the removal and reinsertion of the spikes when the plates are turned and oiled.

(2) That all elastic rail spikes be spun galvanized, to ensure that their life will be at least equal to that of the other track components.

The elastic rail spikes are subjected to high repetitive stresses and may fail by corrosion fatigue. Renewal could only be carried out at high cost, whereas the galvanizing would add only 20 per cent. to the present cost.

(3) That fishbolt holes in fishplates be drilled instead of punched. The present method of punching holes distorts the fishing tables opposite the holes and the undulating surfaces increase rail-web stress when the fishplates are bolted up. Recent tests carried out by the London Midland Region Research Department on 113-lb. flat-bottomed rail and fishplates indicate that the use of fishplates with punched holes may cause rail-web stresses 60–65 per cent. greater than those obtained with drilled fishplates.

(4) That the cast-iron baseplate be to the design shown in *Figs 11*, which has a series of prismoidal projections cast on the underside. The projections are readily forced into the timber under traffic, and offer considerable resistance to lateral thrust.

Chairs with similar projections have been in use on the London Midland and Scottish Railway for many years, with satisfactory results, on curves where gauge widening had previously occurred with plain-base chairs.

ACKNOWLEDGEMENTS.

The Author is indebted to Mr. James Briggs, M.I.C.E., the Civil Engineer, and to Mr. T. M. Herbert, the Scientific Research Manager, both of the London Midland Region, for the information used in the compilation of this Paper and for authority to publish it.

The Author is also indebted to Mr. J. C. Loach, of the London Midland Region Scientific Research Department, who has been responsible for most of the research work mentioned, for his help and interest in the preparation of the Paper.

The Paper is accompanied by eleven sheets of drawings from which the Figures in the text have been prepared.

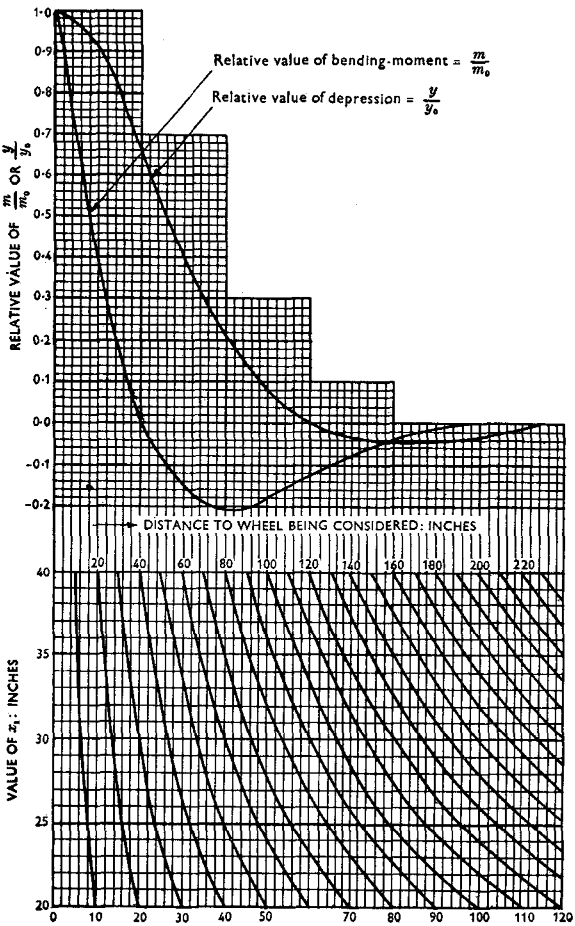
Discussion.

Mr. A. M. Sims presented his Paper with the aid of a lantern slide. He stated that he wished first to explain that the use of the expression "flat-footed" rail sections was due to the fact that the term "flat-bottomed rail" was hardly ever used in India.

In dealing with rail stress calculations much depended upon the master diagram shown in *Fig. 1.* The lower curve towards the left represented the relative bending-moment curve, and the upper one on the right the relative track-depression curve. From the bending-moment curve could be calculated the bending moment at any distance from an isolated axle in relation to the value of the bending moment directly under that axle, which would be seen on the left-hand scale towards the top to be 1, the curve being a relative curve.

The diagram was very simple to use. For instance, the effect of the trailing coupled wheel on the track immediately below the centre coupled wheel would be found by calculating the value of x_1, which in the Paper had been worked out to be 33·92 inches. The coupled wheels were 79 inches

Fig. 1.



MASTER DIAGRAM FOR RAIL-STRESS CALCULATIONS.

apart. •At 33·92 a horizontal line would be run to meet the diagonal line for 79; then a vertical line would be run upwards to meet the bending-moment diagram, the intersection being at —0·195 as shown by the scale on the left. In the middle of the Table shown on p. 9, would be seen the figure 18·41, which was the equivalent wheel load for the trailing coupled wheel. That figure of 18·41, multiplied by the figure of —0·195 read off from the left-hand scale of the master diagram, gave a figure of —3·59, which was entered immediately to the left of the figure of 18·41 in the Table. That was how every figure in that Table had been worked out. The track-depression diagram was used in exactly the same way.

The two Papers before the Meeting had been written independently and from very different points of view but, despite the difference between Indian and British practice and experience, many similar conclusions had been reached. In one particular there was noticeable difference in the vertical wear of the head which was allowed and experienced; the explanation of that was density of traffic. On that account different standard designs might be required for use in Britain and India.

He wished to disclaim any criticism of the British Standards Institution, which had been of considerable assistance in India. Any criticism should really be of the users of the rails and fishplates. Almost all of that technical knowledge had been available by 1930; yet by 1939 very little had been done towards producing more efficient and economical rail sections. In 1939 attention had had to be turned to more important matters, but the research officers in India had continued their work until 1942; some of it had not yet been published.

Mr. N. W. Swinnerton presented his Paper with the aid of a series of lantern slides. He said that a synopsis of the Paper had been submitted by him to the Chairman of the Railway Engineering Division in June 1948 and the Paper had not been influenced by subsequent events, particularly in so far as rail design was concerned.

