

Paper No. 6244

## Long welded rails in France †

by

Robert Lévi

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### *Discussion*

**Mr B. A. E. Hiley** (President of the British Section, Société des Ingénieurs Civils de France) expressed his thanks to the Council of the Institution for inviting the members of the British Section of the Société des Ingénieurs Civils de France, and to the Author for his instructive Paper.

85. He recalled that, in the year 1909, tenders had been invited for tramway rails and the corporation concerned had expected quotations for the usual 45-ft rails. However, a quotation had been received from the Continent for 50-ft rails, which were more advantageous and required fewer joints. Great concern had been expressed in both local and national newspapers, but the longer rails had been used.

86. Between 1910 and 1930 rails had gradually become longer and lengths of 60 ft or more had been used, some being 90 ft, or twice the pre-1910 length. Under what had been considered favourable conditions, 300-ft lengths of welded rail had been employed on the London Underground.<sup>2</sup>

87. In recent years the lengths of welded rail had greatly increased. The Author had said that in France theory and practice worked hand in hand and that in 1949 each Chief Civil Engineer of the French Railways had been given permission to present a choice of applications of welding. In that year trials had been made with long welded rails over a total of 9 miles of track, in 1950 over 15 miles, and in 1954 over 44 miles, with breather switches at every half-mile. The Paper stated (§ 23) that "After some time, since nothing abnormal had happened, the Ministry of Transport gave permission for work to be carried out without notifying the Minister beforehand".

**Mr G. D. S. Alley** (Assistant Engineer, British Railways, Western Region) said that what happened to the track in France might not obtain with the different track in Britain. It was agreed, as the Author had stated in §§ 3 and 5 of the Paper, that it was difficult to simulate track buckling and that perfectly straight track could withstand more longitudinal compression than could be induced thermally without any tendency to buckling.

89. Considering track under static conditions, no main-line track in Britain, under normal maintenance conditions, should have the errors in top which would induce lifting. Although the French might use more R.S. sleepers than the British, their sleeper was lighter and, therefore, the resistance of their track to lifting might even be less than was the case in Britain. As a result lateral buckling appeared more liable than vertical. These views had also been confirmed in a Paper given by Dr Birmann,<sup>3</sup> of Minden, on 22 March, 1957 at Munich.

90. On the other hand, if there were small errors in alignment, it had been found that these, combined with ballast errors, might reduce the factor of safety so that horizontal buckling would take place. These conditions were with normal non-loaded track. When track was loaded, traffic conditions varied; but, from the tests so far

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† Proc. Instn civ. Engrs, vol. 8, p. 93 (Sept. 1957).

<sup>2</sup> References 2 *et seq.* are on p. 491.

carried out, it had been found that much importance had to be attached to the condition of the fastenings. Furthermore, the results of measurements in Britain tended to show that ballast did not provide all the reaction that might be expected in accordance with the Paper. Therefore, the beam effect of the track as a whole greatly influenced the resistance given by the track.

91. If British railway engineers could be persuaded to adopt the thick-webbed rail which had been used in the joint illustrated in Fig. 5, it might be possible to have a similar joint in Britain.

**Mr H. H. Robinson** (Assistant Engineer, Permanent Way, British Railways, Eastern Region) noted that the experience of the S.N.C.F. had led to the encouraging convictions that welded track was less liable to distort in hot weather than jointed track, that it was more easily maintained, and that welded track was justified economically. It had been suggested elsewhere that the reduction in joint maintenance of long welded track was more than offset by the additional precautions required in respect of line and level. He understood that this was not the view in America, and quite clearly it was not the view of the S.N.C.F.

93. The practice so far adopted on the Eastern Region of British Railways was in entire agreement with the Author's conclusions concerning the necessity for plenty of weight in the track. Wherever concrete sleepers had not been used with long welded rails, it was the Eastern Region custom to use jarrah sleepers to provide extra weight to the road. A rubber or rubber-bonded cork pad was placed between the rail and the baseplate. The effect of the pads was to make longitudinal displacement of the rail and, therefore, the process of destressing, very difficult, and in those circumstances, the Authors' findings in § 51 were most interesting. It appeared, from § 24, that the experience of the S.N.C.F. had been similar to that in Britain concerning the resistance of rubber-padded road to longitudinal creep. Would the Author confirm this?

94. In many respects, Eastern Region practice was in the process of development. With reference to the design of insulated or "block" joints, it appeared, from § 38, that on the S.N.C.F. insulated joints were always protected by expansion joints. In Britain, this became very difficult where there was a succession of very short track circuits, as in heavily trafficked suburban lines using colour light signals. What method had been adopted to overcome this difficulty in France?

95. On the Eastern Region, where such difficulties occurred, a type of joint had been specially designed to withstand tensile and compressive loadings of more than 70 tons. Considerable care was required in machining the fishplates for this kind of joint and in cutting the rail ends. The joint was still under test.

96. At present, the design of expansion joints for the Eastern Region closely followed that illustrated in the Paper. Certain components had been found to require strengthening, and it had been considered essential to continue the thickness of the web of each rail unimpaired so that the webs had to be bent laterally on the two halves of the joint.

97. Mr Robinson agreed to the necessity for measuring rail creep relative to fixed datum lines. It was not sufficient to measure variations in the openings of expansion or breather switches, since these might be affected by outside factors. With the fastenings used on the Eastern Region, it had been found, to date, that creep was negligible.

98. The desirability of dividing up the track by expansion joints, thus leaving the rails free to contract or expand, was stressed in § 25. In § 56, however, the length affected by expansion was given as only 88-91 yd at the ends of the long-welded rails, the central part remaining fixed. Thus it would seem necessary to use expansion joints only at the ends of long welded rails, however great the length of the rails, which was Eastern Region practice. Would the Author clarify his contention in this regard?

