

Discussion

The Authors introduced the Paper with the aid of a series of lantern slides and a film. They gave a summary of the additional experience gained to date together with conclusions drawn therefrom. The Paper contained details of all welded lengths laid up to the beginning of September 1956. Since that date five further lengths have been laid, giving a total length of approximately $13\frac{1}{2}$ miles. In addition, the existing BH rail in two other tunnels had been Thermit-welded into continuous lengths.

115. Maintenance records were being kept at Llanwern, Treforest, Caerphilly, and Newport Mill St. which indicated that less maintenance was being given to the long welded rail lengths except on the concrete-sleeper length at Treforest where deterioration and displacement of the rubber pads was taking place together with unsatisfactory tensioning of the T-type spikes, resulting in further gauge widening and variation.

116. Preliminary indications on the lengths were that less maintenance was required than for the normal jointed track on the opposite road, although at Croppedy some trouble had been experienced with the displacement of the rubber pads at the heel and toe of the RD clips, particularly in the vicinity of the central switches, together with partial displacement of the rail pads.

117. Unfortunately no up-to-date reference period data relative to installation and maintenance costs were available and it would be premature at the present stage to attempt an assessment of the economic factor. The lengths laid to date should be regarded as experimental and further knowledge and factual evidence obtained before final standards and a code of practice for long welded rails could be established. Based on experience to date, however, a draft code of practice had been drawn up which might be summarized as follows:

(i) Use

118. Continuous welded rail could be laid under the following conditions:

- (a) On straight and curved track of more than 80 chains radius with breather switches at each end of the length. Where the work was carried out on more than one day, a temporary set of breather switches should be laid at the termination point of each day's work if traffic was to be passed over the track in the interval.
- (b) On curves between 40 and 80 chains radius of different hands, e.g., a LH curve followed by a RH curve, with breather switches at the start of the LH curve, at the reverse and at the termination of the RH curve. Should either curve be longer than $\frac{1}{2}$ mile a breather switch might be required on the curve.
- (c) In tunnels, continuous welded rail could be laid without breather switches provided the whole of the welded length was contained within the tunnel.

119. Additional breather switches should be laid to protect insulated joints in the open. A 60-ft length of rail should be placed on each side of the insulated joint with an ordinary fishplated joint between it and the breather switch which would be welded to the continuous rail.

120. Generally speaking all breather switches would be laid trailing.

121. Where insulated joints occurred in tunnels it was advisable to place a 60-ft rail at each side of the joint to facilitate renewing the end posts. From an economic point of view it does not appear to pay to use continuous welded rail unless more than $\frac{1}{2}$ mile was available for such rail.

(ii) Laying-in

122. When the temperature was above 13°C . (55°F) and likely to rise both rails should be laid concurrently, starting at the mid-point between breather switches and working towards the breather switches. When the rail temperature was below 24°C (75°F) and tended to fall the rail laying would commence at one end of the continuous rail but both rails should be laid concurrently through the whole length.

123. Since the rail length varied with the temperature the final fixing of the continuous rail to the breather switches should be left until the rail laying and fixing to the sleepers had been completed.

(iii) *Destressing*

124. Where the continuous rails had been laid in the open at a rail temperature outside the range 13°C to 24°C (55°F to 75°F) it was necessary to free the rails and destress them when the rail temperature was within that range.

125. It should be emphasized that the present code of practice was purely a draft which might have to be modified in the light of further experience.

126. The automatic recording of movement of the long welded rail at Llanwern and Treforest had been continued, together with laboratory tests. In connexion with the destressing at Llanwern on 18 March, 1956, rubber pads had been inserted on length No. 1. While before creep had been recorded the actual movement had been slight and it appeared that the rubber pads assisted in reducing creep.

127. Until a further destressing was carried out it was not possible to investigate the causes of creep. Since destressing at Treforest was last carried out on 1 July, 1956, it had not been possible to determine the relative anti-creep value of concrete and timber sleepers until data had been made available from a complete year's cycle of recording.

128. Tests in connexion with buckling were still being carried out in Mousehole Tunnel. While it would be premature at the present stage to express a firm judgement on the results, the following significant points emerged.

- (i) Initial misalignment of the rails, particularly at the welds, should be eliminated.
- (ii) The most rigid pattern of fastening was required to ensure the lateral moment of resistance of the track was not less than the vertical moment of resistance, to ensure that any lifting of the track under the possible combined effects of temperature stresses and precession wave was not immediately followed by a buckle caused by loss of ballast resistance. The resistance of the fastenings to torsion had a direct bearing on the strength of the track as a composite structure.
- (iii) Compacted ballast in close contact with the sleepers would ensure maximum ballast resistance.
- (iv) The resistance to buckling of track with concrete sleepers compared to the resistance of track with timber sleepers under similar conditions was as much as 30% greater owing to the resultant greater ballast resistance.