It had not been possible for him to meet Mr. Sims before the Papers were drafted, and it was a source of satisfaction to find that their view-point was similar in many respects.

Railway Transport in Great Britain should be highly efficient if the country was to maintain its high level in the industrial sphere. Goods and passengers should be transported at the highest possible speed from place to place, and with as few interruptions as possible in transit. Those fundamentals alone imposed greater demands on the track, particularly in regard to strength and stability of components. Mr. Swinnerton considered that it was impracticable to design a track to meet the conditions (*a*), (*b*), and (*c*) outlined on page 29, *ante*, using bull-headed rail, and that therefore the use of flat-bottomed rail was a *sine qua non*.

Factor (*a*) referred to traffic conditions relative to the speed and freedom of traffic movements. To move trains from one point to another at higher speeds, that was, to raise the general level of average speeds, obviously increased the frequency of higher stresses in the rail and other components, assuming that propelling power units were as designed at present. To move the trains with the least possible interruptions and delays seemed to be the most potent necessity, if operating costs were to be reduced to the minimum and timetables maintained.

Track delays were occasioned by track renewals and replacement of failed components and the like. What were the possible savings from those less frequent interruptions ? If the fact were accepted that the track life could be extended 2 years by the use of flat-bottomed rail, the approximate savings from fewer interruptions to traffic could be built up.

Assuming an approximate figure of 35,000 miles of running lines for British Railways, with an average life of 20 years, then 1,750 miles of track was renewed each year.

If renewals were carried out piecemeal, and it were assumed that 1 mile of track was renewed per week, then there were 1,750 slacks of one week's duration with speeds of 15 miles per hour.

Taking the 2 years extended life for flat-bottomed track, then only 1,590 miles of track was renewed per annum, and the number of slacks of one week's duration was 1,590—a reduction of 9 per cent. in the number of slacks.

It had been stated that if a train were reduced in speed from 60 miles per hour to 15 miles per hour, and it accelerated again to 60 miles per hour, the approximate additional coal-consumption was $1\frac{1}{2}$ cwt. Assuming that seventy trains per day ran over the line in question, then for a 6-day week the additional coal-consumption was, say, 32 tons, so that the saving in coal arising from the reduction of weekly slacks from 1,750 to 1,590 was 5,120 tons and, at £2 10*s.* 0*d.* per ton, the monetary saving was £12,800—a worthwhile figure. The figure varied with the number of trains passing over a section of line, and their prevailing speed, and also when the renewals were carried out by cranes.

A failed rail gave rise to traffic interruptions, particularly if the failure were in a turnout or in junction work and, as failed rails were not unknown with bull-headed track, it was anticipated that savings would accrue from a smaller number of failures with flat-bottomed rail.

Other savings were realized from fewer traffic interruptions so far as the Operating Department was concerned, but it was an accountant's job to assess them, and the Author had made no attempt to do so.

The psychological effect of delays to traffic was well known, as also was the saving in materials and manpower from less frequent renewals of track.

With regard to available man-power, Mr. Swinnerton suggested that the figure of 30 per cent. less than pre-war was a conservative estimate.

Quite apart from reduced hours and holidays, the effectiveness of a gang might be reduced considerably during the absence of one man on holiday, where the gang strength was five or fewer, in that certain work could not be done with a small gang.

The price of sleepers was approximately ten times that of twenty years ago, but the vital factor was quality, which affected the track life. Sleepers with boxed hearts and vertical grain, and those with fewer than nine annular rings to the inch, would not have been accepted 25 years ago. To-day they had to be accepted, and therefore the sleeper and the stability of the fastenings were the factors which now usually decided track renewals.

Whilst such questions as drainage, ballasting, baseplates, and preservative treatment all played their part in obtaining a maximum life of sleeper, Mr. Swinnerton believed that the stronger and stiffer flat-bottomed rail would also assist in that direction. The flat-bottomed rail would distribute the load over a greater number of sleepers and fastenings, thus reducing mechanical wear, which undoubtedly accelerated decay.

The additional cost involved in the slightly heavier rail would be outweighed by the savings arising from the longer life and reduced traffic interruptions. The improved track stability was obvious.

Mr. J. C. L. Train observed that The Institution had set the pace for the Railway Executive, because the latter had found it necessary to hurry forward an announcement about the adoption of flat-bottomed track as standard for British Railways—an announcement which had been made on the wireless because of the presentation of the Papers. The Chairman of the British Transport Commission, Sir Cyril Hurcomb, had expressed the hope that a Paper on the subject would be presented to The Institution, and Mr. Train had been able to assure him that that had already been arranged. It was most fortuitous that the Authors should have presented Papers on flat-bottomed track at that particular time.

The adoption of the flat-bottomed rail was an historical change, since less than 5 per cent. of the track mileage of the world had been bull-headed track, so that Great Britain had represented a minority. Now, however, when flat-bottomed track had reached a sufficiently high standard, it had been adopted.

He felt that tribute was due to the London Midland and Scottish Railway in particular, and to the London and North Eastern Railway in lesser degree, for the trials which were instituted by the former Railway more than 12 years ago and by the latter Railway 10 years ago.

Mr. W. E. Gelson said that his permanent-way experience had been gathered mainly on Indian railways, where he had been engaged for a number of years on track research. Apart from reports by the American Society of Civil Engineers of work done on American railways, comparatively little data had been available when work was begun in 1935.

Three electric extensometers were purchased from America and formed the nucleus of the laboratory equipment. In an early series of rail-stress measurements taken with those extensometers under electric locomotives, smaller stresses were recorded at 90 miles per hour than at a crawl; he had previously been assured by the late Professor A. N. Talbot, M.I.C.E., that speed effect could be neglected up to 100 miles per hour.

