that everyone was fully employed on a 24-hour system.

It was essential to mark the rails on the train very clearly to show the side of the track to which they belonged and the direction in which they were to lie, and their locations in the tunnels were clearly marked on the tunnel walls. It was useful to mark each rail, before it went into the tunnel, with a white bar where each lifting tackle should be fastened.

The runway method of laying rails had been very fully described in a Paper [1] read before the Railway Engineering Division of the Institution. The runway should be very carefully constructed. The joints in the rolled-steel joists particularly should be flexible and yet free from steps or gaps. All the rollers in the upper carriages which were fastened to the roof and the wheels of the carriages themselves should be well lubricated, and, from personal experience, Mr Wickham advocated the fitting of ball bearings to those wheels, because he had found that many of the initial difficulties in the use of a runway were caused by the wheels binding in their bearings. It was worth while to have a competent mechanic to examine the runway daily and rectify minor faults in preparation for the next shift.

The runway was pulled along the tunnel during each shift by means of a chain attached to one of the leading wagons on the train. In order to avoid dragging the whole runway down in the tunnel, it was advisable to fit a spring device to the chain, so that any undue pull on the chain was taken up before it could be transmitted to the runway or the roof of the tunnel. It had been found worth while to give the runway gang a few days' practice on the use of the runway before any actual rail-laying was attempted.

It was important that, at the end of each day's rail-laying, the exact position of the last rail should be ascertained. In spite of all the care that was taken in measuring rails, it was generally found that there was a small error, which had to be kept under control; if it exceeded 1 inch, the welding station had to correct it on the next set of rails.

For the purpose of levelling and alignment in the tunnels, all the lights were switched off and the rails made wet and, by means of two flood-lamps used at very low level, a beam of light was cast along the track, showing clearly any fault in the alignment or level. In the open the track could be located anywhere for level and alignment, but in the tunnel there was an average clearance of 6 inches outside the standard rolling-stock, which

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[1] C. E. Dunton and K. Brinsmead, "Design, Installation and Maintenance of Long Welded Rails." I.C.E. Railway Paper No. 27, 1948.

limited the opportunities for obtaining perfect alignment and level, and it was necessary to use a very carefully constructed structure-gauge, with adjustable arms to give the extra clearance required on curves. After the track had been fixed in the best position, a skeleton train was run through the tunnel at various speeds to reveal any obstruction that had been overlooked.

A great deal had been said about the problem of expansion of long welded rails; but the matter was not too serious with rails laid in tube tunnels, where variations of temperature were limited. Allowances of up to about ⅜ inch for a 300-foot rail would compensate for expansions likely to take place between the time when the rail was laid and the time when it was concreted. The further rise in temperature afterwards would not be more than about 15° F. The final temperature in the tunnel is 70–75° F. If the track could be anchored so that its movement would be restricted after it was concreted, the stresses likely to accumulate would not be too great; in the Ilford tunnel provision had been made for those stresses by providing concreted sleepers and rail anchors at intervals of five sleepers, to hold the rails securely to the chairs. Short rails had been left near the stations, so that if undue stresses arose the rails could be taken out and shorter ones substituted, and expansion switches (illustrated in *Figs 8* of the Paper by Dunton and Brinsmead) had been put at the tunnel portals, to take up any stresses which were transmitted to the mouth of the tunnel.

Mr Wickham hoped that consideration would be given to obtaining a higher standard of finish in the grinding process on flash-butt-welds. He did not think that the method now adopted gave a surface as good as that of the adjoining rail face, and he would like to see a machine specially made for the purpose of giving a perfect finish to welds. Although the rails used were 300 feet long, there were still many joints in the tunnel; but he did not believe that it was beyond the skill of railway engineers to evolve some method by which the 300-foot lengths could satisfactorily be welded on the site into much longer lengths, giving a closer approach to the perfect track without joints.

Mr G. R. Kent said that he wished to add a few details about the location of the signalling equipment of the Ilford Tube. The design had ensured that most of the equipment was installed in apparatus rooms at the ends of the platforms. One advantage of that system was that, in the event of a failure, the signal lineman could watch the operation of the track relays and associated equipment while the trains were running.