99. When laying in long welded track, it had also so far been Eastern Region practice to lay in the track prefabricated with 60-ft rails, to allow the track to settle and then to replace the 60-ft rails by long welded rails during line possessions for neighbouring jobs, in order not to occupy the line twice to the detriment of traffic. In the first length dealt

with, the whole 3,000-yd length was welded beside the line and the rails slewed into the baseplates.

100. That practice had some real advantages in that the site welding could be done without possession of the line. However, there had been difficulties during the laying in, caused by rapid rise in temperature, and in subsequent jobs the 300-ft rails had been unloaded, slewed on to the baseplates, and site welded in the track. There was no difficulty about this method; it did, however, involve going to the site on two separate occasions and was therefore costly. Moreover, the length of job which could be dealt with was limited to the length which could be site welded during available possessions. Accordingly the search continued for a more economical method, without adopting the French method of taking entire possession of the railway for a long period.

101. It was implied in § 15 that it was unlikely that horizontal buckling took place apart from vertical buckling, and it was suggested in the Paper that an appreciable vertical buckle took place immediately before the track came down in a lateral buckle. Mr Robinson believed that a very small lift was sufficient to break down the resistance of the ballast to lateral movement, and that such a lift was provided readily by the passage of trains. In support of that, it was the experience in Britain that lateral buckles did occur under or immediately behind trains, the ballast resistance having been broken down by the trains.

102. The word "embedment" in §§ 18-21 was taken by Mr Robinson to mean "resistance to torsion", i.e. resistance to rotation of the rail relative to the sleeper. If this assumption was correct, the Author's view seemed to be at variance with that of experimenters in Britain, who had found that the torsional resistance was important. Surely, however, if the fastenings could be given a high resistance to torsion, the track would be far less likely to suffer lateral buckle. The requirement seemed to be for a recessed baseplate in which the rail could rest, with fastenings placed as far as possible from the axis about which rotation was likely to take place. Would the Author comment on this?

103. In § 50, the note about the carriage of long welded rails was not quite clear. It would surely appear that the longer the rails, the more wagons were needed to transport a given length of track. In § 45, the output of the Moulin Neuf depot was quoted as 84 welds per day. This seemed to be a very high figure. What was the length of the working day?

Mr Harry Chanter (Permanent Way Engineer, London Transport) observed that the installation by London Transport of long welded track had been interrupted by the war, but from 1944 onwards the policy had been adopted of installing long welded rails where rail renewal had become necessary; about 150 miles had now been installed. London Transport was not, as such, an underground railway, and more track was maintained on open sections than in tunnels.

105. Probably the most important conclusion to be reached from the Paper was that the risk of distortion on long welded track was no greater than on other track, provided that the principles involved were understood and the necessary precautions taken.

106. The elimination of joints on railway tracks was undoubtedly an advantage. Perhaps it was even more so on London Transport tracks, on which small wheels were used and where the frequency of traffic passing over the joints was probably greater than on some other lines in Britain.

107. London Transport was restricted to a 300-ft length of rail mainly because of the lack of facilities in transportation from the depot to the site, so that only four joints out of five could be eliminated. The question of eliminating the fifth joint was under constant attention; and while the solution appeared to lie in eliminating the fifth joint by site welding, no satisfactory method had yet been forthcoming. So far, London Transport had found a solution in ensuring that where the 300-ft rail lengths had to be joined, a joint of the fishplate type was installed, being made as perfect as was practicable. This was done by machining the fishing angles of the rails and fishplates and installing tight-fitted bolts to eliminate any expansion gap at the joint.

108. The Paper referred to the expansion joints which were installed at every  $\frac{1}{2}$  mile or at other special sites where they were required. This principle was similar to that applied by London Transport, who, however, called the joints "adjustment switches" to emphasize that they could not take care of the expansion over the complete length of the road.

109. Experience on London Transport indicated that the stress in the rail was relieved by the movement of the adjustment switch over the first 100 yd from the switch, the comparable figure mentioned in the Paper being 88-91 yd. The difference probably arose from the different rail section or from the fastening, but the fundamental principle appeared to have been established.

110. The practical difficulties of maintaining long welded track included those of the maintenance of the insulated rail joint or the block joint. The signalling system demanded that these joints should be positioned as required by the signalling and not from the consideration of the track design. The presence of the standard insulated joint with the bolt diameter reduced to  $\frac{3}{4}$  in. introduced a weakness into the long welded rail, where all other joints were either welded or were held together with a machine joint with  $1\frac{1}{2}$ -in.-dia. bolts.

111. In cold temperatures, with the rails in tension, the standard block-joint assembly was by no means satisfactorily designed to meet the requirements, and this called for the release of tensional stresses in the rails before the extreme cold temperatures were experienced. London Transport, under the direction of the Chief Engineer, had designed a plastic-bonded block joint which was more robust in construction and which permitted the use of  $1\frac{1}{2}$ -in.-dia. bolts; from the installations already made it appeared to meet the requirements. Had there been similar maintenance problems on the insulated type of joint on the French Railways?

112. One other particular difficulty arose in the maintenance of long welded track when it was necessary to re-sleeper under long welded rails or to install new long rails and sleepers without the sleepers being thoroughly consolidated before the rails were installed. On the London Transport system, practically all installations had to be done at night, and between April and September the diurnal temperatures varied considerably.

113. While agreeing with the Author that those conditions could be met, the statement that the necessary precautions were easily taken was questionable. Strict supervision was necessary when putting in new sleepers under long welded track at night with the possibility of high temperatures during the next day. Admittedly the position could be overcome, and it was overcome on the London Transport system by special methods of fettling the track after long rails were installed, but it undoubtedly involved greater supervision and also increased the costs of the initial fettling after the re-laying or the re-sleeping had been done.

114. There was no question that the installation of long welded rail track was of undoubted advantage and so far as London Transport was concerned the policy of future installations was quite well established.

