

Mr. Wood. sleepers would have increased stability as shown in Fig. 29. There would be no outside disturbance, but a far better sleeper, and a far better road. With regard to packing, he would not say that a flat plate or a flat wooden sleeper might not be more easily packed than the hollow pot or wrought-iron sleeper, but unquestionably when once the iron sleepers were packed they held their position in the ballast better. The plate-layers on the North Eastern line had told him that they did not require the packing that wooden sleepers did; whilst the saving of cost in relaying or laying a new line was considerable.

### Correspondence.

Mr. Boucher. Mr. A. BOUCHER stated that trial had been made on the Northern of France Railway, some twelve years ago, of five thousand Vautherin sleepers, but the experiment had been abandoned. Beyond the question of price, which need not be alluded to, the system presented certain practical defects. In the first place the sleepers took little grip of the gravel ballast, doubtless from their being open ended. The mode of securing the rail to the sleeper left much to be desired, and needed the employment of too many parts to keep it in good order. Finally it was proved by a case of a train leaving the line that these iron sleepers greatly aggravated the consequences of an accident by increasing the time it took to put the track in order again. In an accident that occurred in October 1867, the wheels of the carriages which left the line destroyed all the iron sleepers which they touched; this would not have happened had the sleepers been of wood.

Mr. Cudworth. Mr. W. CUDWORTH observed that a length of 2 miles the Author's pattern of sleeper had been laid on the mineral lines of the North Eastern Railway for two-and-a-half years; but they were not doing well owing to faults in construction, which might, however, be remedied. Many of them had cracked in the bottom flanges immediately underneath the rails. The clips which held the rails were wearing rapidly where they had projections bearing against the underside of the sleepers, but these projections had been too small at first. The iron sleepers took a good deal more packing than wooden sleepers, as the consolidated ballast within the sleeper had to be broken up. In other respects the sleepers answered very well. They were easy to travel over, and the keys were kept well in place by the clips.

Mr. Demoly. Mr. A. DEMOLY contributed, through Mr. Suquet, Traffic Manager of the Algerian lines of the Paris, Lyons, and Mediterranean Rail-

way Company, some particulars of the Vautherin sleepers used in Mr. Demoly's Algeria, between Algiers and Oran.

In 1867 and 1868 the Paris, Lyons and Mediterranean Company obtained from the Fraisans Works one hundred thousand iron sleepers of the Vautherin type. Of these ninety-five thousand were laid, namely in 1867, twenty thousand between Relizane and Perregaux; in 1868, eighteen thousand between Blidah and El Afroun; and in 1869, fifty-seven thousand between Oued-Sly and les Salines. On the last-named section these Vautherin sleepers had worn very well, and had given satisfactory results. The same applied to their use on the other sections as far as regarded straight lengths, but in curves the fastenings had given much trouble. The rails had a tendency to overturn outwards, and the gauge easily spread, which necessitated the renewal of the sleepers, and entailed greater maintenance than in other parts. The total number of sleepers renewed from the opening of the three sections of line above mentioned to the end of 1881 had been only two thousand one hundred and thirty-eight, or  $2\frac{1}{4}$  per cent., an average of thirteen years of service. The cause of replacement was generally enlarged bolt-holes, with fissures at the points of contact of the fastenings, and occasionally pronounced cracks at the angles of the sleeper, leading to its deformation.

Among the advantages of the iron sleeper were the following: when coated with coal tar before being laid down, it was not liable to become oxidised; its good resistance to passing weights when supported by proper ballast; the retention of its original shape; and durability when laid under suitable conditions of road-bed and ballast. It was already manifest that on lines of small traffic the iron sleepers lasted twice as long as the best wooden ones, and probably that advantage would be increased. Lastly, they cost little for repairs, in this respect showing an economy of from 30 to 50 per cent. as against wood.

On the other hand they had certain disadvantages. Owing to their skeleton character, they were not adapted to resist lateral movements, which rendered their use impracticable in curves of less than 1,600-foot radius, and defective in larger curves even up to 4,000-foot radius (1,200 metres). For the same reason the system was unsuitable on high embankments, where the incessant vibration tended to shift the ballast from its contact with the under part of the sleeper, and it could only be employed on embankments of small height and perfectly consolidated. But its greatest fault was the unstable nature of the fastenings; the keys worked loose continually; driven home again, they enlarged the holes, and eventually gave way. The inner clips did

Mr. Demoly, not secure the foot of the rail firmly enough, and the outer ones easily worked loose and overturned; both indented the sleeper by their friction, and finally cracked it. To sum up, the Vautherin sleeper, good in itself, was destroyed by its fastenings.

A metallic sleeper which Mr. Demoly had designed to fulfil the requirements of traffic in such countries as Algeria, was of iron, of trapezoidal section, with strengthened table, and bent to give the proper inclination to the rail. The attachments were of the simplest, and consisted merely of two clips holding the rail to the sleeper, and two stop-bolts, not threaded, to maintain the tightness of the clips, and allowing, by means of an eccentric washer, of the correct adjustment of the gauge. The saddle-piece of the old system of sleeper, which increased the cost and prevented the use of symmetrical attachments, was suppressed by reason of the inclination of  $\frac{1}{20}$  given to each end of the sleeper itself. The additional strength afforded by the cushion of the old type was compensated by an increase of from  $\frac{1}{4}$  to  $\frac{1}{3}$  of an inch to the thickness of the table of the sleeper, which was thus made of sufficient strength to bear the vibration of the rail and fastenings. At the same time the upper part of the inclined walls of the sleeper was similarly strengthened, to resist the tendency to crack at the angles. The additional thickness thus given allowed of the sleeper being bent as above stated, which otherwise would not be admissible. The Belgian sleepers of ordinary section, bent in the way indicated, without being strengthened, were objectionable. With some other modifications found practicable without loss of solidity, the new sleeper weighed, like its predecessor, 14 kilogrammes per metre ( $28\frac{1}{2}$  lbs. per yard). Mr. Demoly submitted that this system presented many advantages. The gageward fastening of the rail was exactly similar to its outward attachment, a clip, a plain stop-bolt, a spike giving a progressive squeeze, and fixed by means of the eccentric keyed washer. This mode of fastening gave at once all the results sought in his modification of the Vautherin fastenings. The clip adhered to the side of the rail-foot, and prevented its lateral movement; it also overlapped the rail-foot, thus resisting any shifting of the axis of the rail. In both cases intermittent efforts were transformed into continuous frictionless pressure, above all, without hammering or vibration, consequently the sleeper was not damaged. By the double resistance offered from above and below the sleeper to the overturning of the rail, this tendency was diffused and diminished at the same time that it increased the holding power of the fastenings. Mr. Demoly's system also avoided the inconvenience arising from screw-bolts when embedded in ballast, his fastenings being all plain, and deriving their holding

power from the successive helical development of the eccentric washer. An experience of thirteen years had shown that the wear of the fastenings did not affect the sleeper; its only effect was to induce spreading of the gauge. Therefore the advantage would at once be manifest of a system which, by automatically tightening the fastenings at the proper time, prevented the wear alluded to, and thus avoided a source of danger without requiring the frequent provision of new material. His system possessed this merit, and it was certainly not its least one.

Distinct from the question of efficient working was that of difficult replacement of parts. For instance, in the old system the removal of a cushion involved the unfastening of three sleepers and the flexure of the rail, and when the ballast was hard, as frequently was the case, the operation was tedious and difficult. In the new system the clips were easily put in and taken out, and each being independent of its fellows, and not requiring other attachments, the inconveniences alluded to did not exist. Finally, the fastenings being symmetrical, possessed two important economical advantages, viz., the ability to obtain large numbers of two or three forms at a lower price than when many different pieces built up the fastening. Also when in service the outward clip had generally the greater wear, which mostly took place at the neck, without much affecting the head. The gaugeward clip, on the other hand, did little work and lasted long; it was therefore possible to change one for the other, and thus entirely save the provision of one part. Recently Mr. Demoly had devised a new fastening which, though identical in principle, was more simple, and obviated some inconveniences in the manufacture of the earlier fastenings. This improvement reduced the pieces to two, a clip and a cotter, the latter driven in like the spike formerly used for wooden sleepers. It exerted great pressure, and kept the rail so tight, that it might be adopted on lines of the heaviest traffic.