Fig. 24 was a view of an apparatus room, showing a number of the track relays described by the Author. It also showed the condensers which controlled the track relays, the adjustable links which altered the capacity of the condensers, the transformers associated with the track circuits, and the fuses controlling the circuits. The lineman could in many cases locate a fault and clear it without having to work in the tunnels—an important consideration in an intensive service of forty trains per hour. The main 600-volt cable was connected from the link box to the large transformer, where the pressure was reduced to 100 volts.

The signalling equipment in the tube tunnels had been kept to the minimum. *Fig. 25* showed a typical signal lay-out in the Ilford tube, with the two-aspect colour signal. The apparatus cases were open; in addition the electromagnet for controlling the train-stop could be clearly seen, and also the signal relay. When a train was clear of a particular section, the track circuits operated the signal relay, which in turn gave a green light in the signal, and the train-stop arm, which in *Fig. 25* was in the raised position, would be lowered, permitting a following train to pass. If, however, the track relays in the section ahead were occupied by a train, the signal would show a red light, and the train-stop arm would be raised above rail-level; in the event of a driver attempting to pass a signal at "danger," the brakes would be applied automatically.

When the electromagnet of the train-stop was operated, compressed air passed from the air main, via a ½-inch air pipe, through the electromagnet, which in turn lowered the arm. *Fig. 25* showed the cable run, with the 1½-inch air pipe at the top, in which a continuous supply of compressed air was available from the substations.

Fig. 26 showed a disconnexion-box, used for coupling the braided cables from the running rails for the track circuits to the lead cables, which in turn were connected to the track relays. An important feature of the disconnexion boxes was that, in the event of a signal failure occurring, they provided the lineman with a rapid means of isolating the track wires from the cables. It could be seen from *Fig. 26* that in the link box there were two small strips held down by nuts. Those took only a few seconds to remove, a fact which was of great assistance to the lineman in locating faults.

The two-core cables which were generally used on the signalling of the Ilford Tube were specially manufactured to the design of the London Transport Executive. They had an especially long life and would withstand heavy vibration. The signalling circuits were so arranged that, in the event of one of the cables becoming damaged and a short-circuit occurring, the fuse of the appropriate signal would blow and the train-stop would return to the danger position and remain there until the fault was cleared. In addition, the cables had a lead sheath, and, in the event of one of the cores coming into contact with the sheath, the fuse would blow.

Mr A. C. Edrich said, with regard to the Author's reference to the form of control over the several departments concerned in the equipment of a tube railway, that most of those present would know that the London Transport Executive's engineering departments were specialist in type. The people employed in them liked to be regarded as highly skilled artists in their own field; they wanted sympathy and appreciation, rather than the type of control that was normally understood to be necessary. They could control themselves, since they took a pride in performing their individual jobs to the best of their ability and as cheaply as possible. That involved doing the work as speedily as possible but, to do that, representatives of the various departments had to collaborate in arranging a programme to which they could all work. They needed somebody to correlate their efforts and to compile statistics so that the Chief Engineer would know, through up-to-date progress reports, that the work was progressing satisfactorily.

In the sphere of activity of the Permanent Way Department there had been two distinct sections of tube works, the first between Liverpool Street and Stratford and the second between Leytonstone and Newbury Park. In the section between Liverpool Street and Stratford, part of the track had been laid before the war, to a standard which was different from that which had been developed towards the end of the war and which it had been decided to introduce when new works were re-started. To relate the two standards and, where new tracks were laid, to introduce fully the higher standard, had been difficult from the point of view of material and also of training the newly recruited staff in two different methods of operation. An attempt was made to prepare very carefully the production programme for each type of operation and to make allowances for new and untrained staff but, each department suffered badly from delays in materials supply, which had to be overcome by the use of one expedient or another in the last two hectic weeks before the opening date—the ultimate result proving generally unsatisfactory to all. However, they had learned from that experience and had put the lessons into effect when work was started on the tube between Leytonstone and Newbury Park. Proper phasing of works had been evolved between the Permanent Way Department and other departments. The job had gone very well, and had kept to programme ; output was up to pre-war standard, and workmanship was of a uniformly high standard.