129. From the tests conducted to date it was still not possible to be specific on the relative values of spike-type and clip-type fastenings.

130. Resulting from the investigations the requirements for the most efficient type of fastenings had been specified:—

It should be composed of as few components as possible: ideally, of one.

It should be of a type which did not involve adjustment by means of screws, gauges, etc.

It should not require the taking of measurements when adjusting.

It should not require elaborate tools.

It should be resilient.

It should be of materials that did not deteriorate quickly.

It should utilize efficiently the materials of which it was made.

It should be insulating.

It should provide the maximum torsional resistance.

When removed it should leave the top of the sleeper free of projections.

131. None of the fastenings so far tested fully met that specification, and therefore an attempt was being made to design the required fastening.

Mr M. G. R. Smith (Chief Civil Engineer, Western Region, British Railways) said that when it had become clear that the use of long welded rails was likely to spread in the United Kingdom it had also become clear that as much information as possible ought to be collected on factors which would have both a physical and an economical effect with the types of track in normal use. The Paper described what was being done on one Region of British Railways. When the date for its submission had been chosen, it had seemed that by that time most of the answers would have been obtained, but that was not yet so. Much information had been obtained, but a great deal of it concerned fastenings manufactured

by firms in Britain; and, since that information was not complete, it was thought inappropriate to discuss it and it had therefore been excluded from the Paper.

133. The first experimental work had been in the nature of static tests, but it had soon become clear that dynamic tests would also be essential, and the design and construction of the necessary apparatus, with little or no previous knowledge, had proved to be difficult and lengthy. Great credit was due to Mr Protapadakis and his staff for their perseverance and their conviction that, despite all difficulties, they could ultimately produce the information necessary before conclusions could be reached. Tribute should also be paid to them for their refusal to be tempted to produce any statement of results unless satisfied that a sufficient number of tests had been done in any particular case to give a true picture.

134. The stage had now been reached when from the results obtained, many since the writing of the Paper, a clearer picture could be seen of what went on in the track structure when subjected to buckling stresses, and a draft code for installation and maintenance had been drawn up. The importance of the torsional resistance of the fastening assembly had been clearly shown, and it had been found that the greater was that resistance the less would be the effects of ballast shortage and poor maintenance. The torsional resistance was that of the fastening assembly itself—the rail, the fastening, and how it was attached to the sleeper, and the baseplate. Other factors of prime importance were the grip of the ballast on the underside of the sleepers and the degree of misalignment of the track. The weight of the sleepers had no bearing on the lateral resistance of the track, except that it increased the pressure between sleeper and ballast and therefore the grip of the ballast on the underside of the sleeper. The greater that grip could be made by good tamping of the ballast, the lighter and fewer the sleepers could be.

135. Apart from that information, it was essential to assess the drop in the moment of resistance owing to site and maintenance conditions in order to know the margin of safety to be adopted. To give a simple example of torsional resistance, the standard B.H. assembly of chair, key, and screw had a torsional resistance under laboratory tests of, say, 100. If the key was missing it might be said that the resistance dropped to zero and that buckling for a certain temperature rise was inevitable. The effect of the fastening assemblies on the adjoining sleepers, however, had to be taken into consideration, and a figure of zero would be wrong; the correct figure might be 75. If the keys of the assemblies on the adjoining sleepers were also missing, the figure of 75 would come down to 50, and if enough keys were missing would come down to zero. In order to assess the true moment of resistance of the track, it was therefore necessary to know how many keys, with hot weather and poor maintenance, could be expected to be missing at any one time.

136. The tests had shown a significant loss of resistance to buckling with consecutive hanging sleepers. There also facts were needed of the degree to which those conditions were met in actual experience. There was also the question of the degree of tension of the different types of fastenings used with F.B. rails. The facts had therefore to be collected from a large number of sites and, particularly with track approaching the end of its life, on the looseness of the fastenings, the degree of misalignment, and the number of hanging sleepers in a given length.

137. A vital factor was the natural frequency and amplitude of vibration of the rail, the fastening itself, and the fastening assembly with the sleeper when under traffic. To measure those frequencies and amplitudes it would be necessary to acquire apparatus. Authority for that had just been obtained so that that investigation could be begun. Clearly, when the results of tests under laboratory conditions had been tabulated and considered the full answer would depend on the examination of site conditions, and not until then would it be possible to say that one or other of the present types of fastening assembly was fully adequate physically and the best economically. No doubt new ideas would be brought forward for consideration, and there would be need for the collection of a great many facts if the true answer was to be reached.