**Mr D. L. Bartlett** (Assistant, Technical Development (Modernization), British Railways, Western Region) described the observations made by the Western Region on the buckling of long welded track, with special reference to the way in which they differed from those of the Author. The test rig for full-scale buckling experiments had been described by Rhodes and Dart,<sup>4</sup> it consisted of a 120-ft length of welded track laid in an old disused tunnel, and had been arranged so that the conditions were very close to the conditions of thermal expansion on site.

116. So far, the Western Region had carried out about 120 full-scale buckling tests. In every case in which lateral misalignment only had been placed in the track before buckling had been carried out, there had been buckling with no prior lift of the track. This was the basis of the experience to date. It was clear that some form of misalignment was necessary prior to stressing the track, otherwise the load required to cause buckling would be absurdly high for practical consideration.

117. The absence of lifting prior to buckling when only lateral misalignment was

present was not surprising, since without some vertical misalignment there was no vertical component of the compressive force and the forces acting upon the track in compression were such that lateral yield was inevitable.

118. The factors resisting buckling were: in the vertical plane, the weight of the track and its stiffness about a horizontal axis; and in the horizontal plane, the stiffness of the track about a vertical axis and the resistance afforded by the ballast.

119. Actual tests had shown that the static resisting force exerted by the ballast to movement laterally was commonly only approximately one-half to two-thirds of the force exerted by the dead weight of the track. Under conditions of poor ballasting, this value was even less.

120. With reference to the relation between the lateral and vertical stiffness of the track, actual tests had been carried out which measured the lateral stiffness of track under varying sleeper and fastening conditions, but neglected ballast resistance. Fig. 7 showed some typical results. The actual test had been a load-deflexion test on a 30-ft length of track simply supported at each end, loaded centrally, and supported on rollers along its length. Values of central load against central deflexion had been plotted. The results had been non-linear, the only reason being the non-linear torque angle-of-twist relation of the fastenings.

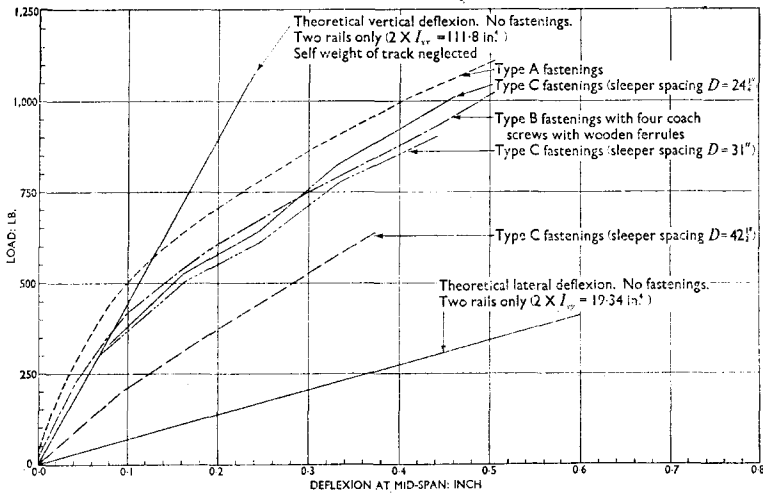


FIG. 7.—LOAD/DEFLEXION GRAPH FOR 109-LB. F.B. RAIL ON WOODEN SLEEPERS

121. The straight line represented the theoretical vertical deflexion obtained from two rails only under similar loading conditions and neglecting the weight of the rails. The remaining curves represented experimental results of the deflexions with different types of fastenings of different sleeper spacings. Type C had been repeated three times, with the same fastenings each time but different sleeper spacings, i.e. 18, 24, and 30 sleepers per rail. Different fastenings had been employed with Types A and B.

122. From the experimental results, it could be clearly seen that so far as the tests had gone to date and within the limits to which the lateral alignment of track could be maintained in practice, the lateral stiffness of the track as a whole obtained experimentally had never exceeded the theoretical vertical stiffness of even two single rails. The curves also made it clear that the fastenings had some effect.

123. For lateral alignments more accurate than  $\frac{1}{8}$  in. in 30 ft, the lateral stiffness shown in Fig. 7 slightly exceeded the theoretical vertical stiffness, but it would be

almost impossible to align a track as accurately as this in practice, i.e. more accurately than  $\frac{1}{8}$  in. in 30 ft. If it was possible to do so, the force required to buckle it would be very great.

124. In the case of track with vertical misalignment, it was obvious that there would be a vertical component of buckling force. The only effect of this vertical component, it appeared, was to decrease the ballast resistance beneath the sleepers, which resistance normally contributed about one-third of the total ballast resistance. There would still seem to be no reason why the track should buckle vertically, although some slight lift might occur because of the vertical component.

125. In the Western Region testing, no consideration had been given to dynamic effects upon the buckling, but it would again seem likely that the precession wave effect would do little more than reduce the ballast resistance, as did a static vertical misalignment, with the same consequences on lateral buckling.

126. A special team was travelling throughout the Western Region inspecting and measuring flat-bottomed track of varying age. So far, it was possible to report, first, that lateral misalignments rarely exceeded  $\frac{1}{4}$  in. in 20 ft; secondly, that vertical misalignments rarely exceeded one-half of this value, i.e.  $\frac{1}{8}$  in. in 20 ft; and thirdly, that the frequency of occurrence of lateral to vertical misalignments was of the order of 4:1.

**Mr K. H. Tredinnick** (District Engineer, Stratford, Eastern Region, British Railways) aligned himself with those who believed that the risk of thermal distortion in long welded track was small provided that the normal safe and reasonable precautions were taken.