Mr. H. ELWORTH, Engineer-in-chief of the Swedish Government Railways, remarked that so long as wooden sleepers could be bought at 1s. 4d. each, the present average price in Sweden, iron permanent way was not likely to come into use in that country; this could scarcely happen until the price of wooden sleepers rose 50 per cent.

Mr. FRANCIS FOX, of Bristol, remarked that the best and most satisfactory of the sections of Macdonnell's, or rather Adams's, system had not been given in Figs. 3 and 4. It was the one with the rib beneath, shown by Fig. 4 in his Paper of 1861.<sup>1</sup> This

<sup>1</sup> *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 268.

Mr. Fox. form proved much stiffer than the sections previously adopted; and the joints of the bearers were also fished with angle-iron fish-plates, and the rail-joints were stiffened by the tee-plates shown in the diagram. This system had been but a short time on trial when his Paper was written, but if he had extended the length of iron permanent way, it was the one which, with some slight modifications, he would have adopted. Its invention was claimed by Mr. W. B. Adams, and a royalty on it was paid to him. He believed that a length of Vignoles rails was laid experimentally upon this section of bearer, the rail joints being fished, in place of the joint plates with middle web (which would obviously be inadmissible). If this were so, the system, with the addition of the pine packing, would, in his opinion, have some advantages over Hilf's.

Mr. Hammett's statement of the present condition of the Macdonnell iron way was of course entitled to more consideration than his own views. He could not, however, fully agree with the strongly unfavourable opinion of the iron way expressed by Mr. Hammett. The Bristol and Exeter Railway, upon which it was laid, was under his charge up to the early part of 1876, and he did not recollect any considerable number of cases of breakage of sleepers during the fifteen to twenty years of trial. The tendency of the nuts to work loose was, however, a serious defect. He tried double nuts, and employed various other contrivances, without much result. Another defect was that the heads of the bolts, underneath the bearers, wore the latter into hollows, and that caused an unsteadiness of the hold of the bolts. The resilience of the wooden packing, when first laid, tended to keep the bolts tight, but after it had become compressed by the traffic, this ceased to be the case. The bolts of the De Bergue system (an experimental length of which was laid on the Bristol and Exeter Railway) where the rails rested directly upon the cast-iron oblong bearing plates, did not work loose. This might have arisen from the fact that the bolts held down clips, which bore upon the flange of the Vignoles rail used. The Author was not quite correct in supposing that he considered broken stone ballast preferable to cinder or gravel for this kind of permanent way. He used the cinder ballast because he thought it less likely to crook the bearers than the rougher and coarser material of broken stone. Mr. Hammett, however, had found that broken stone made a better ballast than cinder, even for the iron way. No doubt it was a severe test of the iron way to turn the broad into a mixed gauge permanent way; and if the mixed gauge were likely to be extended, or permanent, it would be a strong argument in favour of transverse sleepers, whether of iron or timber, both as regarded

efficiency and cost. He agreed with the Author that the corrosion of the iron bearers, which appeared to have taken place more rapidly during the last five or six years than previously (or else possibly it had not been carefully noted earlier), was due to a large extent to the cinder or clinker ballast. It was always found that the parts of fang bolts buried in the clinker ballast, corroded rapidly. There appeared no reason why the Macdonnell bearer should corrode in ordinary ballast more than the Barlow rail, and some of that had been laid for more than thirty years and was in good or fair condition now. He had never been, in the smallest degree, pecuniarily interested in the success of the Macdonnell iron way. He laid it as an experiment, from a conviction that it was highly desirable to find a durable substitute for the perishable timber rail-bearers in general use. He did not, however, consider it expedient to lay an additional length of iron way subsequent to 1860, partly from the difficulty experienced in getting manufacturers to roll the section of sleeper to which he had referred, at a moderate price, and partly because he felt that only a long and careful trial would determine the relative merits of iron and timber permanent way. With all its admitted defects, the fact remained that the different sections of Macdonnell way had been in use on the Bristol and Exeter line for a period of between twenty-one and twenty-eight years; that some of the fastest express trains in the world ran daily over it, and that the Great Western Railway Company, to whom the line had belonged since the end of 1875, had not found it necessary to remove it and replace it with a timber road.

Mr. A. GARET gave the following particulars of the trials of iron permanent way on the Paris, Lyons, and Mediterranean Railway: Four types were employed, viz. Ménans', PLM,A, PLM,B, and Brunon's. They were all adapted to the Vignoles rail. Mr. Garett.

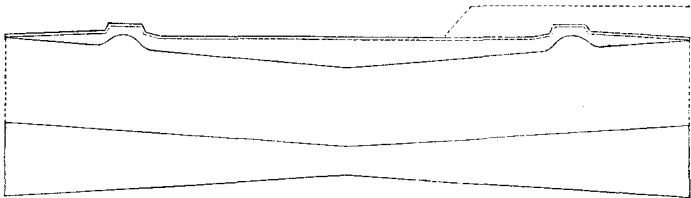
A length of 800 metres of Ménans' sleepers, single track, which was similar in most respects to PLM,A, was laid on the line from Besançon to Bourg, six months before its opening on the 1st of August, 1864. These sleepers, situated between the Byans and Torpes stations, were taken up in September, 1872.

Two lengths of PLM,A were laid in the latter months of 1866 and the beginning of 1867 on the line from Paris to Dijon. The first was 2,000 metres of single line on track 2 between Maison Alfort and Villeneuve St. Georges. It was taken out between the 1st of January and the 31st of May, 1870, on the occasion of substituting steel for iron rails. The second length, 1,500 metres, was double track between Malain and Velars stations. It was

Mr. Garet. removed, under similar circumstances, between February and May, 1869; 3,000 metres of PLM,B (single line) were laid on the Grasse branch when under construction, between the stations of Monans Sartoux, and Grasse. This little branch was opened 13th November, 1871, and the iron sleepers were removed towards the end of 1872.

Of Brunon's sleepers (Fig. 47), five hundred, viz. one hundred and seventy-two of steel and three hundred and twenty-eight of iron, were laid on the main track at the Rive de Gier station in August, 1877. Of the steel sleepers forty-eight were transferred to track 1 of the line from St. Etienne to Lyons, between Rive de Gier and Lorette, in January, 1878; sixteen other sleepers

FIG. 47.

Scale  $\frac{1}{32}$ .

were laid in May, 1878, on track 2 of the line, from Paris to Lyons, near the bridge across the fortifications of Paris. The weights and prices of these different types were :—

	Joint-sleepers.		Counter-joint Sleepers.		Intermediates.	
	Weight.	Price.	Weight.	Price.	Weight.	Price.
	Kilog.	F. C.	Kilog.	F. C.	Kilog.	F. C.
Ménans' sleeper . .	..	14 00	..	10 60	..	10 50
PLM,A " . .	54·38	14 00	40·80	10 60	40·54	10 50
PLM,B " . .	47·14	12 81	36·88	9 75	36·04	9 75
Brunon's " (steel)	..	..	..	..	32·00	10 00

The Ménans' sleepers laid between Byans and Torpes underwent several modifications, bearing chiefly on the form of the saddle riveted to the sleepers and the mode of attaching the rail to the saddle. In the result they very nearly accorded with the type PLM,A, except that they never had angle-irons riveted underneath as in the latter. These sleepers did not give bad results at first. They bedded easily either on broken stone or sand and gave a very smooth road, less noisy than the ordinary one on wooden sleepers. It was above all remarked that the ballast got perfectly

moulded to the interior shape of the sleeper, so as to form part of Mr. Garet. the sleeper, and that the solidity of the track got so much the more augmented. But it was soon found that the fastenings were defective. The bolts, which seemed to hold well at first, became unscrewed, and it was never after possible to tighten them up in a satisfactory way in spite of all the efforts made. Nevertheless on a line so little worked as that between Besançon and Bourg, which only had four or five trains a day, and at low speed, these sleepers were able to remain eight years in track. Apart from the frequent tightening up they exacted no more attention than those of wood; but the renewal of a single sleeper was always more difficult. In such case it was necessary to draw the bolts of the two neighbouring sleepers and force the rail with the crowbar to free the latter from the saddle. In 1872 many of these sleepers were in a bad state. The holes pierced in the saddle and the sleeper enlarged, the cotters were no longer kept fast without the addition of wedges which themselves held with difficulty. For these reasons all these sleepers were taken out and sold as scrap.

The cross sleepers of the type PLM,A (Fig. 48, section at joint, Fig. 49, intermediate section), were laid on the line from

FIG. 48.