Mr C. E. Dunton (Chief Civil Engineer, London Transport Executive) said that the Paper was of great interest to engineers of the London Transport Executive, because they had been over the same ground about 12 years ago. They had been unfortunate in

that, because it was at the end of the war period, their experimental work had had to be much rougher and less well instrumented than that of the Authors. It was of great interest to see how thoroughly the practical tests had now been done to determine factors of safety. No final help, however, could be obtained from a number of practical readings without a theory to connect them, to enable extrapolation and intrapolation to be made and to understand the full meaning of the phenomena. It had been for that reason that they had endeavoured in 1947 to set out in a Paper (see reference 1 on p. 345) a theory of track stability, and he had been hoping to hear to what extent their theoretical predictions had been fulfilled in the more detailed observations which had now been made of actual phenomena on the track. The theory involved a simplified mathematical treatment, but the prediction which it made had not been very different from experience on London Transport tracks.

139. The London Transport Executive were regular, and he thought he might say, satisfied users of long welded track. They had made it their standard since 1939, and the $\frac{1}{2}$ -mile variety since 1944 or 1945.

140. In § 3 there was a reference to the fact that the London Transport Executive tracks had two current rails and it was stated that that had a stabilizing effect. That was not quite correct; not all the L.T.E. tracks had two current rails, and they had long welded $\frac{1}{2}$ -mile track on portions where there were no current rails. It was true, however, that factors of safety were raised by the presence of the conductor rail. In reference 1 it had been stated that without current rails the error in alignment which could be permitted with a certain buckling load was 0.51 in., whilst with conductor rails it went up to 0.85 in. It was clear, therefore, that conductor rails made it possible to have a worse standard track without buckling. Knowing certain difficult portions of his own track, he thought that that was fortunate; however, the L.T.E. did use long welded track where there were no conductor rails, though there was then even greater need for care in maintenance.

141. In § 37 reference was made to breather switches and sleepers getting out of square. There seemed to be some misconception about breathing. The switches he had installed had never been intended to do any expanding except when rail fastenings were released. The idea had been to enable the rail to be destressed, and their intention—although they had not yet fully carried it out—had been that when a stress-free condition had been obtained at a mean temperature they would lock it up. Steel keys had been used on B.H. track and had virtually had that effect; the movement of the breather switches—or adjustment switches, as he preferred to call them—had been reduced to negligible proportions. No doubt the same thing could be done on F.B. track. The idea was not for the switch to keep expanding and contracting, because if the track buckled it would be most likely to buckle where that movement ended. That was the worst point. There was movement of sleepers which disturbed the stability, and there was a full load, the grip of the sleeper resistance being great enough to give the rail no opportunity to relieve itself. He thought that switches which moved to and fro were bad; they should be regarded purely as adjustment switches. If the to-and-fro movement did not occur, the sleepers would not be driven out of square.

142. With regard to § 38, he did not like destressing from the centre of the rail. There could be residual stress at the end. The L.T.E. always worked from the stock rail. When they wanted to make sure that the stress had been lost they used a rail-puller simply to shake the rail a little if the work was being done at night. When trains were running, the trains would do that.

143. He agreed with the Authors' conclusions. There must be a good standard of maintenance. Track was a very valuable piece of equipment, and a good standard of maintenance, even if it was not necessary for safety, would be needed for the life of long rails. It was no good welding rails together and then allowing irregular wear to occur through poor maintenance. In practice, however, where rails had been in use for a long time it was not always possible to rely on a 100% standard of maintenance. Various things could happen; one might have a broken rail, or want to adjust the rails, or have to change a block joint—and on the London Transport lines a great many joints were block joints. Realignment might be necessary, the ballast might get low, or there might be a slip. All those things had to be taken into account.

144. When they had first put in long welded rails, after their fairly crude experiments, and acting on "hunch" and engineering sense, they had wondered what they would do when anything of the kind which he had mentioned happened. The answer was easy: it must be possible to take the stress out of the piece of track concerned. It was a compressed spring. It must be possible to take action, and the action which had to be taken was to destress it, and to destress it very quickly. On the L.T.E. tracks they used keys. He knew that they might be thought to be behind the times, but the key did comply with the Authors' admirable specification of something in one piece which did not require gadgets and tools and which had only to be hit with a hammer. They took out the keys and, to prevent the disastrous consequence of freedom from any restraint, they put in long undersized keys. It was necessary to release the stress quickly and then leave the rail to get rid of its stored energy with a few trains at reduced speed to help it. It was then possible to change the block joints or do whatever else was desired.

145. They had been worried about having strong enough components in the joints. They had had ordinary side fibre insulated joints, but they were not good enough for the job, where there might be loads of 80 tons or more in the rail. They had developed a plastic moulded steel joint which was a pair of one-piece fishplates, put on like ordinary fishplates, and which would stand up to about 80 tons.