128. Long welded rails probably had an assured future in the huge expansion and modernization schemes projected for British railways. He elaborated the view stated by the Author in the Paper in that perhaps the ideal track of the future, if it could be achieved, was long welded rails on concrete sleepers with a flexible support on which the rail sat, and a flexible fastening which not only took into consideration the firm grip on the rail under all conditions but which also would keep a grip on the rail under high frequency oscillations. If such a sleeper and such an arrangement could be produced, the problems of the future might well be considerably reduced and large economies effected.

129. British Railways engineers were trying their hardest to get the concrete sleeper installed under all service conditions and were meeting great difficulties because of sleeper resistance in track circuit areas. What was the concrete-sleeper resistance on the French railways, and what was the permissible resistance allowed by their engineers?

130. Mr Tredinnick said that accepting the fact that long welded rails could be installed safely provided precautions were taken, there were a number of questions which he, as a district engineer of a busy London area, must put to the Author. The track for which he was responsible—and many of his colleagues in Britain were in a similar position—was a very busy one, with high train density, of the order of 200 trains per single line of track per day, and the opportunity or time for obtaining occupation of the track was extremely limited. The train service not only operated throughout the day but continued during the night, mostly with freight movements. The time for any given occupation was therefore reduced and could be 3 or 4 hours only in a day.

131. To do a length of long welded track, or even ordinary re-laying, under those conditions was expensive enough, because the work had to be undertaken outside normal hours, which added considerably to the re-laying costs. If long welded track was installed at the same time, it must be expected that the cost of installation of the long welded rails would be increased similarly. This would have a bearing on the economical track considerations put forward by the Author.

132. Secondly, in the London areas in question, where speeds also were high—up to 80 m.p.h., or perhaps higher in the future—and signals were close together, there was a great deal of general work to be done, much of which demanded line occupation. There were block joints at frequent intervals.

133. The cost of an expansion or adjustment switch had been stated by the Author

to be equivalent to an 8-yd length of track. This, too, would be proportionately high, because of the number required. All this had to be taken into consideration with the actual costing of an installation. It could be said that the maximum length of long welded track that was possible in some of the London areas was as little as 1,000 ft.

134. A noticeable feature of the long-rail tracks illustrated by the Author was that they were all in country areas. Had he installed long welded track in the inner Paris areas or in other industrial towns or cities?

135. Mr Tredinnick then referred to an apparent anomaly concerning the economy of long welded track. Rail-head wear in the London areas, and no doubt in big provincial towns too, was as high as possibly  $1\frac{1}{2}$  lb. of rail wear per year. It was in the London area that the advantages of long welded rails would be most apparent. They should permit savings on joint maintenance, which was at the moment the greatest bugbear and headache. Rail wear was high and the rails would be due for renewal in possibly less than 10 years and in many cases even sooner. Did the Author consider it was justified economically to lay long welded rails under these conditions?

136. The Author's reference to instructions to his staff was of interest to a maintenance engineer. The district for which Mr Tredinnick was responsible had only recently laid in its first length of long welded rails. The greatest care had been taken in issuing not only written instructions, but verbal instructions to everybody at the site. When the installation of long welded track was increased and the total length of it increased throughout Britain, what would the Author, from his experience in France, recommend as a satisfactory and adequate method of instructing the gangs who were responsible for looking after the work at the site? There were many who would agree that written instructions were of no real value and that something more positive was necessary. What procedure had the French railways adopted?

137. Another point of extreme interest to a maintenance engineer was the subject of repair and the method of repair following a rail break in long welded track. Numerous breaks occurred in rails, and were associated with all causes and with all the reasons for fracture. It was not only at joints, but at almost any place where a rail could break if the traffic was dense and fast enough. The existing procedure was simple, inasmuch as it was an easy matter for a gang to go out quickly when occasion demanded and change the rail. The welding repair to which the Author had referred was rather different.

138. The Eastern Region had recently had occasion to break into the centre of a long welded rail length and replace insulated or block joints. The problems encountered in changing over the block joints, by cutting out a length of rail and putting in a new length, were quite considerable and took a long time. In some areas only a very limited time could be allowed by the Traffic Department for making the change-over; moreover, it usually had to be done at extremely awkward hours, when the temperature might not be suitable. The delays caused to traffic by making replacements after breakages might be very considerable and, if they were sufficiently frequent, would have a considerable bearing on the economies to which the Author had referred.

139. Another question arose from the more theoretical approach to long welded track. In 1942 *Campion*<sup>5</sup> had referred to the possibility of a residual load being left in long welded track over the course of years, i.e. during summer the rail ends would expand and then they would contract, but they might not contract to the same extent as they had expanded. In the following year this would be repeated with consequent increase in residual load. What was the Author's experience of residual loads left in long welded track? Did he follow the practice of destressing from time to time? Was this recommended as a common factor? If so, it was an economical consideration which could have a very serious effect when occupation of a line was difficult to obtain.

140. Presumably, now that more and more use was being made of the long welded track, track would never be relaid in future—at least, on British Railways—in the normal way by taking out the rails and sleepers and replacing them by others. Where long welded rails were used, perhaps all that would be done was simply to change the sleepers in the manner to which Mr Chanter had referred or, when the time came, to change the

rails. Had French engineers considered the method and the economics of re-laying or re-railing long welded rails? Did it not require much more time, and was it not much more costly to cut up or to load up a long length of all-welded rail and to replace it by new rail? From the information given by the Author, it appeared that consideration had been given only to taking out the existing short lengths of rail and replacing them by long welded rails. Obviously, in replacing long welded rails by long welded rails, extra costs and charges would be involved, and this, too, might influence considerably the economics of the case.

**Mr Keith Brinsmead** (Assistant Civil Engineer (Permanent Way) British Transport Commission) had inspected long welded track on the S.N.C.F. 4 months previously, particularly to observe the behaviour of the longitudinal-concrete-beam track. It had the great virtue that the bugbear of torsional resistance did not arise, in that there were two successive fastenings on the same rail, on the same piece of concrete. It was necessary, therefore, to slew a very large lump of concrete sideways before the rails could move out of true line.