Mr M. G. R. Smith said that he noticed that, although 7-foot sleepers at 40-inch centres were used throughout the tunnel, there were no cross sleepers at the stations. Was it necessary, in that case, to have the sleepers at all, even in the tunnel ? Would it not be sufficient to provide timber blocks set in the concrete under each chair, and furnish sleepers at 10-foot intervals where there were conductor-rail insulator-blocks ?

With regard to the joining of long lengths of rail, was there some special reason for not using full-fusion thermit welds ? He would be interested to know whether they had been found to fail in other cases.

The Chairman said that he had been interested to hear Mr Wickham refer to the 6-inch clearance beyond the load-gauge of the vehicle and imply that it had been necessary to work to that clearance. Obviously, if there was to be any variation at all in the alignment or level of the track, that clearance would have to vary a little. He wondered whether, for instance, it was possible to get a clearance of 7 inches on one side while not infringing the minimum of 6 inches on the other.

Since there were curves in tubes, presumably there should be superelevation. If the diameter of the tube were constant, he wondered what sort of problems arose in overcoming the throw-over and superelevation due to curve alignment.

He had been interested in Fig. 3, Plate 1, since it had been his good fortune to see the tube when it was in use as a factory; the conversion from tube to factory had been a wonderful piece of work. The factory workers had been close to the air-supply and, in certain places where oil fumes came from the machines, extractors had been installed.

Mr A. G. Ticehurst asked why, in view of the small temperature-change in tube tunnels, it was found necessary to have such large expansion gaps in the conductor rails.

In his experience of compressed air and the transmission of power in compressed air, it was difficult to dry the air sufficiently. Nearly all the tools he had seen in the field and in works had been subject to considerable condensation at the exhaust, entailing special attention to keep them running. How had the signal engineers overcome that difficulty ?

Mr W. F. Beatty inquired, further to the Chairman's remarks, whether the allowances in the tunnel for end-throw and centre-throw were the same.

Mr E. F. Humphries said that he gathered from the Paper that the breaking out and demolition work in the rehabilitation had been accomplished from the existing (factory) compressed-air main, which appeared to be of quite small diameter. Had difficulty been experienced in operating the concrete-breakers efficiently from a small-diameter main at a distance of possibly $\frac{1}{2}$ mile or more from the compressor ?

Mr G. C. N. Elliot, referring to Mr Wickham's remarks on longer rails, said that it was possible that a rail 1 mile long without joints would wear unevenly ; how would such a long rail be dealt with in a tube.

Mr P. Mason asked how the false ceiling was suspended in the tunnel section. He had understood the Author to say that it was made of Ruberoid, and it was presumably flexible. How was it fixed so that the effect of a rigid ceiling was obtained without interfering with the water running away from the guttering ?

The Author, in reply, observed that Mr Smith had asked why blocks, equivalent to the pit blocks in the stations, were not used throughout the running tunnels. Whilst he was not a permanent-way engineer, the Author thought the answer was fairly clear from what he had seen of some of the pit blocks at Wanstead, Redbridge, and Gants Hill : their anchorage in the concrete bed was not entirely satisfactory. They could be seen to rise and fall as a train approached, because they were not held rigidly in the concrete. The angle cleats had, however, prevented changes of gauge. It was unfortunate that, owing to the intervention of the war, the concrete in which the blocks were set had had to be keyed to concrete which had been placed several years earlier ; but, even in the case of a tube built to-day, a considerable time lag would occur between the deposition of the concrete forming the track foundation and the concreting-in of the pit blocks. Those disadvantages accounted for the retention of full-length sleepers in running tunnels, in order to ensure that the track remained in its correct alignment.

He was not competent to answer Mr Smith's question about site-welding experiments, but he knew that on the Bakerloo-line tube, a few years before the war, some site welding had been done.

It had been asked how the battery locomotives performed, and at what speed cables were unwound. The 250-yard-long cables had been unwound at approximately 3 miles per hour.