146. There was then the question of the length to which the rails should be welded. It should not be so long that it was not possible to fasten it down in a reasonably short time when it had been destressed at the right temperature. If for instance there were 10 miles of it, it would not stay at 65°F for a long enough period. It must be possible to fasten the whole length down at the right temperature between the two ends with the adjustment switches. They had come to the conclusion that $\frac{1}{2}$ -mile would be about the right length, and in practice they had been able to cope with that length. It was possible to destress it quickly if any trouble occurred and adjust it. The unit seemed a reasonable one to adopt. If it could be all welded in the shop, that would be far the best thing to do. The French used the diplory apparatus, but Mr Dunton had not a train berth on his system longer than 425 ft, so that he could not weld more than 300 ft, since allowance had to be made for a motor coach at each end of the rail train. In every case there would be some practical limiting factor owing to train berths, shop accommodation, and so on.

147. Their own answer had been to use the best fishplate which they could make. He called the process "welding with bolts." They jig-drilled the rail and the fishplate. It was an extra large fishplate. It was machined, and the fishing angles of the rails were machined. There was no provision for expansion. It was bedded down with red lead and mica and fastened firmly with large bolts. If a defective rail occurred it could be taken out quickly. They also avoided the complications of casting Thermit welds on the tracks and the worries of their possible brittleness.

148. He had one small criticism of the Paper; he was sorry that the Authors had given temperatures on the Centigrade scale. If plate-layers were to use the information it must be given in degrees Fahrenheit. He had an idea of the temperature if told that it was 40°F, but if told that it was 10°C he did not know where he was. In work of the kind in question they were not using the c.g.s. system, so that the Fahrenheit scale should be employed.

149. Having adopted the long welded rail, the L.T.E. would not wish to go back. They were saving money. How much? The agreed formula at present in force reduced the manning by 15% for welded track, but he did not think that that was all they were saving.

Mr L. G. B. Rock (Assistant Engineer (Permanent Way), Southern Region, British Railways) wished to correct a slight mis-statement in § 10 about the "special" wagons used by the Southern Region for conveyance of 300-ft rails. Those wagons were in fact not special, but standard 64-ft so-called "Borail" wagons, a rake of five being used to convey the 300-ft rails, which were chained down tightly at the centre and not quite so tightly at the two other points. The rails were kept separate and free to move longitudinally relative to each other by steel straps, with end stops which prevented them from spreading out laterally.

151. With regard to Thermit welding, in spite of Mr Dunton's caustic comments about "foundries on the track," Mr Rock felt that the process had proved its worth as a site-welding method. On the Southern Railway before the war there had been many Thermit welds of a type which he thought had now been abandoned, the old shim weld, which had not been above criticism. Subsequently the S.R. had changed over to a complete fusion weld, which had given very much better results, and they had used that type of weld for joining together 300-ft flash butt welded 109-lb rails to form a 1,800-yd length of track which was the Southern Region's contribution to the experimental lengths laid down by the different Regions. He showed a slide of a general view of part of that length which had been laid in September 1955 in the West of England main line not far from Crewkerne. There were three reverse curves 83, 60, and 108 chains radius. For most of the passenger trains the speeds were high, 80-85 m.p.h., but the traffic intensity was not great, being about 35 trains per 24 hours. The track was laid on concrete sleepers with bolts and spring clips of the French type. The concrete sleepers had been laid with service rails 60 ft long, which took three week-ends, and then, a fortnight later, the 300-ft rails were laid in with $\frac{7}{16}$ -in steel end-posts between them to accommodate the Thermit welding afterwards. The re-railing took a further two week-ends. After the Thermit welding came destressing, or attempted destressing.

152. That assembly had been adopted largely on the basis of the very wide experience in France and the knowledge that the heavier the sleeper the more stable the track was likely to be. It was felt that it was useful to go right ahead and lay some continuous welded track under fast-running main-line conditions. That had since been done in other Regions. So far it had behaved very well.

153. The type of fastening used was similar to that used in France. Internally it was a little different, because when the design was evolved a satisfactory holding for a screw in a plug cast in a concrete sleeper had not been perfected, so it had been decided, for that experimental batch, to have nuts, made of special high-tensile corrosion-resisting steel cast in the concrete sleeper, in the hope that if any thread failed it would be not in the nut but on the bolt, which could be removed and replaced. That fastening did not fulfil every clause in Mr Rhodes's specification, but it seemed to provide a good resistance to torsion and to longitudinal movement.