142. The section which had been of particular interest was one under conditions comparable to those likely to be encountered on British Railways and on a track which carried trains at a maximum speed of 88 m.p.h. The passenger and freight trains were hauled by Bobo electric locomotives, with 23-ton axle loads, and the traffic per track was about 50,000 tons per day. The track had been laid in June 1956.

143. Did the Author, now that he was gaining experience with this design under main-line conditions, consider that it had a considerable future for use with long welded rails, or must it remain for some years as an experimental design of track?

**Mr A. H. Cantrell** (Assistant Civil Engineer, British Railways, Southern Region) recalled that 2 or 3 years earlier, when the possibilities of installing a long length of welded track were being investigated, it had been realized during a visit to France that the French railways had already overcome some of the difficulties that were being encountered. As a result the Southern Region had been able to modify details of fastenings and install, with confidence, a 1,800-yd length of track on the West of England route.

145. With the type of occupation of the line that was available on British Railways, the engineer had only a series of short possessions, after which he had to give up the track to allow traffic to pass. The result was that the 1,800-yd track had been installed only after a series of possessions, generally during overtime working, and had been very costly. In view of the great volume of traffic carried by many lines, it was therefore not certain that long welded rails would be an economical proposition. There was no doubt that by reducing the number of rail joints, maintenance would be decreased, but when that was equated against the unusually large expenditure in installing the track, the gain was doubtful.

146. In the event of rail breakage, it was extremely difficult to do anything about it quickly and to get the traffic moving again. Fortunately, the Southern Region had not had to do this yet and did not, of course, know when such experience would be gained. There was, however, a place in the long welded track where, owing to engines slipping on a slight upward grade near a signal, there had been burnt rails. Fortunately, it had occurred at the end of the long welded length and, therefore, the solution was easy. It could, however, occur in the middle of a length, in which event the repairs would be far more difficult and, no doubt, more expensive.

147. It was stated by the Author that in cold weather there were rail breakages. How often had they happened?

The following contributions were received in writing.

**Mr A. F. Bruyns-Haylett** (of Pietermaritzburg, Natal, South Africa) had noted the Author's reference to engineers being hostile to the idea of long welded rails, and suggested that in many cases their attitude was one of apprehension rather than hostility.

This attitude was difficult to understand, for long welded rails had been in use in America since 1933 and their use was well understood today. There was no longer any mystery about expansion.

149. The first long welded rail, 3 miles in length, had been laid on the Lynchburg-Durham Railway in 1889!

150. In 1946, 96-lb. rails, 480 ft long, had been put on a test length between Mapleton and Roodekop on the Natal Main Line in South Africa and were still in use. These rails had been butt-welded into 120-ft lengths at the welding depot, then put into the track and welded into 480-ft lengths with joints staggered 6 ft 11½ in. to reduce hammer-blow and to obviate lurching.

151. Mr Bruÿns-Haylett, on becoming Research Engineer of the S.A. Railways in 1948, had introduced 960-ft-long rails on the same section and they were still in use. In 1951, two 960-ft rails had been joined by a special switch-joint to allow for "breathing" and was working satisfactorily. Owing to enforced retirement he had been unable to press forward with the introduction of long welded rails, particularly on the main lines carrying fast traffic. He had given a summary of the position in South Africa in his Presidential Address<sup>6</sup> to the South African Institution of Civil Engineers.

152. The long rails on the test section mentioned above had been in use for 11 years and had given no trouble whatever. They had been laid at the mean annual temperature of 82°F with allowance for a ¼-in. expansion joint. There certainly had been no indication of vertical humping nor any tendency to kick out or buckle; there were 2,376 hardwood sleepers and 2,200 cu. yd of ballast per mile.

153. Another pair of 960-ft rails had been laid on 2,376 steel sleepers and 2,000 cu. yd of ballast per mile and had given no trouble whatever.

154. A further pair of 960-ft rails had been laid with 2,574 and 2,772 sleepers per mile on each half-length. Mr Bruÿns-Haylett had left before the completion of this test but he would guess that the additional sleepers had not reduced the end movements of the rails, although adding to the weight to obviate lifting of the track. Similarly, shovel packing was likely to increase the end movement of rails for there was less ballast-sleeper resistance to longitudinal movement.

155. Electric SR-4 strain gauges had been used to record the rail stress due to temperature at selected points along the length of the rail, both when lying loose on the sleepers and also when finally fixed in the track. Dynamic recordings had also been taken under traffic.

156. From the records taken he felt that there was no danger of the track buckling either vertically or horizontally for a class 1 track, provided the maintenance was up to standard and that under no circumstance was the ganger to open up more than 40 ft of track at a time for the purpose of packing the sleepers.

157. The limit for long rails on curves was fixed at 2° minimum and, as a matter of fact, that two 960-ft rails with a switch joint in the middle were laid on a curve of 2,800-ft rad.

158. Long rails were basically sound and all that remained was to fix the economical length to justify the comparatively expensive special switch joint and to have first class maintenance. It was noted that the Author fixed the economical length at ½ mile.

159. There was no reason why the rails should not be welded into say 1,320-ft lengths at the butt-welding depot, loaded into special bolster trucks, taken direct to the site, and pulled off like "spaghetti" as was done in America. A 960-ft rail had been laid in 10 min by barring about 40 ft of the long rail at a time into the cast-iron chairs and then securing the rail by steel keys.

160. It had been found that about one-third of the rail at each end tended to breathe. The middle third remained static, with a stress of about 4 tons/sq. in. corresponding to a temperature difference of 45°F, i.e. about 196 lb/sq. in/1°F giving a total force of 37 tons for the middle third of the rail.

161. It was interesting to note that when the rails were laid butting-up in summer they contracted to the maximum allowed by the fish bolts during the winter but never closed up again during the following summer!