Contemporary theoretical analysis showed that maximum rail stress and sleeper depression would increase with speed in a continuous manner under a wheel load passing over a given track, if the rails were assumed to be continuously and uniformly supported, and if a figure were assumed for effective mass of the track per unit length. Although good agreement was found between theory and experiment in the case of sleeper depressions, rail stresses measured with the extensometers (after they had been re-designed by Mr. E. A. Blackwood, A.M.I.C.E., to give a faithful record at service speeds) appeared to be erratic and often much higher at speed than predicted by the continuous-support theory. That was attributed partly to resonance at sleeper frequencies. The question of sleeper resonance had been considered subsequently in a Paper [1] presented to The Institution in 1939, where the advantages to be gained by increasing the vertical stiffness of the rail were clearly brought out. Until such time as continuous longitudinal rail-support could be incorporated into a practical design, the effects of sleeper resonance had to be appreciated and provided for. They seemed to Mr. Gelson to set a definite upper limit to the safe speed of rail travel.

With the valuable increase in vertical stiffness of about 25 per cent. obtained by changing over to flat-bottomed rails came certain problems. That type of section was peculiarly susceptible to the effect of eccentric and lateral forces, and had, therefore, to be carefully designed to avoid distortion. Mr. Sims had dealt with that aspect of the matter. The bull-headed rail was well adapted to withstand lateral loads without overstress so long as its supports and fastenings remained in good order; but that, as Mr. Swinnerton had said, was difficult to ensure under modern conditions.

A second problem, with which both Authors had dealt, was the design of adequate fishplates for flat-bottomed rails. In modern practice, joint-sleepers were closely spaced, and it was a simple matter to arrange joint-sleeper and intermediate-sleeper spacings so that the joint depression under a given wheel load was substantially less at crawl speeds than the depression at intermediate sections away from the joint even with uniform packing throughout. In such cases, maximum fishplate stresses at speed were frequently less than those in the rail at intermediate sections, and even better results were obtained when the rails were experimentally cambered upwards $\frac{1}{32}$ inch for a length of 1 foot at the ends.

Mr. Sims, who was a strong and consistent supporter of track research in India, had pleaded for higher strength of fishplate steel to meet the requirements of everyday conditions. That was a major recommendation arising from Mr. Gelson's own research. Whilst it was true that experiments on heat-treated fishplates were made on a small scale in India, the

[1] C. E. Inglis, "The Vertical Path of a Wheel Moving Along a Railway Track." J. Instn Civ. Engrs, vol. 11 (1938–39, Part 2), p. 262 (March 1939).

matter was shelved during the recent war and no revised standard had yet been evolved.

When proportioning the web of a new rail section, it was well to remember that tensile stresses were induced in the webs at the rail ends. Mr. Sims might recall that a number of very heavy cast or drop-stamped fishplates had had to be scrapped because of their tendency to induce a longitudinal horizontal crack, starting at the rail end and extending to the bolt-holes.

Compensated engine-springing was, he understood, largely abandoned on British railways at a time before the war when track was well maintained. Records taken in India of movement of the compensating beams showed that they played a useful part even on good track. The incidence of fishplate fractures on British railways, to which Mr. Swinnerton had referred, might have been affected by reversion to independent springing.

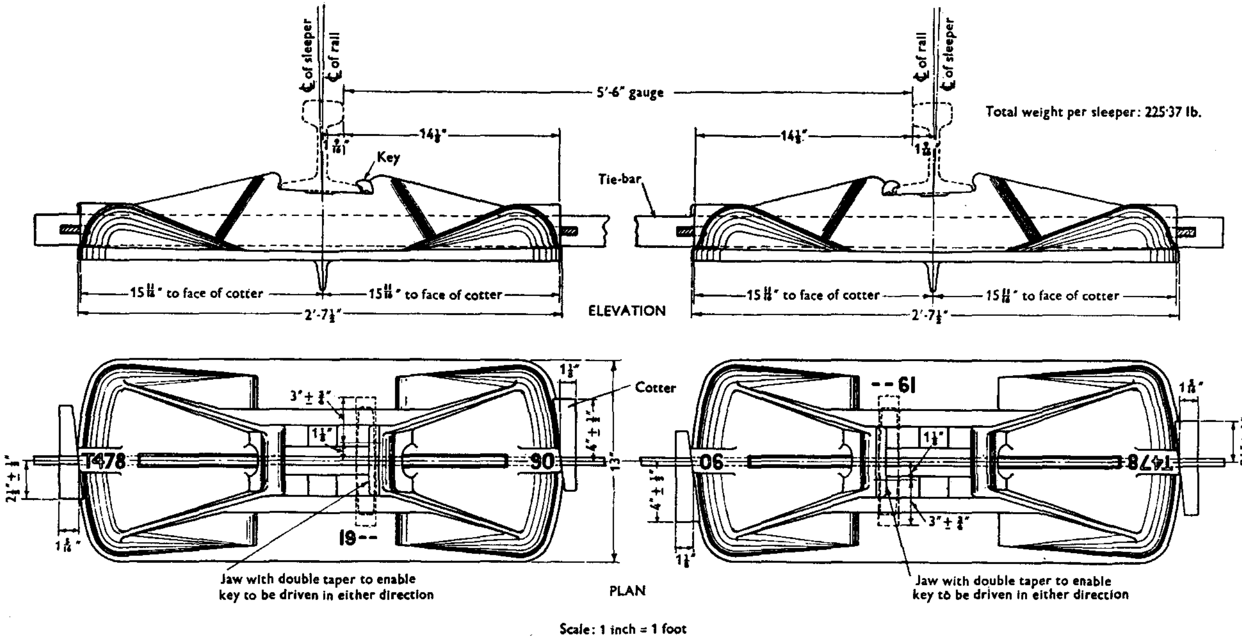
Mr. Swinnerton had made only brief references to the important requirement of lateral strength, stiffness, and stability. Lateral effects had been the subject of much investigation in recent years, notably in India, where the Bhita accident and the Pacific locomotive inquiry had provided a stimulus which might not otherwise have arisen. Mr. Gelson believed that lateral effects would continue to be important so long as spring suspension, running gear, flange profiles, and clearances retained their present characteristics. The vehicle body and its suspension formed a dynamical system which oscillated laterally and otherwise by reason of flange action. That was accentuated by tire wear and coning, but experiments made in America and India had shown that a locomotive with cylindrical tire-profiles might oscillate violently unless properly controlled.