154. The Thermit welding had presented no special difficulty, except with two joints where during the preheating period the temperature had risen very rapidly. As usual the clips had been slackened off for 70 ft on each side of the joint to be welded, and in those two cases the gaps gradually closed up during preheating so that by the time they were ready for the Thermit metal to be poured, the gaps had become too narrow to ensure reliable welding, and that had to be done again at a more appropriate temperature. That was a difficulty which might be encountered at any time.

155. Secondly, Fig. 2 showed the general appearance of a Thermit weld as described in the Paper. It should be borne in mind that almost all Thermit welds which failed in the track failed at the change of section at the edge of the "bulb" of weld metal. For the Crewkerne length, with the co-operation of the contractors, a collar 3 in. long had been used with a much less pronounced section between the rail and the bulb of weld metal.

156. Thirdly, the Thermit welds were post-heated. That was not usually done, but it was something to which Mr Rock attached much importance. The results of trip tests—admittedly not very many—consistently showed greater resistance to impact.

157. One of the difficulties which seemed likely to slow down the introduction of long welded track to a great extent was that the lengths of track most likely to benefit from the elimination of rail joints were those where the traffic intensity was high, and it was in those places that it was most difficult to get long possessions. In §18 reference was made to a possession at Llanwern from midnight until 6 p.m. He felt that the Western Region engineers had been very fortunate to get that. A great deal of work on the Southern Region had to be done in a possession of the order of 6 hours, which might mean that a different procedure would have to be adopted. In such conditions it seemed desirable to do what had been done at Crewkerne (although there the possession had not been so short) and put in the sleepers first with service rails and, after an interval for consolidation

of ballast, re-rail with long welded rails. Even so, a large number of extra possessions were required arising out of the introduction of the welded rail, and he was afraid that on many routes in the Southern Region it would be impossible to arrange for a big programme of long welded track in addition to the normal re-laying requirements, merely because of the traffic circumstances which limited the duration and number of possessions.

158. The Authors referred briefly to the small amount of movement which occurred at both the Western Region sites during the destressing process, and mention was made of the friction of the rubber pads. That could be confirmed from experience on the Southern Region. At Crewkerne the temperature had risen from 56°F to 84°F in 4 hours while the freed rails were being re-fastened, and despite that, and the fact that the rails had originally been laid at average temperatures of 65°F and 70°F respectively during the two Sundays, there had been an end movement of only about $\frac{3}{16}$ in., so that they had been satisfied that they had a fastening which would at any rate restrict rail creep and expansion movement fairly successfully. Records—possibly not so accurate as those obtained from the highly instrumented Western Region test sites—were being kept once a week of the longitudinal movement of the rails at several places near both ends and at three places near the centre in relation to the rail temperature.

Mr G. D. S. Alley (Assistant Engineer, Western Region, British Railways) said that in § 5 RP was mentioned. RP was a term which had been chosen to represent a resilient pad. The standard baseplate had the shoulders raised slightly to provide room for fitting a rubber or other resilient pad. A BR1 RP was the standard BR1 baseplate with raised shoulders, and a STRP was the standard ST baseplate with raised shoulders. The ST 3B, referred to in the penultimate line of § 5, was not a standard ST baseplate, but one provided with three through-bolts. That baseplate had been designed originally when F.B. track had been used in the Severn tunnel. The three through-bolts made provision for clips, as used with ordinary switches and crossings; he could not say that it was a standard clip, because he had found that there was no standard clip on British Railways.

160. In § 8 it was stated that the spacing of the sleepers was at 2-ft-6-in. centres. It had also been provided that the sleepers had to be spaced uniformly on either side of the Thermit joint, so that although they were nominally at 2-ft-6-in. centres throughout the length, they were not uniformly exactly 2 ft 6 in.

161. In § 10 the Authors had stated that the longest length of rail which could be transported was 300 ft. Mr Dunton had also referred to that. It was not the longest length which could be transported. They were unfortunate in the Western Region in not having a flash butt welding depot of their own, and had to get their supplies from other people, who were very helpful but who were restricted in what they could achieve at their depots. That was the reason for the length of 300 ft. As was probably well known, $\frac{1}{2}$ -mile rails were transported in the United States, the only limit on transport being the lengths of loops and refuge sidings.

162. Mr Dunton had referred to breather switches, and showed a slide of the type of L.T.E. breather switch which had been made use of on the Western Region. One reason for using it had been that it was an existing fitting proved in practice. The switch toes had been staggered 60 ft. On the Western Region they had found great trouble from that. Mr Dunton said that movement was not expected at those switches, but all long welded lengths when the ballast was loose were bound to move to some extent, and with that slight unequal movement in different directions, which was wrong, there was bound to be uneven movement which pushed the sleepers out of square between the toes of the two switches. When the Western Region had had to change over they had changed over simply to F.B. laid square and thus avoided the awkward joint, which they had previously made with Thermit, between B.H. and F.B. at the ends of the switches. Mr Alley agreed with Mr Dunton that something better had to be done; in the existing arrangement with the stock rail held fast, a $\frac{1}{2}$ -in. movement could only occur by pushing the timbers through the ballast. Something more like the typical French arrangement was desirable where both rails were free to slide and the timbers were held. Until something of that kind was obtained there was bound to be trouble in addition to increased first cost.