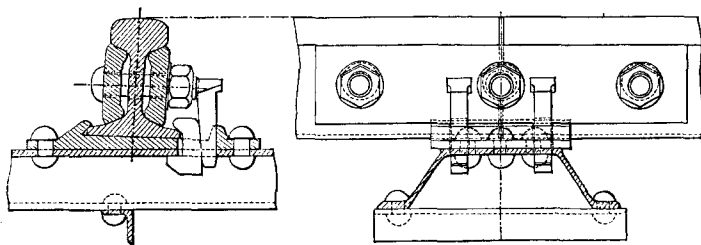
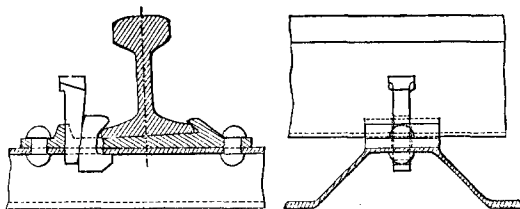


FIG. 49.



Paris to Dijon, and revealed, very shortly after laying, defects even more serious than the loosening of the fastenings. They split at the upper angles of the V irons to the right of the rivets holding the saddle, and the joint-sleepers, which had angle-irons riveted to

Mr. Garet. the underside, broke right across at this place. Sleepers of type PLM,A being removed, they were replaced by those of type B, which, not having resisted better than the first, remain with them experiments only. The fastenings held much less than in the Besançon and Bourg line, on account of the number and speed of the trains. After less than two years and a half the road got so shattered between Malain and Velars that it was necessary to remove all the sleepers.

Towards this time the wedge and cotter were experimentally replaced in a certain number of sleepers by a clip-and-bolt fastening, as in Fig. 50. Fifty sleepers were so provided on the length between Maison Alfort and Villeneuve St. Georges. This fastening gave much better results, but the breakages did not cease; the holes of the bolts and cotters continued to enlarge, and it became dangerous to let the sleepers remain longer in service, when the substitution of steel for iron rails opportunely put an end to the experiment in the early part of 1870.

A length of 3,000 metres of type PLM,B, laid on the Grasse branch, was furnished partly with clip and cotter fastenings and partly with bolts and washers. In the first case a great many broken cotters were found, in the second virtually none. It was attributed to excess of grip, which was more readily occasioned with wedges driven by blows of a hammer than with the screwing up of bolts. It was necessary to renew a large number of fittings; so, under the fear of absolute failure, the sleepers PLM,B were removed towards the end of 1872.

The simplicity and at the same time the solidity of the fastenings in the Brunon sleeper (Fig. 51) led to some further experiments on

Fig. 50.

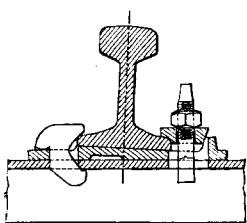
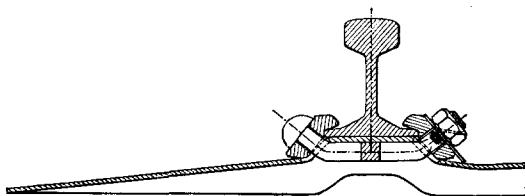


FIG. 51.



a small scale. In this case defects were no longer manifested in the fastenings, but there were other faults. The three hundred and twenty-eight iron sleepers had nearly all disappeared in February,

1878, on account of cross-fractures outside the rail seat. The Mr. Garcet. one hundred and seventy-two steel sleepers were distributed as follows: forty-eight on the main line and one hundred and twenty-four on a siding having very heavy traffic at the Rive de Gier station. Of the former, eight were broken in September, 1878, and of the latter scarcely one remained in good condition.

As regarded the sixteen sleepers laid near Paris, they had resisted well so far; but it must be mentioned that these sixteen sleepers were very carefully attended to during manufacture, in a way altogether special; eight had been annealed, and eight were besides tempered in oil.

On the whole these trials of iron sleepers did not give sufficiently good results to encourage further experiment. At the present time, moreover, they were of comparatively little interest, seeing the low price at which wooden sleepers could still be obtained. The employment of iron sleepers, in his opinion, was attended also with one very serious drawback: in case of derailment, every sleeper touched by a wheel was at once broken; and in that way hundreds might be broken in succession. From this resulted the almost impossibility of making the track good unless by holding a large surplus of stores. Since the 23rd of December, 1878, when the above information was compiled, no further experiment had been made; but the sixteen steel sleepers, tempered or annealed, had remained in the road, near Paris, until the 12th of November, 1881, under very heavy traffic, and continued to hold out well. It was alleged, however, that they tended to pulverize the ballast (gravel and sand), to form mud quicker, and to require more frequent packing.

Mr. W. HOHENEGGER was of opinion that the Author's imitation Mr. Hohenegger. of the Vautherin sleeper could give no useful result; in it the tendency of this section of sleeper to generate longitudinal cracks was even increased by the form of clip-fastenings. This clip necessitated a large hole in the weakest part of the sleeper, and this greatly diminished its strength. Further, the fastening by a wooden key was inadmissible in a dry climate like that of Austria.

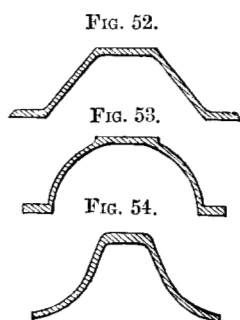
Mr. W. JACOMB stated that his experience of permanent way led Mr. Jacomb. to the conclusion that the simplest was the best and most economical. On the South-Western Railway one uniform arrangement had been adopted.

The rails were of steel, double-headed, weighing 82 lbs. per lineal yard. The chairs had a width at the base of  $6\frac{1}{4}$  inches; their weight was 40 lbs. each, and they were attached to rectangular creosoted sleepers with three combined fastenings of spikes and

Mr. Jacomb. compressed hollow oaken trenails. The keys, 6 inches in length of compressed oak, were secured in the chair by a simple contrivance, a cut nail being driven into a vertical slot which was cast in the jaw of the chair. The rails were turned a good while before they got chair-worn.

Mr. Ledru. Mr. C. LEDRU, Chief Mechanical Engineer of the Eastern Railway of France, submitted the annexed report of Mr. Guillaume, presented to that company in May, 1877, on the results of experiments with metallic permanent way of various systems. The negative results so obtained accorded perfectly with the experience of the Belgian State Railway Company recently made public, which was that for lines of heavy traffic, or with heavy gradients and sharp curves, tracks with iron sleepers on the Hilf system were difficult to maintain, and much more costly than the ordinary wooden sleeper system. For the present the Eastern Company had abandoned all idea of further experiment in the same direction.

In this report it was stated that the trials of iron cross sleepers went back as far as 1865, when ninety-nine sleepers from the Fraisans Works and forty-eight from the Hayange Forge were laid in track II., kilometre 23, of the Mülhausen line. Forty-eight of the Hayange sleepers were laid at the same time in track I. between kilometres 6 and 7 of the Strasburg line. Finally, two thousand and ninety-eight additional sleepers of the Hayange type were laid in 1868 between kilometres 19 and 21, track II. of the Strasburg line. The Fraisans sleepers were of two types, and comprised—



1. Fifteen joint, and forty-four intermediate sleepers of trapezoidal section (Fig. 52).

2. Forty intermediate sleepers of half-round (Zorès) section (Fig. 53); these were laid with joint-sleepers of oak.

The sleepers of the latter type all broke under the rails; their average life did not exceed six years and two months. The trapezoidal sleepers resisted better; nevertheless at the end of 1873, eight years after laying, out of fifty-nine, thirty-seven had been replaced, ten of which had split longitudinally. In consequence of the results, the trial of these types was not continued. The Hayange sleepers (Fig. 54), were laid as intermediates between joint-sleepers of oak, with the exception of two short lengths of 120 metres, laid, one with iron joint-sleepers, and the other with

suspended fish-joints. At these two places the joint-sleepers, or Mr. Ledru those nearest a joint, were notched to receive small wedges destined to prevent the longitudinal creep of the rails.