Lateral forces at speed were found to be affected by resonance at sleeper-spacing frequency. Arrangements for recording the lateral forces from separate wheels had been devised but had not yet been used in India, and it had been possible, so far, only to measure the net force between the wheel pair and the track; but he had reason to think that the lateral load of 10 tons taken by Mr. Sims might be an underestimation for the XC Pacific engine which had coupled-axle loads of almost 20 tons.

The current design of Indian cast-iron sleeper shown in *Figs 2* (p.58) met all requirements in regard to resistance to lateral shift and longitudinal creep. The length of rail seat was short, in order that the rail-rock under wave action should be taken up by torsional strain in the rail foot, which was keyed to the sleeper, in which rock was eliminated. In its standard form, track circuiting could not be used with that sleeper, but he nevertheless commended the design to the attention of permanent-way engineers, as it seemed to avoid troubles with abrasion and creep attending the use of orthodox sleepers and laminated-spring spikes.

Mr. J. Taylor Thompson said that it was important to realize that designing a rail and track was a very different problem from designing a

Figs 2.



TYPE OF CAST-IRON SLEEPER WITH LONG TIE-BAR, USED IN INDIA FOR B.G. 90R RAIL.

This design is suitable for the B.S. 90-lb. flat-bottomed rail, but in this case the position of the key will be altered, the 3-inch ± ¾-inch dimension on the plan being increased to 5 inches ± ¾ inch.

normal structure, and that variations in the conditions of loading, maintenance, and support gave rise to a very wide range of stresses.

It would be uneconomic to design a rail for a combination of all the worst possible circumstances of loading and support, and to lay such a rail throughout the railways of Great Britain—although a very high stress could be allowed where the conditions were quite abnormal for a short time.

He would like to make a comparison between the method suggested in Mr. Sims's Paper for the design of a flat-bottomed rail and the general method adopted in designing the new rail to which Mr. Train had referred. Mr. Sims, having gone very fully into the stress calculations, proceeded to design the rail on practical considerations, without reference to loading or stresses. He began by stipulating a 5½-inch base, which was sufficient to give adequate lateral stiffness, and then determined the depth by adopting a depth/height ratio of 1·2. The head radius and width were then determined and the depth of head was fixed by the wear of ⅛ inch (which seemed a very low figure) and the flange clearance. He adopted a fishing angle of 1 in 3 with large fillets, which were now common practice.

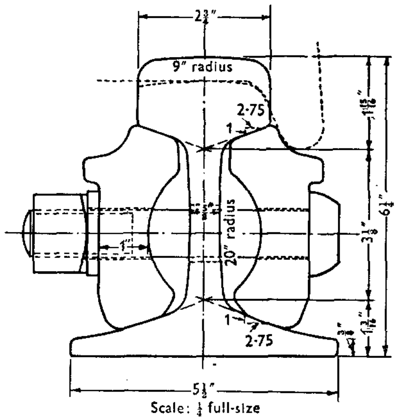
Mr. Sims determined the foot depth by saying, in effect, that a flat angle would place the metal favourably from a stress-carrying point of view, whereas a steep angle would put the metal in a less favourable stress-carrying position. The web was determined from the shear and the practical questions of maintenance and rolling. There were, therefore, four features which determined the design, but it did not appear that Mr. Sims had worked to any particular required strength. He appeared to design each part on practical considerations, finally determining the modulus and the load for which it was suitable. That was the reverse of normal design practice.

By contrast, the method adopted in designing the 109-lb. rail was to begin with the head. It was found that rails wore to a radius of 9 inches; that radius was, therefore, adopted and, with that one alteration, the new head followed the design of the present 95-lb. rail, which had been found so satisfactory. A large fillet was provided and the foot was then fixed, 5½ inches being determined as the width which would give sufficient lateral rigidity. The next determination was the edge depth, which was important since corrosion should be prevented from arising between the edge of the rail and the base-plate. It was decided that equal fishing angles should be provided, thus reducing the stresses set up by the fishbolts and, in order to do that without producing a very heavy foot, a double-angle foot was decided upon.

The thickness of the web was determined from the shear forces and by experience of failures, and was fixed at ⅝ inch. Lastly, the depth was calculated to give the required modulus, and *Fig. 3* showed the final result. With semi-supported joints, the section provided a strength of joint at least equal to the plain track.

Another rail, weighing 98 lb., with the same width of base, had been designed on similar lines to take the place of the present 85-lb. bull-headed rail, so that recovered sleepers with base-plates could be used for the lighter rail after having first carried the heavier rail.

Fig. 3.



109-LB. FLAT-BOTTOMED RAIL.

Mr. C. E. Dunton, referring to the maintenance savings from the use of flat-bottomed rail, said that in experiments made by the London Transport Board with welded bull-headed rail, the savings obtained were 14 per cent. in the on-track hours—only 7 per cent. of the total man-hours on the whole of the work, including the " hedging and ditching." By comparison, the figures for welded flat-bottomed 90-lb. rail were 20 per cent. of the on-track hours, representing 11 per cent. of the total work. The elimination of joints was, therefore, another means by which it was possible to effect considerable maintenance saving.