The minimum radius of curvature on the section between Leytonstone and Newbury Park was 20 chains; for tube rolling-stock which was just over 51 feet long, with bogies at 35-foot centres, the allowance for versine was $1\frac{1}{4}$ inch and that for end throw was $1\frac{5}{8}$ inch. On vertical curves, the appropriate allowance was approximately $\frac{3}{8}$ inch. Fig. 5, Plate 1, showed the minimum structure-gauge for straight track. It would be seen that the minimum clearances laterally (to the wing nut of a signal relay case) and vertically (to the soffit of the tunnel) satisfied the requirements.

At the ends of curves the tunnels were constructed to an alignment ensuring that the track would follow the correct cubic transition curve, whilst the super-elevation was obtained by rolling round the tunnel at a constant distance from the axis. Curves gave rise to problems of equipment, since the segments themselves had not been rolled; and that accounted for the difficulties which Mr Wickham had encountered in track-laying, when longitudinal segment-joints had fouled sleeper positions. Some trouble had been experienced with the benching, labelled "Contractor's concrete" in Fig. 5, Plate 1. In some cases, that benching had not had the super-elevation required for the track, with the result that on the low-rail side the sleepers were down on the benching, whilst a considerable thickness of packing was required on the high-rail side. Attention was being given to that in further designs, and care would be taken to construct the tunnels to suit the alignment of the track. The tolerance permitted in driving the tunnels was 1 inch in any direction.

The conductor rails were welded in $\frac{1}{2}$-mile lengths, and the copper bonds between the out-of-gauge rails and the conductor rails provided for a movement of about 6 inches. The length of the gap was governed by the spacing of the sleepers, the siting of the insulators supporting the conductor-rail ramps, and the design of the collector-shoes on the rolling stock.

The air-compressors were situated inside certain sub-stations, with large drying-grids fitted with drainage cocks immediately outside. In cases where the compressed-air main went overground for some way before reaching the tracks, drying grids were provided also at the tunnel mouth.

The longest distance over which air had to be passed through the $1\frac{1}{2}$-inch-diameter factory air-mains was rather less than $\frac{1}{2}$ mile. Between stations, there were working shafts at which it was possible to site the compressors, so that the distance was generally of the order of $\frac{1}{4}$ mile. The pressure did drop, but the work to be done with breakers was not excessive, consisting mainly of breaking out the concrete round the factory track and the haunching on which the slabs rested at the sides of the tunnel. The remainder of the decking, being in pre-cast units, could be removed conveniently without a breaker. The Author had, however, seen breakers which certainly were not doing their full duty.

The construction of the false ceilings could best be understood by reference to Fig. 7, Plate 1. The Ruberoid sheeting was retained in position by mild-steel flat strips curved to the shape of the tunnel and supported by brackets grouted into the concrete filling between the segments below the level of the gutters, whilst the sheeting terminated in the gutters. White-painted fibre-board panels supported by light steel tee-section ribs, also curved to the shape of the tunnel, concealed the Ruberoid sheeting. The down pipes from the gutters were laid in the thickness of the concrete between the segments, and ran thence to the platform invert or anti-suicide pit.

Mr H. A. Wickham, supplementing the Author's reply, said that pit blocks were used in the stations to provide anti-suicide pits. In general, they were not satisfactory for the purpose of laying railway track, since they caused great difficulty in maintaining gauge and level. In a station, however, a train was usually slowing down to a stop.

He did not think that he need say anything on the subject of expansion, which had been very ably discussed and explained in all its aspects by Messrs Dunton and Brinsmead in their Paper; he advised anyone who was interested in the subject to study that Paper.

The thermit joint had been vastly improved over a number of years, but he had experienced cracking of thermit welds. If a joint failed on the open track it could be reached with comparative ease, but in a tunnel with a clearance of about 6 inches, with trains running at intervals of a few minutes, the service was bound to be seriously held up if a joint failed.

With regard to the 1-mile length of rail and the question of uneven wear, the bugbear of permanent-way maintenance was joint trouble, and the elimination of joints would mean the elimination of 75 per cent. of the permanent-way maintenance. If joint trouble could be eliminated, the risk of having to renew a mile of track, by reason of the uneven wearing of some part of it, was, in Mr Wickham's opinion, worth while running.

With reference to the Chairman's remarks, there was, on straight track, more than 6 inches clearance—up to 3 inches extra in some cases.