All these Hayange sleepers had perfectly served to the present time, *i.e.*, twelve and nine years respectively, with the exception of those furnished with stop wedges and employed as joint-sleepers; seventeen out of twenty of these were taken out after eight years' wear, broken at the wedge notch. But they needed great attention. Since the second half of 1874, namely in 1877, for two and a half years, exact record had been kept of the state of the Strasburg line, and it had thus been possible to compare track II., furnished with iron cross sleepers, with track I., having wooden sleepers. The following was the total cost of labour for maintenance (not including the cost of new rails), taking the cost of wooden sleepers in track I. as unity.

1st trial (1865), 48 metres of track on intermediate sleepers of iron and wooden joint-sleepers between kilometres 6·600 and 6·648, track I. . . . .	} 1·53
2nd trial (1868), 120 metres of track on iron sleepers, joint and intermediate between kilometres 19·002 and 19·122, track II. . . . .	
3rd trial (1868), 120 metres of track on iron sleepers with suspended fished joints, between kilometres 19·122 and 19·242, track II. . . . .	} 1·82
4th trial (1868), 1,753 metres of track on iron intermediate sleepers with wooden joint sleepers, between kilometres 19·242 and 21·000, track II. . . . .	

The last trial was the most conclusive, owing to the greater length. The annual averages for labour reached, per kilometre—

For intermediate sleepers of iron with joint-sleepers of wood . . . . .	} 255·98	Days.
For wooden sleepers . . . . .		167·34
Difference in favour of wooden sleepers, per kilometre per annum . . . . .	} 88·64	

or, taking the price for the working day at 3 francs 50 centimes, a difference of 310 francs 24 centimes per kilometre.

The iron sleepers lacked stability; they required frequent packing; after heavy rains the water got inside the sleeper and dislodged the ballast, which thus failed to provide a permanent support against the sleeper. Nevertheless the trials were made under favourable conditions for the formation of such support, and it was probable that with broken stone ballast the gap in the sleeper would be still more difficult to fill up.

Mr. Ledru. Much attention had been devoted to the mode of fastening the rail to the sleeper. It was inferred that the sole difficulty lay here, and that success depended upon this alone. The trials on the Northern, the Paris and Lyons, and the Eastern railways, showed that this difficulty was not important; in particular the clip and cotter fastening of the Fraisans sleeper gave good results. The Hayange fastening, consisting of a frog kept tight by a bolt, was less successful; at first the nuts got unscrewed, and the frogs were displaced by the vibration; but tightening the nuts only demanded trifling attention, and afterwards the working loose was stopped by notching the thread of the bolt.

In 1862 Mr. Barroux, chief engineer, laid on the Bar-sur-Seine line, near Troyes, 120 metres of Vignoles rails on longitudinal sleepers of flat iron, 9·8 inches broad and 0·39 inch thick, connected at every 10 feet (3 metres) by angle-iron ties, furnished at mid-length with wingpieces forming stops (*arrêts de ripage*). This track, laid on excellent ballast and on a solid subsoil, and having to support only a small traffic at low speed, answered fairly well, but cost notably more for maintenance than the cross-sleeper road. The joints of the rails were especially difficult to keep in order, although they broke joint with those of the sleepers, which latter offered but slight resistance to bending. Also this line becoming part of the principal line to Mülhausen, Mr. Barroux judged that it would be difficult to maintain the longitudinal sleepers, and authorised their replacement by the ordinary track.

Hartwich's system, so enticing at first view by reason of its simplicity and low price, was the subject of a trial followed with close attention from April 1869. A length of 1,200 metres of single track was laid on the Mülhausen line between kilometres 312·900 and 314·000, of which 420 metres were in a cutting, the road bed of which was clayey, wet, and of little consistence, and 780 metres on embankment formed of excavation from the cutting. The ballast was broken stone mixed with earth and clay. There was a gradient of 1 in 166 for 890 metres, and a curve of 3,280-foot radius for 310 metres. Ten trains passed daily. This track always showed great instability.

In the cutting, the pressure on the rails formed ruts in the road-bed, which changed from side to side. Numerous lateral deformations arose in spite of the precautions taken never to lay bare the middle of the track. It was endeavoured to remedy this by draining the road-bed, covering it with a mattress, and renewing the ballast. Further, some of the round rods not being strong enough to maintain the cant of the rail, were replaced by

rigid ties, and sole-plates were laid under the joints to remedy the Mr. Ledru. subsidence which there was more pronounced.

But notwithstanding the improvement thus produced, the Hartwich track always necessitated much more labour than the P. M. fished track between which it was introduced, and which was subject to the same conditions. At the end of the first half of 1876, for a period of one hundred and six months (allowing for the six months' interruption caused by the war), the average monthly cost for labour of the Hartwich track was 186 fr. 41 c., and of the P. M. fished track 92 fr. 7 c. In presence of these figures it need only be said that the Hartwich track must be definitively rejected; this was indeed the result arrived at in Germany.

The Hilf track had not been tried on the Eastern of France Railway; but the results of Messrs. Petsche and Bruniquel's trials in Alsace and Lorraine might be summed up in the following extracts from the report of Mr. Bruniquel, dated the 14th of November, 1876 :—

“ Although the opinions of the German engineers are generally favourable to the new (Hilf) system, the following faults are alleged against it :—

“ 1. The sleepers, even on slight gradients, get displaced longitudinally.

“ 2. The rails slide on the sleepers.

“ Finally, as the sleeper is only buried  $2\frac{1}{2}$  inches, it is feared that frost and thaw have great influence on the track, and one is led to think that to obviate this recourse must be had to broken stone ballast.”

\* \* \* \* \*

“ It has not been possible to obtain exact information as to the cost of maintenance of the Hilf track. Indeed, its application in Alsace-Lorraine is too recent for the repairs to the present time affording a fair criterion of the average cost of maintenance. All that can be said is that labour does not appear to have been spared.”

Mr. Petsche, among other comments added to the report of Mr. Bruniquel, said :—

“ The laying of the permanent way is far from being done with all the care necessary. I have seen tracks laid only a few months which showed rises and sinuosities never noticed on our lines when arrived at their normal condition.”

The foregoing showed clearly that the Hilf system lacked stability. Laid, so to speak, on the surface of the ballast, it was exposed to all the atmospheric influences. The gauge of the rails

Mr. Ledru. was only maintained by feeble ties of rod-iron, which did not resist the slightest derailment, and which were otherwise powerless to preserve the proper cant of the rails, so necessary for the steadiness of the rolling stock.

The cost of the Hilf track was very high. The weight of the longitudinals, ties, fastenings, &c., reached 134 lbs. per yard. It was true that the weight of the rails was reduced to 58 lbs. per yard; but these rails, of steel, had weak heads, which would not stand, as did 66-lb. rails, a wear of  $\frac{1}{3}$  to  $\frac{1}{2}$  inch. The sum of which was that the Hilf system, of which the German engineers were so enamoured, would have a similar fate to that of Hartwich, heralded at first with an enthusiasm quite as general, and at present completely abandoned.

Mr. Mangini. Mr. MANGINI, Engineer of the Dombes and South-Eastern Railway of France, had used for the last twelve years on that line blocks of hard close-grained limestone for supporting the rails, and with excellent results. Various modes were employed: one consisted in placing ordinary sleepers under the joints of the rails, blocks forming the intermediate supports; another alternated a stone block with a sleeper. All these systems gave satisfaction; but experience was in favour of the combination indicated by S S B S B S B S S (two sleepers for the rail-joint, then a block and sleeper alternately to the next joint). This necessitated six hundred and twenty-five sleepers and seven hundred and fifty blocks per kilometre of single line (one thousand and twelve hundred and fifty per mile respectively). The rails were steel of Vignoles section, 8 metres ( $26\frac{1}{4}$  feet) long, and weighed 60 lbs. per yard. The dimensions of the blocks were 50 centimetres by 50 centimetres and 25 centimetres deep (say, 20 inches by 20 inches by 10 inches). The rails were spiked to oak plugs inserted in holes  $1\frac{1}{2}$  inch in diameter sunk in the block. It was necessary to use dog-spikes instead of wooden-screws, the plugs being cut the way of the fibre. The surface of the block on which the rail rested must be perfectly dressed; as in the case of sleepers it was slightly recessed. The proper cant for the rail was given by tilting the block. The cost price was 1f. 50c. to 2f. 10c. per block drilled and plugged. It had been especially noticed that this road opposed more resistance to lateral displacement, owing either to the weight of the blocks or to their large surface. For instance, ordinary steel rails of 60 to 70 lbs. per yard gave stability at least equal to the 80-lb. rails on cross sleepers used for a length of 12 kilometres elsewhere. The limestone being excellent the blocks were in no way deteriorated by a

service of twelve years. Similar blocks made of concrete had been found equally serviceable, but their employment was superfluous, the limestone being cheap and abundant. He now used that sort of permanent way only, and was about to lay it on the line from La Cluse-Nantua to Bellegarde.