On p. 29, *ante*, Mr. Swinnerton had referred to the use of a stiffer and stronger rail as being economically the best proposition. It was sometimes thought that stiffness and strength were closely-related properties, but that was by no means the case. He compared the lateral stiffness and strength of the 95-lb. bull-headed rail with those of the 113-lb. flat-bottomed rail. The strength of a rail by the well-known formula $\frac{p}{y} = \frac{M}{I} = \frac{E}{R}$ was $\frac{pI}{y}$. The I_{yy} figure for the bull-headed rail (the lateral moment of inertia) was 4·1, and for the flat-bottomed rail, 8·9. The strength, however, was $\frac{I_{yy}}{x}$, where x denoted the distance to the extreme fibre, and it could be shown that, whilst the strength of the flat-bottomed rail was approximately the same as that of the bull-headed rail, the stiffness was doubled.

The support of a sill on ballast or earth would depend on the stiffness. With a stiff beam the load would be spread on the peaks, whilst a weak beam would follow the ground more closely and spread on a much shorter length. With a stiffer beam, therefore, the load would be spread over a greater length, and the bending moment would be higher. Since the strengths of the two rails were equal, it should be expected that the lateral bending stresses would be higher for the flat-bottomed rail than for the bull-headed rail.

Mr. Sims, using Professor Timoshenko's method, had calculated a stress for the 90R Indian rail of 6·99 tons per square inch, due to a lateral point-loading of 10 tons. That calculation was made on the assumption that there was no elastic or permanent movement of the sleeper. Although that condition might obtain in India, Mr. Dunton did not think that it was true of Great Britain. Deformation might increase the stress to about 8 tons.

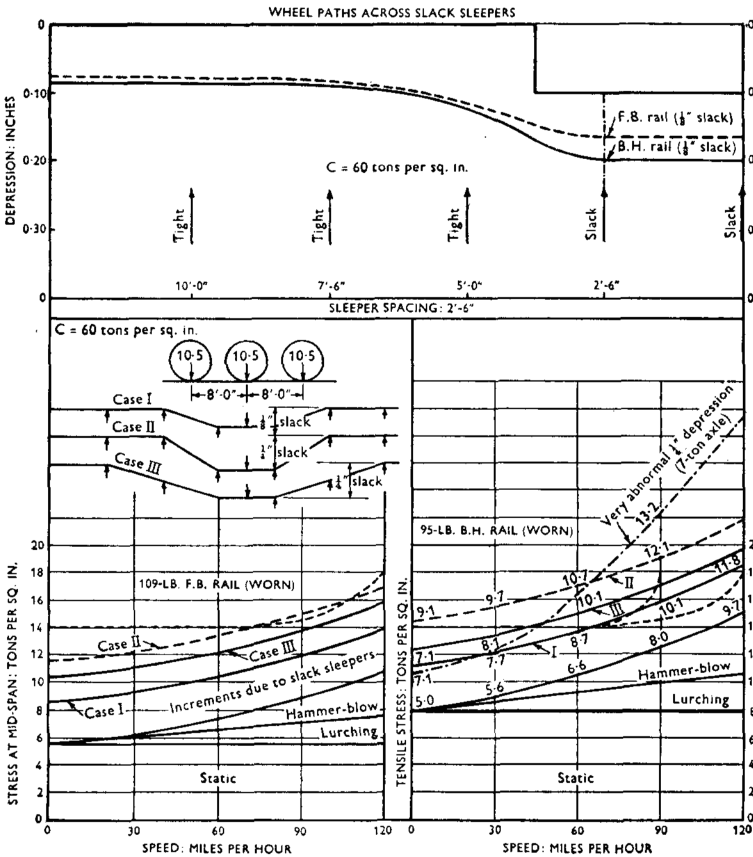
The bending stresses in the side of the foot of flat-bottomed rail were a combination of vertical and lateral bending, and might reach a very high value. In America they had been as high as 25 or 26 tons, although the mean stress over the whole of the foot might be only 18 or 19 tons. There was, therefore, a potential source of high stress, due entirely to the width of the foot, which should not be overlooked in any consideration of the flat-bottomed rail.

Mr. Arthur Dean observed that a decision that an old rail was no longer good enough was very difficult to make. The recent war had emphasized the difficulty in the United Kingdom. Experiments had been made before the war to determine the economies of maintenance which would arise from the use of a stiff flat-bottomed rail, but it was the experience which had been gained from reduced maintenance during the war which had led to the conclusion that it would never again be economical to maintain the desired standard of 95-lb. bull-headed rail. It was possible to maintain the heavier and stiffer flat-bottomed rail more economically to the standard necessary to keep its stresses within a reasonable margin, although, if the 95-lb. rail could be maintained perfectly, it would meet requirements for a long time. Until recently, 90-lb. South Western rail, 30 to 35 years old, had been used on the West of England main line of the Southern Region, carrying some of the fastest traffic in the country without the slightest trouble.

It was interesting to compare the various design bases which had been adopted. Mr. Taylor Thompson worked on a value of 8 tons per square inch, Mr. Swinnerton recommended 11 tons per square inch, and Mr. Sims gave 14 tons per square inch, and yet they arrived at the same rail design; *Fig. 4* might illustrate how that arose. The Indian results, like the American ones, were based on their relatively soft track. Mr. Dean suspected that, on British track, irregularity of the track support was one of the biggest stress-raising factors. At present some heavy-locomotive axles had an unsprung weight approaching 7 tons, and vertical acceleration when travelling over a depression could add considerably to rail stresses.

The lower right-hand diagram of *Fig. 4* showed the effects of lurching and hammer-blow in the case of the 95-lb. bull-headed rail, and also the effects of various degrees of slack supporting sleepers. The chain-dotted line running up to the high-stress range showed the effect of a particular

Fig. 4.



form of track irregularity which was, fortunately, infrequent, but indicated that the 300-inch-ton bending moment to which Mr. Swinnerton had referred could quite possibly be attained. The safe-stress value obtained depended on the method of calculation; that accounted for the fact that three different figures had been quoted.

From *Fig. 4* it could be seen that the effect of the heavier rail was considerable; not only did it reduce the stresses but it also smoothed out the effects of irregularities of track support. One of the consequences of the introduction of a rail of such a weight would be the elimination of high peak-stresses which, on track not packed and maintained as well as it should be, were a major cause of trouble.