162. The advantages of long welded rails far outweighed the disadvantages and it was only prejudice or fear which was keeping them out of their rightful use on a large scale, provided of course the track was up to the required standard and the curve limits observed.

163. Far more accurate results could be obtained by the use of SR-4 electric strain gauges than by trying to solve the problem mathematically by treating the long rail as a strut. Too many assumptions had to be made, whereas the SR-4 gauges gave direct readings of the stresses which were automatically recorded on sensitized paper, which when developed, gave a permanent record of the static and dynamic stresses for the tests.

164. No trouble had been experienced with the switch-type joint connecting the two 960-ft rails on the Irene-Lyttleton section of the electrified main line between Johannesburg and Pretoria where trains travelled at high speeds. The maximum movement was  $2\frac{1}{16}$  in.

165. It had been a great disappointment to Mr Bruÿns-Haylett that so little progress with long welded rails appeared to have been made in South Africa during the past 6 years and he trusted that the Paper would act as an incentive for more extensive use to be made of them on suitable main lines.

Mr H. A. Wickham (Principal Development Assistant, Permanent Way, London Transport Executive) referred to the Author's suggestion that track buckling was generally preceded by track lifting. During all his track observations and studies of long-welded-rail tests he had never encountered anything to support this theory, nevertheless he felt it was one which deserved earnest attention.

167. Believing that secure rail fastenings were primarily necessary to restrict unwanted movement in long welded rails, London Transport had been carrying out experiments with steel keying with a view to eliminating unwanted rail movement, also to avoid the need for the annual distressing of long welded rails.

168. Seven sites had been chosen, each comprising a  $\frac{1}{4}$ -mile length of 300-ft flash-butt-welded 95-lb. B.H. rails joined together with L.T.E. machined joints, and provided at each end of the  $\frac{1}{4}$ -mile length with L.T.E.-pattern adjustment switches. The rails had been keyed in standard S.I. chairs with steel keys. The sleepers had been creosoted softwood laid on good limestone ballast. The lengths had been selected to provide information on the behaviour of the track under differing site, track, and speed conditions as followed:—

|  |                                     |           |              |
|--|-------------------------------------|-----------|--------------|
| Perivale to Hanger Lane, Central Line  | Straight track E.B.                 | . . .     | 40/45 m.p.h. |
| Hanger Lane to Perivale                | „ „ W.B.                            | . . .     | 35/40 „      |
| South Ruislip to Northolt              | Reverse 40-ch curve                 | . . .     | 35/40 „      |
| Debden to Theydon Bois                 | Reverse 80-ch curve in cutting      | . . . . . | 35/40 „      |
| Brent to Hendon Central, Northern Line | Up grade 40- to 120-ch curve        | . . . . . | 35 „         |
| Barnet to Totteridge                   | Straight track, down-grade          | . . . . . | 40/45 „      |
| Chalfont to Amersham Met. & G.C.       | Up-grade, straight, not electrified | . . . . . | 40/50 „      |

169. Observations had been taken since 1951 at fortnightly intervals. The observed temperature ranged from 30°F to 115°F but more extreme temperatures probably obtained occasionally.

170. These lengths had been steel-keyed when at a length corresponding to what each was calculated it should be at the mid-range temperature of 65° to 75°F.

171. Observations of rail movement had been made at five stations spaced equally along each length, stations Nos 1 and 5 being close to the adjustment switches at the ends. During the period of observation the maximum rail movement at stations Nos 1 and 5 had been found to be  $-1\frac{1}{2}$  in. and the movement at the intermediate stations Nos 2, 3, and 4 had been almost negligible.

172. These experiments indicated that rail movement could be limited and probably eliminated by the use of suitable track fastenings.

173. Considering a long stretch of successive  $\frac{1}{2}$ -mile lengths with their adjustment switches at  $\frac{1}{4}$ -mile intervals, and assuming that the central portion of each length did not move appreciably, then it was reasonable to assume that if the adjustment switches were replaced by plain rail, steel-keyed, then rail movement could be restrained over an indefinite length of track.

174. Adjustment switches appeared to be required only where it was unavoidably necessary to change rails or to adjust them for some reason, such as giving attention to conventional insulated joints.

175. In that way it was possible to avoid using conventional rail joints or anything which breaks the running face of the rails—the primary reason for using long welded rails.

176. Mr Wickham noted that in France insulated joints were protected by siting expansion joints or switches near them. Such a practice would be intolerable on a railway system with an intensive signalling system and furthermore such a practice was to be deplored as introducing unwanted breaks in the running face of the rails.

177. Where there was a need for a robust type of insulated joint to withstand the stresses in long welded rails, tests had demonstrated that the L.T.E. plastic-bonded joint, with its completely insulated plates and oversize bolts, provided a joint of sufficient strength without the need for adjacent relieving joints.

178. The Author had made reference to the use of Thermit welds for the site-joining of long welded rails. Was he fully satisfied with this method? Had any other methods of site welding been tried in France? Were the Thermit welds post-heated?

179. Although there were many Thermit-welded tracks carrying frequent heavy traffic satisfactorily, Mr Wickham gathered from recent B.T.C. Research Department reports that laboratory tests indicated that Thermit and some other site-welded joints had considerably less resistance to fatigue stresses than flash butt-welds and that it could be assumed that failures of such joints might be frequent after they had been subjected to a large number of fatigue-stress repetitions.

180. In considering the future of long-welded-rail practice he felt that methods of rail making and rail laying would have to be reviewed. He earnestly believed that the eventual development would be in the flash-butt-welding and laying train as outlined in B.T.C. Research report No. E. 147. There were many difficulties to overcome but they were not insuperable and he looked forward confidently to the time when long flash-butt-welded rails were made in any required length on the site where they were to be laid in the track.