163. In § 26 the Authors referred to the need to lay both rails simultaneously. That operation was being carried out, of course, on the Western Region, and District Engineers on the Western Region were District Engineers. It had been felt at headquarters that the two rails should be laid at the same time, but since the District Engineer did not seem to agree and did not seem to be likely to have too much trouble he had been allowed to go ahead. They were glad to know that he had realized afterwards that it was advisable to lay the two at the same time. Mr Alley did not agree with the Authors, however, that it was necessary to have additional rail parties to enable both rails to be laid simultaneously. In France he had seen fourteen men laying two $\frac{1}{2}$ -mile rails practically simultaneously. They carried in one lift on the first half with nips, moved over the four-foot, carried in the second rail and moved along it for the next "pick", and dealt with the two just as quickly as would be done in Britain with two or three times that number of men. Britain still had a good deal to learn, and it was chiefly better organization and not more men that was required.

164. In § 54 the Authors mentioned the 19-chain-radius curve at Treforest. The code to which Mr Rhodes referred limited the radius to 40 chains. In France and on the Continent generally the limit was 50 chains, but it was felt in the United Kingdom, after making calculations, that the moment of resistance could be such that a radius of 40 chains might be employed quite reasonably. Mr Smith, the Chief Civil Engineer of the Western Region, wanted to have a tougher test, and so the very severe figure of 19 chains radius had been chosen. Unfortunately, except for 100 sleepers, it had not been possible to obtain the type of sleeper which was wanted and the same type as that used by the Southern Region at Wylve had therefore been used, with the two T13 spikes. The Authors had described how these, in the soft wood inserts, caused trouble with regard to gauge. That, of course, had been on the low rail side, because traffic had passed round that sharp curve of 19-chains radius at slow speed, whilst the cant was provided for considerably greater speed. The result had been that the low rail had been pressed inwards on the curve. That had been overcome, as on the Southern Region, by introducing slivers of hard wood. On the 19-chain curve they were now having trouble with the high rail and were having to do the same on that side.

165. Fig. 14 showed the results of thirty-nine tests under various conditions of the 120-ft length of track in the Mousehole Tunnel when it was carried on timber sleepers (twenty-four per 60-ft length) and B.R.1 baseplates with three elastic spikes per plate. The track was laid on 6 in. of unconsolidated ballast. The number against each plotted point referred to the number of the test; e.g., No. 18 was a test with $\frac{1}{8}$ -in. misalignment in 39 ft, whereas No. 19 had a misalignment of $\frac{3}{8}$ in. in the same length. The horizontal line at 95°F indicated the worst rise that might be expected if rails were finally fastened at the temperature of 55°F and their temperature rose to 150°F. The maximum rail temperature so far recorded at any place on the Western Region was below 125°F. It would be seen therefore, from those thirty-nine tests that temperatures of over the 150°F were necessary before a buckle occurred. Of thirteen other tests three had been made with the sleepers resting on rollers with no boxing, two with 50% of the spikes detensioned, and five with hanging sleepers and ballast conditions specially imposed.

166. The question was often asked as to what was being taught by the varied track and laboratory tests. First and foremost the site tests had shown the need for improving the techniques of both flash butt and site welding. With regard to the former the first requirement was to have the rails straightened before welding and again after welding. The close attention now being given to that would undoubtedly lead to better results in the track. Again, the overheating with the final flashing pressure in the welder, together with the difficulties caused by the uneven heating in the post-heater, were being studied to avoid undue grinding being required.

167. So far as site welds were concerned, Thermit welds had been used since 1935 in fast-running main lines on the Western Region, the early ones having been re-laid in the normal way when the track had worn out. It was agreed that if a better joint could be obtained as easily it would be considered, but such welds had been used with great success in Italy, Germany, France, and many other countries. The worst criticism that Mr Alley

170. Mr Rhodes, in his specification for a fastening, had left out one of its most important qualities, which was that it must be vibration-proof. Clearly a fastening was used to fasten things, and fastenings came undone because of vibration. The lock-nut was a well-known device. Some time ago Mr Inglis had seen and read of experiments on lock-nuts intended to find out exactly how they worked. The ordinary engineering approach to a lock-nut was "tighten it up well and then it cannot move," but all fastenings depended on friction and friction was affected by vibration. One tapped an instrument before reading it in order by vibration to lessen its friction. That was a platitude, but it was a principle which was of universal application.