Mr. T. E. M. MARSH observed that the subject had received much of his attention, extending back to the earliest attempts to substitute iron for timber, and when he had the special charge of such matters for the late Mr. I. K. Brunel. The combinations of cast iron should not, however, be excluded, as unquestionably ordinary rails and fastenings on cast iron sleepers, or forms known as Livesey's, or De Bergue's and others, were deserving of consideration; for in some cases they superseded the use of wood with marked economy. The efficiency of the fastenings and strength generally of most of the Continental permanent ways referred to by the Author, would, he thought, hardly prove satisfactory on most of the heavily worked high-speed English lines, though they compared advantageously with their own previous construction with dog-nail spike and fastenings on fir sleepers. The iron or steel cross sleeper and fastening, such as the specimen prepared by Mr. Webb, was, he thought, most satisfactory, and it would be desirable to have the results of the trials on the London and North-Western Railway or other first-class lines; and especially to know at what cost the complete sleeper with affixed chair could be purchased in the open market, to contrast it with the best wooden sleepers, with its chairs and fastenings, which had gradually come to be so large a portion of the first cost. The iron sleeper appeared to give good prospect of its advantageous introduction, if the cost came so close to the wooden one with its fastenings. The jaws might of course be varied in form to suit any rail; and he thought possibly some improvement might be made in the three plate surfaces and the riveting connection. The Barlow rail permanent way had been extensively used by the late Mr. Brunel, as the simplest and cheapest form of permanent way, having the required strength for the heavy rolling loads. The faults were chiefly due to the defects at the joints after some wear. There was also another difficulty in the way of continuing the use of these rails on main lines, arising out of the fact that manufacturers did not care to roll them when wanted; and the form of pile used and mode of rolling was unfavourable to the production of good rails such as Mr. Brunel generally obtained. These rails, however, did good service now in sidings, and would long survive, costing little for maintenance. They were also

Mr. Marsh eagerly sought after for bridge decking and platforms, when useless as rails. Now that such sections could be produced of steel as readily as the longitudinal and cross-sleeper forms of bearers, he thought they might be so improved as to render good service for some cases, such as opening up poor countries and colonies where the first cost of other rails capable of carrying heavy loads could not be entertained, and when also simplicity and transport of material were desiderata. He might be considered rash in the notion of resuscitating this form of permanent way, but in steel there was much to recommend it for such cases.

Mr. Mathieu. MR. HENRI MATHIEU, though not quite conversant with what was being done in France relative to metallic sleepers, believed himself justified in saying that their use had hitherto been confined to some short experimental lengths. It was principally urged against them that they provided insufficient attachment to the rail, which was doubtless owing to the small thickness of the material employed.

On the Southern of France Railway, with which he was connected as Engineer-in-Chief, they had never even been tried, and the company had no interest in the question. The Landes, which that line traversed, and also the Pyrenees provided all the pine and oak necessary, and at a price so low that iron sleepers would never be able to compete with them. Thus pine sleepers unprepared cost 1s. 7d. to 1s. 8d. each delivered on the line, and when impregnated with sulphate of copper or with creosote, 2s. 2d. and 2s. 4d. respectively. When in England in 1875, he had been much struck with the stability of the track, which he attributed to its weight. This varied from 230 to 250 kilograms per lineal metre (463 to 504 lbs. per yard), while in France, the greatest weight then attained, did not exceed 200 kilograms per metre. This impressed the manager of the Southern Company, who did not hesitate to follow the example of the English engineers, and at present the track consisted of steel rails 11 metres (36 feet) long, weighing 76 lbs. per lineal metre, of 33-lb. chairs, and sleepers 8·8 feet long by 13 inches wide and 11 inches deep, and weighing (when of creosoted pine) 166 to 220 lbs. each. The weight of such a track was thus about 436 lbs. per lineal yard, and that was not too great. If, instead of wooden sleepers, costing at the outside 2s. 4d. each, iron sleepers were used, the same price would only purchase sleepers weighing from 24 to 26 lbs. (11 or 12 kilograms), while the wooden sleeper attained 220 lbs. In presence of such inferiority it would be imagined that as long as the Landes and the Pyrenees were covered with forests, the

type of permanent way adopted on the Southern of France Railway Mr. Mathieu. would not be altered. Finally, the wooden sleepers were less noisy than tracks entirely of iron.

Mr. ROUGIER, Engineer-in-Chief of the Paris and Orleans Railway, Mr. Rougier. remarked that the French companies had not hitherto concerned themselves much with metallic sleepers, because, apart from engineering considerations, in the French market the price was at present much in favour of wood (his company paid from 3s. 9d. to 4s. 2d. each sleeper). He only knew of the experiments made by the Lyons Company, first with sleepers of *zorcés* iron, and later with Brunon's steel sleepers. The results obtained seemed to indicate but moderate success, and the experiments had not led to the introduction of metallic sleepers for general service. He did not think it possible to obtain the same stability, elasticity, and easy running, from iron sleepers as from those of wood. The experience of the German companies from an extended use of the Vautherin sleeper seemed to put this past dispute. They showed besides that the complication, and the unstable nature of the connection between rail and sleeper, led to excessive cost of maintenance, besides importing risk to security of running.

Mr. C. P. SANDBERG observed that he was familiar with the Mr. Sandberg. systems of iron permanent way laid in Germany. He was inclined to regard the iron permanent way as an evil, which would have to be adopted in the course of time. It wanted elasticity, which would increase the liability to fracture of the rolling stock, and the rails, and the danger of accidents, particularly where the speed was high and climate cold. In the systems hitherto used there was much difficulty in maintaining the gauge, and in fixing the rail to the sleeper. And it was unpleasant travelling for passengers, from the rigidity and noise of the iron roads as compared with rails on wooden sleepers. He thought iron sleepers would supersede wooden ones, owing to the necessity of sparing the forests, for wood was becoming every day dearer, and iron cheaper. With the increased mileage of railways a period might come, under the present system, when all the forests would be consumed. It was well known, too, that as forests were destroyed, the climate was deteriorated, and many countries might in this way become uninhabited. There was much truth in the popular saying in Sweden during a cold winter that "The forest is the poor man's coat." Hence the necessity of not using wood when iron would serve as well.

The present high speed would certainly retard the introduction of iron permanent way on railways in England. Steel, and especially iron, was apt to lose its elasticity in the course of time when

Mr. Sandberg. subjected to incessant strain. There had not been sufficient experience, however, to prove this. It did not exclude the adoption of iron permanent way on lines where the traffic was light and the speed low. It only meant that precaution should be taken, not to introduce it first on main lines, but on branch railways. This had been done on the Continent. On the main line of the Cologne and Minden Railway, where fast expresses were run, the iron permanent way had been much more slowly adopted than on the Rheinische and the Bergisch-Märkisch Railways, where the speed was not so great. Climate had a marked influence on the success or otherwise of iron permanent way. In hot climates the corrosion of wrought iron and steel was great as compared with cast-iron or pot sleepers. Nevertheless, the high cost of wooden sleepers in those countries often rendered the adoption of some sort of iron sleeper essential. A temperate climate was the best, such as that of England and central Europe; for corrosion was not so rapid as in the South, nor was the ground so long frozen as in the North, and this was certainly one of the reasons why German engineers had been comparatively early in the field in introducing iron permanent way.

Happily in countries with cold climate, such as Canada, Russia, and Scandinavia, forests were comparatively plentiful, and hence the economical advantage was seldom so great as to tempt engineers to substitute iron for wood. The last calculation made by the Swedish Government State Railway Department as to the comparative value of iron and wooden sleepers for their roads showed, that even if wooden sleepers should become twice as dear as at present, 1s. each, they would still be more economical; and for safety of traffic they were almost invaluable.