Mr. J. C. Loach said that on reading the Papers he had come to the conclusion that there were three ways of assessing the bending moment which a rail should withstand. One was the method adopted by Mr. Sims, who calculated the effect of hammer-blow and piston-thrust, worked out the bending moment which the rail should withstand, and so obtained the stress, which he quoted to the second decimal place of a ton per square inch. He then added a nominal 6 tons per square inch for the increase of stresses in the foot due to lateral bending. Mr. Sims made that addition to the compressive stress, which presumably was in the head of the rail as well as in the foot, and to the tensile stress; it would be interesting to know the reason.

Secondly, a rail could be designed as Mr. Swinnerton had done, designing the fishplate and rail to obtain sections which would be satisfactory in service, then finding the moment of inertia, and feeling satisfied that the resulting rail was better than those which were normally used.

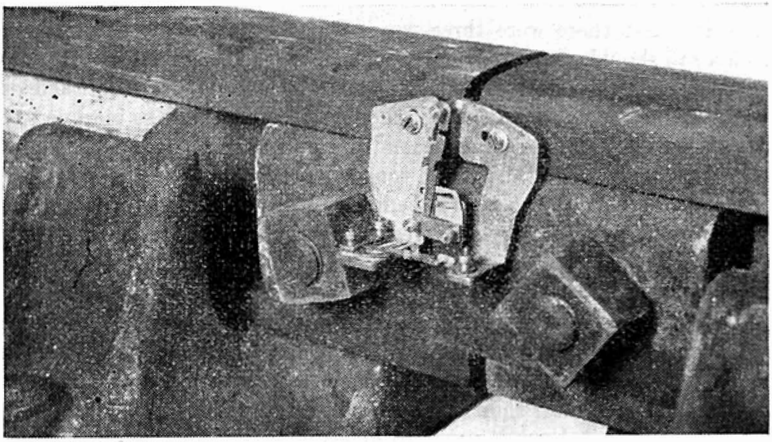
A third method, however, was to measure strains in existing rails and thereby obtain the bending moment which rails had to withstand in service, and to design the new rail accordingly; that was the method adopted by the Track Committee of British Railways in connexion with the new 109-lb. rail which Mr. Taylor Thompson had described. Mr. Loach thought that that was the most logical method of approach, and he described how it was done.

The extensometer used was a modified Deforest type working on a 4-inch gauge length. The high stresses caused by locomotive coupled wheels were interesting; the three coupled wheels of a 4-6-0 gave stresses of 6, 7, or 8 tons per square inch, and sometimes more. Taking the records was easy and quick. Working with one and sometimes two assistants, he had obtained 200 to 300 strain measurements due to locomotive driving-wheels per day, the highest number being 334 in one day. A few days' work gave ample records to produce a frequency diagram of bending moments occurring in the rail.

Mr. Swinnerton had stated (p. 33) that "The behaviour of the several forms of joints was watched and extensometer readings were taken." Mr. Loach thought that that deserved a little further explanation, because the extensometer was not used for measuring strains in material. *Fig. 5* showed what was done. Two small brackets were clamped to the rail ends and one end of the extensometer was fastened to each, so that the extensometer recorded the relative movements between rail ends, the vertical one for vertical movements and the horizontal one for the other movements.

Mr. Loach thought that, even though experimental data were so desirable, the calculation of bending moments in rails should not be completely overlooked. *Figs 6* showed results of a method using Relaxation, developed by Dr. H. I. Andrews and illustrated by Sir Richard Southwell in the

Fig. 5.



EXTENSOMETERS ADAPTED FOR MEASURING RELATIVE VERTICAL AND HORIZONTAL MOVEMENTS OF RAIL-ENDS.

James Forrest Lecture of 1948.[1] The bending moments obtained were shown at the bottom of *Figs 6*. For a 95-lb. rail the calculated bending moment under the leading wheel was 74·3 inch-tons. With the stiffer rail the bending moment was higher, 81·4 inch-tons, even though the same loads were carried. That answered a query raised by Mr. Dunton. With a softer bed there was an increase in bending moment of about 9 per cent.

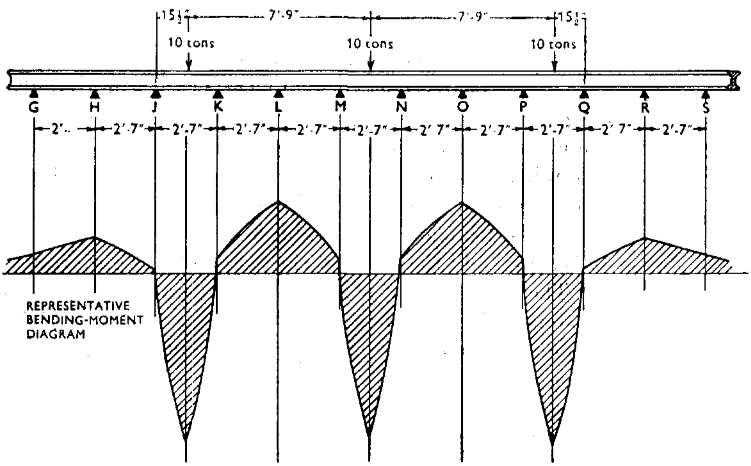
The discussion had displayed a surprising divergence of ideas of what working stress should be used in a rail. It had been established for a long time that the maximum stress-alternation about a mean zero stress which a nicely-machined specimen would withstand was from three-eighths to one-half of its ultimate tensile strength. That was the intrinsic fatigue strength of the material and, without experimental verification for any particular case, was usually regarded as 0·45 of the ultimate tensile strength.