171. In considering the problem of fastenings he had been glad to find, when he had had the good fortune recently to visit Mr. Smith's research laboratory, that they were undertaking some research work on fastenings from a vibration point of view. He believed that that was quite right, because the question was exceedingly difficult. The kind of problem to be faced could be illustrated by the case of the lock-nut. An investigator had held a 1-in. bolt in a vice, put a nut loosely on the bolt, applied vibration to the bolt head, and the nut slowly wound itself up, but on changing the frequency of that vibration the nut unwound. There were various anomalies which were not clearly understood, and Mr Inglis suggested, with great respect to those who knew much more about it than he did, that the fastening problem would be well on the way to solution when they really understood what vibration did. He regarded that as of major importance.

172. With regard to the recording of thermal movements, what happened if the rail twisted and the bar rose in an angular way? Would not that produce the effect of a vertical motion of the rail?

173. Secondly, he had had an opportunity to see, in the installation near the Severn tunnel, the use of Magslips. Had the Authors ever thought of using differential Magslips? In that way it was possible to record the difference between two motions, and one could at will record the difference between a point in space and a portion of the track and another portion of the track $\frac{1}{2}$ mile away.

Mr. A. H. Cantrell (Assistant Civil Engineer, Southern Region, British Railways) remarked that he had been very interested in the Paper, because before 1938 a certain number of tests had been made on the Southern Railway on the lines described by the Authors, but not nearly so complicated, because they had been trying to do them with as little trouble as possible. They put in some 180-ft rails in rather a warm cutting, with reference points concreted in at 15-ft intervals along one length and took micrometer gauge readings to determine how much the rail moved at different points. From the results they deduced that with a rail very much longer than that used it would be only the last 150 ft at each end which would move. That appeared to have been borne out to a large extent in the practical results which had been obtained since that time.

175. He noticed, however, that the Authors referred to a slightly shorter length. The difference was due, of course, to the resistance of the sleepers in the ballast. In the 1938 experiment jarrah sleepers had been used, and there had therefore not been much friction between the bottom of the sleeper and the top of the ballast, as the stone did not bite into the timber. It was thought that a softer sleeper might be better, but with the deeper concrete sleeper there was a bigger resistance to sleeper movement along the whole of its width.

176. It had always been his opinion that too much was made of breather switches. As Mr Duntton had said, they were not really there to take up any movement which might occur during ordinary temperature changes; they were there for ease in making adjustments, and therefore from a theoretical point of view there was no reason against having much longer lengths, and even doing away with breather switches altogether, although there would then be difficulties when it was desired to adjust the stresses in the rails.

177. There would be general agreement with the conclusions which the Authors reached regarding the basis of the successful use of long welded rails, but with regard to ballast it seemed to him that more emphasis should be laid not only on well-consolidated ballast but

also on good ballast shoulders. Had the Authors so far reached any conclusion on the amount of the ballast shoulder?

Mr J. W. Hunter (Civil Engineer Manager, Portsmouth Naval Works District) observed that Thermit-welded joints between rails were now replacing fishplates in Naval Establishments with success, particularly in the Dockyard where the traffic was heavy owing to the wheel loading of the loco-cranes (maximum 28 tons per wheel). Rails used in the Dockyard were mainly of 126.2-lb/yd dock section and tests confirmed what the Authors had said in § 17 about the hardness of the weld metal. The Brinell hardness varied from 240 in the parent rail material to 220 in the heat-affected zone, and in the weld metal itself ranged between 270 and 300.

179. Mr Hunter presented a photograph (not reproduced) of the micro-structure of the weld metal. The junction between weld metal and parent metal showed a coarse micro-structure with large grains of fine partially spheroidized pearlite with grain boundary ferrite. There were also a large number of small dispersed inclusions of alumina, which might have been a cause of the low ductility of the weld metal.

180. Chemical analysis of the weld metal gave the following results:—

	Weld metal	Composition: per cent B.S.11/1955	
		Min.	Max.
Carbon	0.52	0.40	0.60
Silicon	0.43	0.08	0.20
Manganese	1.31	0.95	1.25
Phosphorus	0.033		0.06
Sulphur	0.046		0.06
Chromium	0.38		
Aluminium	0.45		
Alumina	0.092		

181. The mechanical properties across the junction of the weld and the parent metal and also of the weld metal itself were as followed:—

	Across weld	All weld metal	B.S.11/1955 Min.
Yield point: tons/sq. in.	25.6	—	—
Ultimate tensile strength: tons/sq. in.	48.4	56.0	44
Elongation: per cent	2.85	6	11
Reduction of area: per cent	2.4	7	—

182. The specimen containing the junction of the weld metal to the parent rail broke at the junction, and the elongation occurred mainly in the weld metal.