The nature of the soil, the road-bed and ballast affected iron more than wooden sleepers. So far as he knew ordinary ballast or sand had nowhere given satisfaction when used with the former; coarse ballast of stone or slag was absolutely necessary for iron sleepers. Another matter of great importance was the solidity of the road-bed. Hitherto iron sleepers had only been used on old roads where the bed had been already set, during many years of traffic on ordinary sleepers. Sufficient experience had not yet been gained of the behaviour of iron sleepers on newly-constructed ordinary roads; therefore in calculating the comparative cost of sleepers the extra cost of stone ballast should be taken into account. Another difficulty in using iron sleepers in cold climates would follow from the sudden change of level of the sleepers through the freezing of the water when the drainage was imperfect. This,

sometimes in a few hours, would alter the level of the line 6 or 7 Mr. Sandberg. inches, where water poured up in the ballast under the sleeper, and would obviously be much more difficult to remedy than with wooden sleepers.

Mr. H. SCHEFFLER observed that a scheme for a system of iron Mr. Scheffler. permanent way, described in the "Organ für die Fortschritte des Eisenbahnwesens" in 1862, had been carried out on two portions of the busiest part of the Brunswick Railway, each 0·45 mile long, in September, 1864. The construction of the permanent way on these two lengths was shown in Figs. 55 and 56. Different designs were used on each to ascertain the best position for the transverse connections, and the minimum dimensions admissible for the

FIG. 55.

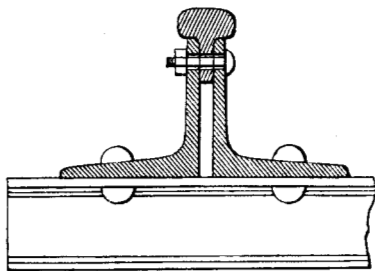
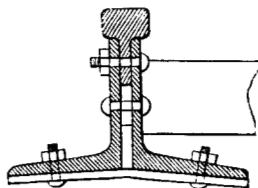


FIG. 56.



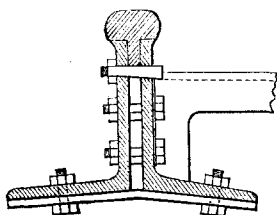
sleepers. Sleepers and transverse ties were connected by rivets, the rails were fastened to the sleepers by bolts at intervals of 1·4 foot. The joints of the rails and sleepers overlapped each other, and those of the latter were strengthened by wrought-iron fish-plates screwed on underneath. The bolt-holes in the latter and in the rails were oval, to allow of any elongation due to differences of temperature. Both portions of line lay side by side, and were straight; one half of each was laid on good and porous, the other in poor, fine, and impervious gravel; they had been in use for sixteen years, and were traversed daily by from twenty-five to forty trains of all kinds, including very heavy goods and coal trains. The condition of both lengths of permanent way had been, on the whole, satisfactory, less repairs being necessary than for other parts of the line. With the design, Fig. 56, some cases of depression and deflection had occurred on the breaking up of a severe frost in 1865, which were subsequently traced to defective ballast and foundations.

The great depth of the sleepers might be principally credited with the good results obtained, as it rendered a low position of the

Mr. Scheffler. base of the sleeper possible, and protected it from the action of frost. The permanent way was easily raised and packed. Apprehensions, widely expressed, that the smooth under-surface of the sleepers would lead to lateral displacement, had proved groundless; in every case where this had taken place it was due to the ballast having been washed away. .


Up to the end of the year 1880 the number of sleepers replaced on account of fractures was: for Fig. 55, 25; for Fig. 56, 41. In latter years, here and there depressions in the upper surface of the sleepers had occurred under the rail joints in both constructions, and in Fig. 56 the rivets fastening the transverse ties had frequently worked loose; the first defect was met by altering the position of the rail joint, the latter by hammering cold. As with ordinary fish-plates, the bolts securing the rails required in places frequent tightening up. With the design, Fig. 56, a tendency of the rails had latterly appeared to move forward in the direction in which the trains ran. This was probably due to the fact that the ballast between the rails could only be brought up to the lower edge of the transverse ties, otherwise these, owing to their light character,

Fig. 57.



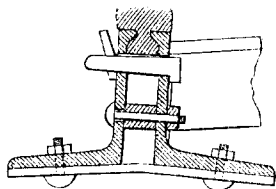
might easily have been bent by the thrust. The form of transverse connection shown in Fig. 57 met this evil. In the sixteen years ending 1880, all the iron rails had been replaced; but as they were subjected to the heaviest traffic on the Brunswick Railway, this was not remarkable. The oxidation of the iron permanent way had been insignificant. Neither construction appeared to possess any marked advantage

over the other; trains ran rather harder over the iron sleepers than over wooden ones, but more uniformly and quietly. It was found difficult to roll the vertical flanges of the sleepers in systems, Figs. 55 and 56, with the upper edges, on which the rails rested sufficiently accurate, and hence it became necessary to partially plane them. To avoid this, a third system of permanent way, represented in Fig. 57, had been laid, to the extent of 0.93 mile, partly on a curve, on the line between Brunswick and Wolfenbüttel; it had been in use since the beginning of 1867 to the extent of 0.8 mile.

In this system cotter-bolts were used to attach the rail to the sleeper. The rails were of cast-steel, the transverse ties of  section, and 5 feet apart. The Bessemer steel used for the rails was so brittle that some of the latter were broken by falls

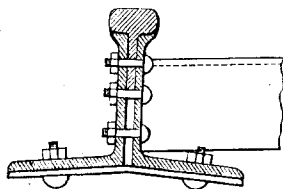
during unloading; and after being laid, four hundred and twenty-  
 three out of five hundred and twenty had to be replaced by puddled  
 steel rails, in consequence of fractures, up to the end of 1880.  
 The fractures always occurred where the rails were punched. In  
 latter years fractures had taken place in some of the sleepers, and  
 here and there, as in systems Figs. 55 and 56, the ends of the rails  
 had been driven into the upper surface of the sleepers, although  
 not to the same extent as in the former structures. The system  
 shown in Fig. 57 possessed the advantage over ordinary wooden  
 sleepers, that broken rails might be retained; but to avoid break-  
 ages altogether, a fourth system, Fig. 58, had been adopted.  
 This system was laid on the line be-  
 tween Kreiensen and Holzminden, for a  
 length of  $11\frac{1}{4}$  miles, the maximum  
 gradient being 1 in 80, and the sharpest  
 curves of 1,197 feet radius. One portion  
 of this line had been at work for twelve  
 and a half, the other for twelve years.  
 The rails were principally of cast  
 steel. The pressure resulting from the  
 tendency of the rails to creep forward,  
 was in this system sustained by a single  
 bolt at the end of each rail, and, conse-  
 quently, the former had been indented  
 by the latter, and in some cases abra-  
 sion of both parts had occurred; besides  
 this, depressions in the sleepers occur-  
 red under the rail joints, and on sharp  
 curves the ends of the rails were crush-  
 ed. These depressions were generally  
 the result of defective welding or of  
 fractured sleepers; the fractures, which  
 here and there took place, were always  
 at the points where the sleepers were  
 punched for the cotter-bolts. The wear  
 of the steel rails had hitherto been in-  
 significant on this section of the rail-  
 way, except where the brake was regu-  
 larly applied. The use of cotter-bolts  
 had been, on the whole, successful.

FIG. 58.



In 1879 and 1880, when the line was  
 undergoing repairs, the iron bolts were  
 replaced by steel ones. The good results  
 obtained with systems, Figs. 55 and 56,  
 led to the adoption of another design,  
 Fig. 59; this modification was intended  
 to obviate the difficulty presented by  
 system, Fig. 58, to the formation of  
 switches, and to bring down the cost of  
 the iron permanent way as nearly as possible  
 to that of ordinary wooden sleepers. It  
 differed from Fig. 57 in having reduced

FIG. 59.




Mr. Schettler. dimensions for the angle-irons, in being furnished with transverse ties of angle-iron instead of -iron, and in the connections being made with common bolts instead of cotter-bolts. This system had been laid on the line between Seesen and Osterode for a length of 9 miles, and having gradients up to 1 in 180, and curves of 1,493 feet radius, the rails being of fine-grained iron. The results obtained with system, Fig. 59, were not so favourable as was expected; the material of which it was made being, however, defective, it was impossible to decide whether the large number of depressions on the sleepers during the ten years the permanent way had been in use were due exclusively to the latter cause, or partly to the reduced dimensions, or the freshness of the earth-works and ballasting. To prevent the depressions in the sleepers above referred to, the experiment was made, in 1877, of laying separate plates under each rail-joint. In the annexed Table the cost of these plates had been included.