Rails were forgings and so had a decarburized layer and a black surface; occasionally they also contained small rolling defects. Since fatigue flaws which occurred in rails in Britain usually started from a face, it was necessary to consider the conditions obtaining on the surface: in that way

[1] "Relaxation Methods: An Engineering Approach to Computations." J. Instn Civ. Engrs, vol. 30 (1947–48, Part II), p. 351 (October 1948).

the fatigue limit for "as-rolled" medium-manganese rails, the ultimate strength of which was about 53 tons per square inch, was reduced to values between ± 11 tons and ± 11·5 tons per square inch. But that was not all: during service rails were subject to atmospheric corrosion which, probably aided by the stresses imposed in the rail while the corrosion was proceeding, reduced the fatigue limit during the first life of the rails to values of the order of ± 9 tons per square inch in rural atmospheres and still lower in other places.

Figs 6.



RAIL	ELASTICITY OF BED: TONS PER IN.	BENDING MOMENTS IN RAIL: INCH-TONS				
95 lb./yd B.H.	120	− 74·3	+ 30·6	− 72·4	+ 30·6	− 74·3
113 lb./yd F.B.	120	− 81·4	+ 36·9	− 75·8	+ 36·9	− 81·4
95 lb./yd B.H.	60	− 80·8	+ 38·1	− 75·5	+ 38·1	− 80·8
95 lb./yd F.B.	60	− 88·8	+ 41·3	− 77·6	+ 41·3	− 88·8

Strain-gauge diagrams and relaxation computations suggested that, at most, the compressive stresses in the foot of the rail were only half the value of the tensile stresses, and so the range ±9 tons per square inch might be regarded as equivalent to a range from +11 to −5·5 tons per square inch, the figure used by Mr. Swinnerton.

Obviously stresses would, on some occasions, exceed those values; then the rail would withstand only a limited number of them. Rails withstanding an infinite number of stress-changes of from +11 to −5·5 tons per square inch could, in addition, withstand approximately 450,000 stress-changes of +14·4 to −7·2 tons per square inch or approximately 90,000 stress-changes from +17·6 to −8·8 tons per square inch. The chances of such numbers of repetitions of larger stress being reached could be assessed from the frequency diagrams of bending moments obtained experimentally.

Mr. Walter Leigh stressed the importance of fishplate design. The present design of rail joints was not entirely satisfactory, owing to difficulty and time occupied in maintenance, rail hammer, slackening of bolts, and breakages of fishplates and rails due to high stresses. To investigate the possibility of overcoming those defects, a series of trials, extending over nearly 4 years, had been made on bull-headed rails, under main line running conditions, using fishplates which extended from chair to chair, so forming a girder which carried and supported the ends of the running rails. The trials had shown that that type of fishplate had fulfilled the beneficial purposes for which it was designed.

For such a joint to be efficient it was essential to ensure the bearing of the fishplate ends on the chairs, regardless of whether the rail itself also had a bearing on the chairs. In order to ensure the necessary bearing, the fishplates had to be manufactured slightly deeper than the rail, so that in the first instance the rail was raised above the chair seating. That gap might soon disappear by the wear of the underside of the fishplate on the chair, but the bearing of the fishplate was established, even when the rail had taken a normal bearing, and the value of the fishplate as a girder was in no way impaired. The joint chairs or base plates were made of sufficient width to accommodate the fishplates.

The joint assembly formed a compound girder between the two joint sleepers, consisting of the fishplates acting as a girder and the rail ends acting as cantilevers resting on the top of the fishplates, thus producing a strong elastic girder without causing an undesirable high local rigidity or an attempted high moment of inertia at the joint. For want of a better term, it might be described as a " flexible " or " working " joint rather than as a " static " or " rigid " joint. The fishplates were so designed that, when working in conjunction with the rail ends as cantilevers, the strength of the joint assembly was equivalent to the strength of the rail.

Two other features of the joint were significant. First, the tightening of the fishing bolts did not increase the pressure on the surfaces which supported the vertical live load and, since the intensity of pressure on those surfaces was due to the live load, no galling should occur, or had yet occurred on them. The necessity for the use of taper shims should, therefore, be entirely eliminated for the full life of the joint. Secondly, especially in the case of bull-headed rails, the efficiency of the joint was not entirely dependent upon the tightness of the fishing bolts, since the fishplates were securely held in position against the rail by means of the cheeks of the joint chairs.

The results of Mr. Leigh's experiments had made it clear that the stresses and strains in the girder-type fishplate were much less than those in the standard-type fishplates. That seemed to be of considerable importance in view of Mr. Sims's remarks in paragraph iii, p. 5, *ante*. The relative strain characteristics appeared to be :—

Standard-type fishplate : from −3·83 units to + 5·83 units, a total of 9·66 units.

Girder-type fishplate : −1·87 unit to + 5·5 units, a total of 7·37 units.

Furthermore, the depth of the girder-type fishplate was not limited to the distance between the underside of the head and the upper surface of the base of the rail, which allowed a higher value of I_{xx} for the fishplate, with consequent increase in the ratio : $\frac{I_{xx} \text{ of two fishplates}}{I_{xx} \text{ of rail}}$, referred to by Mr. Swinnerton as 30·7 per cent. (p. 43, *ante*).

The girder-type fishplates for bull-headed rails provided two rail bearings, the underside of the rail head and web of the rail bearing on the upper edge of the fishplate, and the side of the lower rail head bearing on the lower edge of the fishplate ; there was thus a " foot-free " fishplate, an interesting feature in view of Mr. Sims's remarks on pp. 15 and 16, *ante*.

The use of the girder-type plate avoided the possibility of over-stiffening the joint and so causing rail-end damage.

The satisfactory results already recorded, and with maintenance costs of standard joints (quoted by Mr. Swinnerton as high as 25 per cent. of total time), suggested that further experimental tests might profitably be carried out with the girder-type plate.

Mr. Sims, in reply, said that Indian practice was a combination of a free rail and a rail tightly held to the sleepers. The same rail length contained both the ordinary steel bearing-plate with the dog spike and an " anchor plate ", which had a tapered steel key holding the plate to the rail, the plate being held to the sleeper by separate round spikes.