181. The difficulties of laying long welded rails on intensively worked suburban lines, were well known to London Transport Executive. Such conditions, including four-rail electrification, obtained over practically the whole of their railway system and yet they have pioneered and practised the long-welded-rail system successfully during the past 20 years in spite of the facts that:—

- (a) night possessions were usually only  $3\frac{1}{2}$  hours with 5 hours on Saturday nights;
- (b) there were many places subject to night traffic operation where only a short possession of 2 or 3 hours was available on Saturday night, while sometimes only 1 to  $1\frac{1}{2}$  hours possession was available during ordinary nights;
- (c) possessions of short duration at many places could be obtained only by hard-fought arrangements with the Traffic Operating Department for special diversions.

182. The Executive firmly believed, however, that the economies and advantages to be obtained from long welded rails in providing better riding for trains followed by a reduction in wear-and-tear of the track and rolling stock, fully justified every effort being made to introduce long welded rails wherever possible, in spite of difficulties which appeared at times to be insurmountable.

183. The work did not lend itself to the large-scale mechanization described by the

Author and every job had to be carefully studied as to methods to be adopted and programmed accordingly.

184. Generally speaking, owing to the irregularity of track wear, full-scale complete track renewal was seldom carried out and usually rail re-laying on existing sleepers was done, followed at a later date by sleeper renewals where necessary.

185. Long welded rails were usually pulled off the rail train and temporarily spiked down alongside the rails they were to replace; then rail changing was done at the first favourable opportunity.

186. Where complete track renewal was carried out, new sleepers were threaded in between existing sleepers with the positive-insulator ends projecting into the 6-ft way or the cess sufficiently to form a temporary platform on which the new long welded rails were laid, one in its proper bedplates or chairs adjacent to the new positive insulators and one temporarily spiked down alongside it.

187. On a night when a suitable possession was available the existing positive conductor rail was lifted over on to its new insulators and the negative rail was moved temporarily clear on the other side of the track. The old track was then removed in 60-ft assembled sections by crane. The other long welded rail was then moved over to, and fastened on to its proper bedplates or chairs. The new track was then slewed over to its proper alignment and then the negative rail was lifted on to its appropriate insulators.

188. An alternative method was to remove the conductor rails which were laid temporarily alongside the track and then remove the old track in 60-ft assembled sections.

189. The new sleepers were positioned by lifting them in as 60-ft lengths of pre-assembled track with serviceable rails. The serviceable rails were then replaced by the long welded rails and the conductor rails lifted into the insulators.

190. A review of current track-maintenance expenditure revealed an underspending which could be attributed to the economies effected by long-welded-rail practice.

**The Author**, in reply, pointed out three errors in the Paper:—

- (i) In the third paragraph of the Synopsis, the final word should be “ineffective”, not “inefficient”.
- (ii) In Fig. 4 (p. 96) the denominator  $P$  should be replaced by some other symbol, the significance of which was the rate of longitudinal friction against the ballast per unit of length.
- (iii) In § 42, the second sentence should read: “In this case only, the work was done . . .”

192. He agreed with Mr Hiley concerning the growth of the use of longer rails. It had at times been a fight against a myth, and mythology was always difficult to break down. The myth was the necessity of free expansion. The idea of the necessity of free expansion sometimes amounted, in fact, to a *mystique*. There were, of course, no expansion joints in mountains. Even though they were exposed to wide variations of temperature, however, they did not crumble away into dust. The paradox was difficult to impress upon various people.

193. Mr Robinson and others had made serious criticism against the assertion that vertical buckling was the only type of buckling to be taken into consideration. The Author said that perhaps the mistake was his own, but he was a very obstinate man. He had made up his mind 25 years ago and he had never changed it.

194. The likelihood of a track distorting horizontally, as related to its likelihood of distorting vertically was not easy to discuss at a formal gathering.

195. Mr Bartlett had stated that one-half or two-thirds of the transverse resistance offered by the ballast arose from the dead weight of the track. Now, it should be remembered that rails distorted vertically in the neighbourhood of the wheels. This distortion, though very small, was important because of the strains and tensions it caused. It had been ascertained, indeed, that a small lifting of the track occurred on

both sides of the wheels, and faded away along a more or less long distance, subject to the elasticity of the ballast. It had also been ascertained that the vertical distortion of a longitudinally compressed rail tended to increase as though the dead weight of the track was considerably reduced. This was attributable to both the compression and the curvature of the rails. In conformity with Mr Bartlett's observations, a lowering of the transverse resistance resulted.

196. A further statement confirmed the apparent lowering of the weight of a compressed bar; when maintenance people made the mistake of using jacks in order to lift a welded track in hot weather, the lifting required only slight effort; this lifting proved that they were actually mistaken.

197. If a length of track, compressed by the heat, was found distorted after a train had run over it, it was impossible to ascertain whether it had really lifted before distorting horizontally, and how important that lifting was, but the above reasoning, based upon the effects of an initial lifting of compressed rails, showed what a part it played in distortions.

198. It was clear, therefore, that the vertical distribution would appear to be the most serious factor. Static experiments were not likely to be conducive to any proper evaluation of the problem because of the risk of vertical distortion, which must always be considered. This did not, however, mean that lateral distortion should be forgotten; it should certainly be taken into account. As various speakers had pointed out, a method for the embedment of rails on sleepers should be found, in order to ensure the greatest possible degree of rigidity. However, no method so far developed either in Europe or in the United States of America had yet provided a sufficient degree of rigidity to have any real influence on the rigidity of the track as a whole.

199. From the theoretical viewpoint concerning horizontal distortion, those who wished to go into the matter might be interested to know that the Author had recently published an article containing all the relevant equations. In particular, it quoted an example which showed that the so-called rigid German K superstructure really had little effectiveness. Although theoretically there was supposed to be a close link between the rails and the sleepers, in effect, in view of the particular nature of the attachment devices and points, this relationship had no significant effect.