Fig. 60 was a modification of the construction of Fig. 59, in which the vertical flanges of the sleepers were increased in thickness, and so arranged that the rail received a double support. These sleepers had been in use on a length of 984 feet since 1877. Hitherto this design had given good results, and during the three years it had been at work not the slightest depression had taken place under any of

the rail-joints. The following were the weights and prices, delivered where required, exclusive of the cost of laying and ballasting:—

System Fig. 55	=	120 lbs.	=	35·9 marks.
"    " 56	=	109 "	=	30·1 "
"    " 57	=	102 "	=	30·3 "
"    " 58	=	96 "	=	28·6 "
"    " 59	=	84 "	=	24·9 "
"    " 60	=	92 "	=	27·6 "

As compared with this, the ordinary system of permanent way, with rails 5·4 inches high of cast steel, costs 22·3 marks, and with rails 4·8 inches high, 18 marks. The iron permanent way, when once the workmen were accustomed to it, could be put together and laid quickly and easily.

The depth of the ballast bed under the sleepers was the same as for wooden sleepers, *i.e.*, 11·2 inches; this had been found sufficient, but it was of great importance that a clean porous ballast should

be used, and efficient arrangements for drainage made, also that the iron permanent way should be entirely bedded in good gravel, which ensured easy travelling. The cost of maintenance in different years had varied from 0·37 to 0·8 mark per lineal metre. None of the apprehensions entertained by many engineers as to the want of success of iron permanent way had been justified. The following was a statement for each of the systems of permanent way, Figs. 55, 56, 57, 58, and 59, of the average proportion of rails replaced per annum, expressed as percentage of the total length of line laid on the system in question :—

System.	Number of Years.	Average Percentage.
Fig. 55 . . . . .	16	6·791
„ 56 . . . . .	16	7·110
„ 57 . . . . .	14	5·758
„ 58 . . . . .	12	2·833
„ 59 . . . . .	10	4·860

No rails of system, Fig. 60, had as yet been replaced.

The use of rivets in the construction of those portions of the iron permanent way which did not need frequent renewal, more particularly those which were covered by the ballast, was by no means objectionable. Cotter-bolts had not proved more effective than ordinary bolts. The fears entertained as to the lateral displacement of the permanent way had proved groundless, except where the ballast was defective. Changes of temperature had produced no bad effects as regarded longitudinal expansions. Experience had shown that on railways with considerable traffic, a width of 11·6 inches was necessary for the sleepers.

The design, Fig. 60, might be regarded as the final embodiment of the experience gained by the trials described. With every system the drawback had been found, that the ballast-bed under the sleepers was always becoming more compact and impervious from the continued accumulation of dirt; on the other hand, this had the advantage of giving increased resistance to lateral displacement, and affording greater protection against frost.

Of late years the experiment had been made of placing drain-pipes transversely under the longitudinal sleepers, to facilitate the drainage of the ballast, and as far as could be ascertained hitherto with success.

Notwithstanding sixteen years' experience, the Directors of the Brunswick Railway did not consider the trials as concluded; but in spite of the reduced price of iron, permanent way with wooden cross sleepers was still cheaper than any of the iron systems. It should be mentioned that on the line between Stadtoldendorf and

Mr. Scheffler. Holzminden with a descending gradient, as well as on that between Brunswick and Wolfenbüttel, the iron permanent way had sustained admirably the running off the line of several wagons, the result being only a slight deflection of the transverse ties, and the destruction of some of the connections, but without displacement or change in the gauge.

The oaken sleepers used on the Brunswick railways had the following dimensions: Length, 8 feet  $2\frac{1}{2}$  inches; width, 11 inches; and thickness, 5.5 inches, giving a bearing surface of 7.53 square feet, and side area for resisting longitudinal displacement of the permanent way of 3.77 square feet, a cubic capacity of 0.13 cubic yard, and when damp, a weight of 198 to 220 lbs. The price of a sleeper, including impregnation, planing and carriage, was in 1878, 5.86 marks, and this varied little from year to year. The average duration of sleepers impregnated with chloride of zinc was about twenty years. Old sleepers might be valued at 0.5 mark each as fuel. The transverse iron sleeper proposed by the "Horster Union," which corresponded in dimensions with that used on the Bergisch-Märkisch Railway, had a length of 7.2 feet, width of 0.75 foot at the bottom and 3 inches at the top, and a height of 2.6 inches. It was made of iron plate 0.3 to 0.5 inch thick, and was open at both ends; the bearing surface was 5.38 square feet, the side area 1.51 square foot; the cubic capacity buried in the ballast was 0.78 cubic foot, and the weight 103.5 lbs. Sleepers with open ends having proved defective on other lines, the Bergisch-Märkisch Railway Company used sleepers in which the lower ends of the flanges were connected by two angle-irons, which increased the above-mentioned weight to 115 lbs.; on other railways it was found necessary to use four transverse ribs. The sleepers, without transverse connections, cost 5.84 marks each; those with two angle-irons 7.12 marks, and those with four connections 7.8 marks, delivered at a station near the ironworks; for the Brunswick Railway the cost of carriage would bring these prices up to 6.36, 7.7, and 8.4 marks respectively.

The deflection of iron sleepers of this pattern under a given load was greater than that of the oak sleepers previously described; with the points of support 7.2 feet apart, the deflection was—

For an oak sleeper with	3,085 lbs.,	inappreciable.
" "	" 5,511 "	" 0.157 inch.
" iron "	" 3,085 "	" 0.394 "
" "	" 5,511 "	" 0.945 "

and with the latter load the iron sleeper sustained a permanent deflection of 0.413 inch.

The iron sleepers in question did not comply with the regulations for the Prussian State railways, and if the necessary modifications were made, the prices would be increased for the three types of construction referred to, to 7·33, 8·67, and 9·37 marks respectively. Mr. Scheffler.

The value of any system of sleepers depended on the bearing surface necessary to carry the traffic.

The square-metre bearing surface (10·76 square feet) cost, for wooden sleepers, 8·37 marks; for iron sleepers of the kind in question, 16·2 marks. The wooden sleepers were buried deeper under the surface than the iron ones; were consequently less exposed to the action of water and frost, and, on account of their form, they offered greater facilities for packing up with ballast.

The wooden sleeper opposed an area of resistance to longitudinal displacement of 3·77 square feet; the iron one 1·61 square foot; against lateral displacement the areas presented were respectively 0·43 and 0·22 square foot. On account of the greater friction of iron sleepers, where gravel must slide on gravel, the resistance to displacement was probably not less for the latter than for wooden sleepers. The unsupported length of rails with wooden sleepers was 2·13 feet; with iron ones, 2·49 feet. Iron transverse sleepers required, for every different radius of curve, different methods of attachment, or holes differently punched. The conclusion arrived at was that no pecuniary advantage could be derived from the use of iron transverse sleepers instead of wooden sleepers of the same carrying capacity, as the first cost was at least twice as great for the former, and it was uncertain whether this could be neutralised by greater durability.

In England, where iron was cheap and wood dear, and where the heaviest traffic prevailed, perhaps the best field for a trial of iron sleepers was presented, but in Germany the conditions were different.

The total length of iron permanent way laid on the Brunswick railways since 1864 has been 23½ miles, and, as already stated, the results had been satisfactory. Hitherto, however, every system of iron permanent way had, at average prices, proved dearer than permanent way with wooden sleepers. If it was assumed that the greater first cost of iron sleepers was compensated by their greater durability, the question as to relative value would depend on the wear and tear of the rails. The system of permanent way in three parts was the result of the reduction of size of rail to the admissible minimum. The construction in two pieces, and still less in one piece, did not admit of this reduction. The separation of the rail

Mr. Scheffler. from its support was an essential feature of any practical system of permanent way. It was only necessary, therefore, to compare the triple with the double system. A careful comparison led to the following conclusions:—

Systems of iron permanent way, with transverse as well as with longitudinal sleepers, might be of a firmer and more durable design than those constructed with wooden sleepers; the first cost would however be greater, and the cost of maintenance could scarcely be reduced to the extent of compensating for this—iron sleepers, on account of the thinness of the metal, not having much durability. The use of iron permanent way of sufficient proportions thus involved a pecuniary sacrifice in the interests of safety. At present, iron permanent way might be considered as in an experimental stage. In designing any new system, attention should be paid to the following particulars and conditions: The dimensions should not be reduced at the expense of efficiency; great attention should be paid to the quality of the material; forms should be used which did not involve excessive strains on the iron in rolling; constructions avoided which necessitated great strains on the connections, &c.; the transverse ties should be placed as deep as possible; sufficient strength of the attachment of the rail against longitudinal displacement provided; and, finally, efficient drainage and good ballast.