Mr. Gelson had referred to resonance at sleeper spacing frequency ; Mr. Sims hoped that his research work and conclusions regarding that would be published and that his great interest in that type of work would continue. With regard to the cast-iron sleeper, the steel trough sleeper with loose jaws and keys was considered to be superior in service ; it had the same features of resistance to lateral and longitudinal movement and rail seating advantages.

Since the wireless announcement had given no technical information, he had been very interested in Mr. Taylor Thompson's illustration of the new rail section. One feature of the new design struck him immediately, namely, that the height of the rail was shown as $6\frac{1}{4}$ inches to a width of base of $5\frac{1}{2}$ inches, a ratio of 1·136 to 1, which was rather a reduction on what would be adopted in India. Design in India was not really founded on the strength of the rail. It was to some extent based on the weight, and represented the most economical distribution of the metal available, producing a particular form of rail section to which theoretical considerations were afterwards applied to ascertain whether a locomotive could run on it at maximum speed. It was not true to say that the design had been based on a bending-moment calculation. A range of British Standard designs, varying by 5 lb. per yard, had always been available, from which a selection according to strength required could be made; the 90R rails and fishplates were being re-designed in India to obtain a better distribution of the same amount of metal for the rail section. Mr. Sims now advocated a range of rails with larger intermediate steps.

There was another point which he would like to mention with regard to the design of the new 109-lb. rail. He noticed that the top and bottom fishing angles were 2·75 to 1; that was a steeper angle than had been usual in India or, as far as he knew, in England, and he wondered whether practical tests of the rail would be carried out before it was adopted as standard.

The method of determining the height of the new 109-lb. rail appeared to assume a somewhat arbitrary figure for the bending moment, with little reference to the rail itself and to dimensions and loading characteristics of locomotives. The greater disadvantage of the reduced height of the new rail lay, in his opinion, in the relatively larger reduction in the height of the fishplates and the design for those appeared to have reverted to a more rectangular form, rather than towards an I-section, as much as possible, particularly for the 98-lb. rail. With regard to the strength of the joint being equal to that of plain track, that might be true in so far as deflexion was concerned, with close sleeper spacing, but Mr. Sims feared that extremely high stresses would be found to occur in the new fishplates. Punched holes in the fishplates for ribbed fishbolts always had the effect, in India, of forming small ridges on the fishing planes, with disadvantages in regard to fit; Mr. Swinnerton's recommendation for drilled holes was strongly endorsed. The double-angle foot of the rail would not be suitable for Indian conditions, because the standard over-riding type of switch was planed in one stage to bear directly on the foot of the stock-rail.

Mr. Dunton had referred to the possibility of lateral bending stresses rising as high as 8 tons per square inch, and being higher with a flat-footed rail than with a bull-headed rail; that had been taken care of by the margin between 14 tons and 23·4 tons per square inch. The lateral stresses in flat-footed rails were of great importance, as mentioned by Mr. Dunton; the high figures indicated the necessity for the maintenance of a full boxing section of ballast to prevent lateral sleeper movement.

Mr. Dean had stated that maintenance considerations caused the change-over in Britain from bull-headed track to flat-footed track. In India the main consideration had been the greater strength of the rail which could be obtained from a flat-footed section, but the question of finance also came into it. In Mr. Sims's own experience, money could be spent much more economically on flat-footed rails.

With regard to Mr. Loach's remarks, it was not intended to add that 6 tons per square inch to the compressive stress in the head of the rail, but only to the tensile stress in the foot of the rail. The correct relative plus and minus signs for the tensile and compressive stresses in the rail-foot due to twisting and bending, on account of the lateral load, were given almost at the end of the Appendix to Mr. Sims's Paper.

With regard to the third method mentioned by Mr. Loach, the bending moment was dependent on the particular rail in the track, the loading of the locomotive on the track, and the elastic modulus of the track; it would be necessary to have the new rail in use in order to obtain the required figure. The method recommended by Mr. Sims gave a reasonable estimate of the bending moment for any loading and rail section, provided that an average figure for the elastic modulus of the track was available from experimental determination, as had been done on the North-Western Railway of India. Mr. Loach's extensometer records would be of great interest to Mr. Gelson.

Mr. Sims had not gathered from Mr. Leigh's description of special joints the precise purpose for which the joint was designed, apart from spanning the joint sleepers, and he would like to know more about the technical claims for such joints. Those joints required special sleeper chairs, which meant more track fittings. Reversal of stress did occur in both rail and fishplate between axles where the track, instead of bending down under the axle, bent up between the axles, causing tension in the head of the rail and compression in the foot of the rail.

The important test for any pair of fishplates lay in the measurement of the stresses in the plates and whether those were within the elastic limit for the material.

It had been hoped that the discussion would bring out more information regarding the properties and behaviour of heat-treated fishplates, because in that direction lay an obvious channel for advancement in the selection of better material for fishplate steel.

Mr. Swinnerton, in reply, mentioned that the 1-in-2·75 fishing angle in the 109-lb. rail was the same as in the bull-headed 95-lb. rail, so that the necessary experience was available.

Mr. Gelson had referred to rails cambered up at the end; the L.M.S. Research department had carried out some experiments on rail joints packed hard, but the stresses in the rail ends and fishplates increased to such an extent that the practice was dropped, which rather contradicted Mr. Gelson's experience.

Mr. Dunton had referred to the maintenance figures given in Mr. Swinnerton's Paper and had suggested removing part of the difficulty by using welded rails. In addition to the logs kept by the length gangs to obtain maintenance statistics, lengths of track with bull-headed rail had been selected and brought up to standard maintenance for purposes of comparison. It was found that the bull-headed track always needed maintenance work before flat-bottomed track, particularly where there was a poor formation. In some cases the flat-bottomed track went for two years without any maintenance work other than routine inspection and tightening of fish-bolts, and in many other cases it went from 12 to 18 months, whereas the bull-headed track required maintaining three or four times during the same period.

MADE AND PRINTED IN GREAT BRITAIN BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.