183. Further macrosections showed that the heat-affected zones extended about 2½ in. each side the centre of the weld and that the quality of welding was good.

184. Thermit welding had also been used at joints in a crane track consisting of duplex rails weighing approximately 275 lb/yd. In those cases the weld had been run from both sides using two crucibles similar to the arrangement shown in Fig. 1. That had proved satisfactory although there had been some difficulty in obtaining sound weld metal owing to the large heat loss through the weight of the rails; that had caused some blow holes to occur in the welds.

Mr Rhodes, in reply, agreed with Mr Dunton that to a certain extent the investigations described had covered the same ground as that dealt with in the earlier Paper by Dunton and Brinsmead, but said that in the present investigation the Western Region engineers had been fortunate in being able to go into much greater detail, and, of course, they had been concerned with F.B. long welded rail and there had been a need to obtain information about its properties in the track. Those investigations tended to confirm the original theories suggested by Messrs Dunton and Brinsmead. With regard to breather

switches, the measurements made tended to confirm the theory that the rails in effect did breathe at the ends.

186. Mr Alley had answered the question of what should be done with regard to the future design of breather switches. The Authors would like to thank him for emphasizing certain points which they had slurred over and for drawing their attention to the length of rail which could be transported, the limiting factor being the ability to weld rather than any problem of loading the rail on to wagons.

187. Mr Rock had drawn attention to a problem which Mr Rhodes had always very much in mind, that of traffic density and possessions, and which to him did have a bearing on whether or not long welded rails could be laid. On the Western Region lengths had been laid by means of service rails, and that, of course, did increase the possession required.

188. The Authors must accept Mr Inglis's statement that the fastening should be vibration-proof. It was an omission on their part not to have drawn attention to that and not to have mentioned the investigations which they were now making into the problem. Mr Smith had covered this point in his remarks.

189. In reply to Mr Cantrell, it was felt that further information was needed regarding the effect of ballast shoulder. The information available at present about compacted ballast seemed to show that beyond a 6-in. shoulder there did not seem to be any significant increase in resistance to buckling, but the 6-in. shoulder was definitely a contributory factor in such resistance.

Mr Dart, who also replied, said that the French fastening mentioned by Mr Rock had been tested in the laboratory and it had been found that it had quite a high torsion resistance. Mr Rock's description of the wider fillet on the Thermit weld was interesting. Mr Dart had seen a few failures of Thermit welds, and they had arisen from lack of pre-heating of the rails. A crack had started at the junction of the fillet and the parent metal. In those cases the width of the fillet was quite small, but if it was increased to 3 in. there might be a danger that lack of pre-heating would have a more significant effect.

191. Mr Inglis referred to twisting of the rail. That would affect only the measurement of vertical movement, and they were more interested in vertical movement under static conditions rather than during the passage of a train. During the passage of a train, of course, some measurement of the degree of packing was obtained. The flashes seen in the film had been caused by the electric fires when the explosive buckling knocked them over. It was not possible to fasten them securely to the sleepers, and it was better to allow them to be knocked over. They had not been damaged.

The Authors, in a further reply, stated their opinion that although the main reason for laying-in breather switches was destressing, they were of added value in taking up any movement arising from creep and therefore acting as a safeguard to the normal-jointed track ahead of the long welded length.

193. In the scientific approach to the problem for ease of calculation and analysis the centigrade scale was used together with measurement of rail movement in millimetres.

194. For the issue of any information to the men on the track data would be given in Fahrenheit and feet and inches. The latter scales were adopted in the draft code of practice.

195. With regard to Mr Rock's observations on the failure of Thermit welds, the failure referred to by Mr Dart had not occurred in any of the long welded lengths but in a length of track where two or three 60-ft rails had been Thermit welded together some 5 years ago.

196. The Authors agreed with Mr Alley that the man power requirements for laying-in long welded lengths called for a high degree of planning, but the number of rail parties would be governed by climatic conditions, the physical conditions of the site, and the overall length to be laid during the period of occupation.

197. Mr Inglis had asked if consideration had been given to the use of differential Magslips. Those had not been considered since the instrumentation installed had given the required information in the most suitable form.

198. Mr Cantrell in his remarks referred to experiments undertaken with 180-ft rails from which it had been deduced that with a much longer length only the last 150 ft at each end would move. That was shorter than the length determined in the Western Region experiments, not longer, being approximately 100 yd. The efficiency of the fastenings would, of course, have a bearing on that length.

The closing date for correspondence on this Paper was 15 May, 1957. No contribution received after that date will be published in the Proceedings.—SEC.