200. The account of the work done on the Western Region was of great interest, as was the serious consideration given by the engineers of that region to vertical and lateral distortions in their work in the tunnel. It should, however, be stressed that although static experiments might provide a basis for evaluating possible distortions, they were not sufficient and the vibrations caused by the passage of trains must be fully taken into account.

201. Referring to the remarks of Mr Tredennick and Mr Cantrell concerning the high cost of laying or re-laying long welded rails, especially on very busy tracks, the Author observed that some methods of renewal had been found which required but a short occupation of the track. He described one of them.

202. First, he substituted the expansion joints for the previous track at their final locations; connexion with the remaining track was temporarily assumed by fishplates. Then he displaced the track between the expansion joints by about 10 in. towards the cess; this work was performed automatically by cleaning machines, making use of the lifting of the track for the purpose. Afterwards he slightly loosened the fastenings and spaced the old sleepers transversally so that it was possible to insert the new ones at their right places under the old rails, these rails being supported by, and fastened to, the old sleepers.

203. Then the adzings of the new sleepers were lined up in order to allow the new rails to be tightened, except in the neighbourhood of the expansion joints.

204. During an occupation of track not exceeding 2 hours, the temporary fishplates could be taken off, the transition curve of old plates disposed of and the expansion joints dealt with. There was then plenty of time to dismantle the old track.

205. A misunderstanding had perhaps arisen from the Paper concerning the problem of insulating joints. The French railways did not install any insulating joints in their

very long rails, since these would lead to considerable difficulties of resistance where there was considerable traction. This, therefore, prevented the welding of long rails in any areas where there was a considerable number of track circuits.

206. Some apparently contradictory remarks had been made concerning the spacing between a series of expansion joints. Mr Robinson had said that he saw no objection to the fact that expansion joints could be very far apart, but this was in contradiction of those who indicated that there were serious difficulties when broken rails had to be changed. The replacement of broken rails fully justified the policy in terms of which expansion joints would not be placed too far apart. The spacing adopted in France was  $\frac{1}{2}$  mile, which had also been adopted, it was thought, by London Transport, and appeared to be very suitable.

207. Accurate figures could not be given, but it could be said that if instead of  $\frac{1}{2}$ -mile spacing there was 1-mile spacing along the length of track, the additional cost would be reduced only from 1 to  $\frac{1}{2}\%$ , which was a minimum figure when compared with all the objections that would arise and the advantages that would be lost in the replacement of broken rails.

208. Questions had been asked concerning the length of rails transported from the factory to the site where they were to be used. As indicated in the Paper, the length of rail laid was generally 288 m (a little more than 300 yd). London Transport, it was stated, tried to apply electrical welding procedures to the largest possible number of rails ends and found this to be the best method. It was an advantage to do as much electrical welding as possible in the shop rather than at the site. Where, however, conditions did not permit of welding in the shops and it had to be done on the site, alumino-thermic welding had been found to give quite satisfactory results.

209. The question of the frequency of breaks on long welded rails had been raised. The French practice was to classify the failures according to the year of laying and the age of the rails. Thus it was possible to know the average percentage of rails laid, for instance, in 1951 and which had broken early, or, say, the average percentage of rails broken during their fourth year of life. All these figures seem to converge to a rate of one breaking per 15 miles per year.

210. Mr Tredinnick had asked whether the costs quoted in the Paper took account of the actual cost of installation of the long welded rails and of the installations necessary for their manufacture and transportation. The answer was that these factors were taken into account and that, in particular, the transport of the long rails was cheaper than that of standard lengths of rails.

211. It was important to try to ensure maximum safety by giving the maintenance or installation men effective instructions. Admittedly, written instructions were not usually sufficient. The French method was to ensure that there were always present a few people among the installation or maintenance teams in the shops or at the site who were particularly interested in the problem and well informed concerning it. These men were given general instructions concerning the degree of supervision to be applied, and it was done either on a limited local or a larger regional basis.

212. It was quite true that from the viewpoint of economy, it was difficult to lay long welded rails on badly worn tracks. This had been found to be true on London Transport lines and on the Western Region. Where there were conductor rails, the economics were not as satisfactory. The figures quoted in the Paper were, however, pessimistic rather than optimistic.

213. The Author was pleased to hear that longitudinal sleepers were still considered to possess some efficacy, because their conception arose from his own recommendation when confronted with the problem of providing a means of ensuring sufficient weight to be able to avoid any distortions of rail. Although he did not know whether it would work in practice, he was pleased to know that it was found to be sufficiently effective to ensure the necessary torsional resistance.

214. Referring to § 91 the Author mentioned that the breather joint used by the S.N.C.F. had been recently improved by making use of a usual rail, of the type normally used in tunnels, weighing 113 lb/yd.

215. He confirmed that the anti-creeping effect of the French double elastic fastenings (see § 93) had been attributed mainly to friction against rubber.

216. The word "embedment" (see § 102) had been used by the Author to mean the lateral resistance of the whole of the track. The "resistance to torsion" also played a part therein, but the Author considered it as insufficient to be reasonably relied upon as a means of preventing transverse distortions.

217. The figure of 84 weldings per day (see § 103), obtained at Moulin Neuf, referred to double-team work. He agreed that the number of wagons required for the transport of the welded rails increased, though to a very small extent, as related to the total length of those rails.

218. In reply to the questions in §§ 134, 135, the Author believed that the economical superiority of welded rails existed on heavily loaded sections as well as on others; besides, he stated that those rails were used on all lines, regardless to their traffic, even on Paris suburban sections electrified with a conductor rail.

219. No yearly alteration of the actual length of long welded rails (§ 139) had yet been experienced. A new device had been designed, which would give, it was hoped, continuous accurate information about the actual lengthwise stress.

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