In conclusion he wished to correct a few errors in the Paper. Mr. Hartwich had not laid the first iron permanent way in Germany, as he had executed a project, in 1864, which he had contemplated in 1862. Then again, the statement: "But the rail is weak, and causes trouble by lifting and breaking. To meet the difficulty, Mr. Daelen introduced a modification in 1868," was probably based on an erroneous report. The road in question, A.B.C., was still in use after seventeen years' traffic, and fitted with the original rails laid in 1864 and 1867. The breaking of the steel permanent way was not due to the construction, but to the brittle character of the material, and had occurred on all lines, even those provided with Vignoles rails. Steel rails had, however, a great advantage over ordinary three-part iron rails, in that there was no danger even when they broke. Fracture, when it did occur, was generally in those parts where the rails were riveted, and so the construction Fig. 58 was used, in which no rivet-holes were necessary. This form had not been introduced by Mr. Daelen, but by himself, although the introduction was the result of a conference with Mr. Daelen, who was the manager of the rolling-mills and proposed the new form. But in this system the

rail could not be riveted to the chair, and had therefore a strong tendency to lift, for it was not kept sufficiently down by the rail with which it was connected at the end. Owing to this fact he had latterly returned to the original system of form Figs. 59 and 60.

Mr. J. W. SCHWEDLER, of Berlin, remarked that to form an opinion as to the suitability of the construction of any permanent way, experience alone was insufficient. The theoretical conditions to which the form of structure was subject must first be determined, and then the sufficiency of the hypothesis tested by observation of the actual phenomena. With this purpose he would first discuss the theory of the longitudinal sleeper permanent way. The two assumptions on which this theory was based were the following:

1. The ground under the longitudinal sleepers was compressed to an extent corresponding to the load rolling over it until almost complete elasticity was produced. After this the elastic compression of the ground was proportional to the load and inversely proportional to the continuous bearing-surface of the sleeper.

If the coefficient of elasticity of the ground was denoted by  $C$ , the width of the sleeper by  $B$ , the depression by  $y$ , then the reaction  $p$  per unit of length (centimetre) of the sleeper was

$$- p = C . B . y .$$

Now as rails and sleepers together formed a single system of girders, subject to the deflections  $y$ , when the pressure of the wheels  $P = 7,000$  kg. (15,432 lbs.) acted upon it, and as for elastic beams, the equation  $E I \frac{\delta^4 y}{\delta x^4} = p$  held good, where  $E$  was the coefficient of elasticity of the material composing the permanent way, and  $I = I_1 + I_{11}$ , the sum of the moments of inertia of the sectional areas of rail and sleeper, with reference to the respective centres of gravity of these areas; therefore the theoretical fundamental equation for this system was

$$E I \frac{d^4 y}{d x^4} = - C . B . y .$$

2. The resistance of the ground, increased in the first place with the compression, reached a limit at which yielding took place through displacement. This, for the unit of length of the sleeper, was proportional to  $B^2$ , as demonstrated in the sequel. Hence the equation

$$p = \sigma B^2,$$

where  $\sigma$  denoted the coefficient of resistance of the ground.

Experiments on the Alsace-Lorraine Railways had shown that, with

Mr. Schwedler. wet and soft ground,  $C$  was as low as 2 kilograms per square centimetre, and that with firm ground it reached 8 (113·52 lbs.) and more kilograms, but generally 3 kilograms (42·57 lbs.) might be taken. The coefficient  $\sigma$  had not yet been experimentally determined. Theoretically it would amount for sharp sand to about 0·08; with different kinds of longitudinal and transverse sleepers it was calculated at from 0·04 to 0·08 (0·567 to 1·135 for English measure). The larger this coefficient was assumed to be, the more must the permanent way sink to attain elastic resistance; hence it constituted the measure for the permanent level of the rails if the vertical load only was considered.

On the basis of these two hypotheses the mathematical development of the fundamental equation for the longitudinal sleeper permanent way gave, for the resistance of the latter to a vertical concentrated load, the two following relations between the dimensions and coefficients:—<sup>1</sup>

$$1. k = \frac{P e}{4 I} \sqrt[4]{\frac{4 E I}{C B}}$$

$$2. \sigma = \frac{P}{2 B^2} \sqrt[4]{\frac{C B}{4 E I}}$$

where  $k$  was the maximum stress per square centimetre in the flange of the rail, and  $e$  the height of the centre of gravity of the partially-worn rail above the base of the latter. If the factor  $\sqrt[4]{\frac{C B}{4 E I}}$  was denoted by  $m$ , and by  $M_0$  was understood the bending moment of the permanent way under the wheel, the above formulæ might be more conveniently written

$$M_0 = \frac{I k}{e} = \frac{P}{4 m}; p_0 = B^2 \sigma = \frac{P m}{2},$$

and the application correspondingly adapted. In illustration of the preceding formulæ the behaviour of the permanent way of the

<sup>1</sup> The moments of inertia  $I, I_1, I_{11}$ , modulus of elasticity  $E$  and coefficients  $C, \sigma, m$ , were given generally in the original metric measure, the centimetre being the unit of length, the kilogram that of weight.

To obtain the equivalent values for English standards, the units being the inch and pound, multiply

$$\begin{array}{l} I, I_1, I_{11} \text{ by } \frac{1}{(2 \cdot 54)^4}; \\ E \quad \text{,,} \quad 2 \cdot 205 (2 \cdot 54)^2; \\ C \quad \text{,,} \quad \text{,,} \quad \text{,,} \\ \sigma \quad \text{,,} \quad \text{,,} \quad \text{,,} \end{array}$$

$m$  was merely an abbreviation for convenience in calculation.

1 inch = 2·54 centimetres; 1 kilogram = 2·205 lbs.

Berliner Stadtbahn upon different kinds of ground, denoted and Mr. Schwedler. characterised by the coefficients of elasticity  $C = 2, 3, 4, 8$  ( $28\cdot38, 42\cdot57, 56\cdot76, 113\cdot52$ ), would be numerically calculated in the sequel.

This system of permanent way had been represented in Fig. 16. In this case the moment of inertia of the worn-out rail  $I_1 = 570$ , the height of the centre of gravity of its cross-section  $e = 5\cdot7$  ( $2\frac{1}{4}$  inches), the moment of inertia of the longitudinal sleeper  $I_{11} = 130$ ; consequently  $I = I_1 + I_2 = 700$ . The width  $B$  of the sleeper was 32 centimetres ( $12\cdot6$  inches).

The results, if  $P = 7,000$  kilograms ( $15,432$  lbs.),  
 $E = 2,000,000$  „

were—

for	C =	2	3	4	8
	$\frac{1}{m} =$	97	88	81	65
$M = \frac{P}{4m} = \left\{ \right.$		170,000 (147,492)	154,000 (133,610)	142,000 (123,199)	114,000 (98,947)
		kg. cm.			inch lbs.
$p = \frac{2P}{m} = \left\{ \right.$		35 (196)	40 (224)	43 (240·8)	54 (302·4)
		kg. per lineal cm.			lbs. per lin. in.
$k = \frac{Me}{I} = \left\{ \right.$		1,385 (19,699)	1,254 (17,836)	1,145 (16,285)	929 (13,213)
		kg. per sq. cm.			lbs. per sq. in.
$\sigma = \frac{p}{B^2} =$		0·035	0·039	0·042	0·052

For Hilf's system of permanent way, Fig. 10, if a high rail with  $e = 5\cdot8$  centimetres ( $2\cdot28$  inches) was used, the following figures would be obtained :—

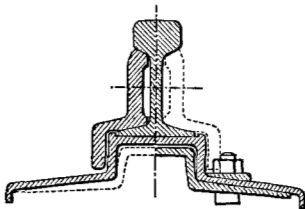
	$I_1 = 680, I_{11} = 70, I = 680 + 70 = 750, B = 30,$				
for	C =	2	3	4	8
	$\frac{1}{m} =$	100	90	84	70
$M = \left\{ \right.$		175,000 (151,892)	157,500 (136,704)	147,000 (127,590)	122,500 (106,325)
$p = \left\{ \right.$		35 (196)	39 (218·4)	42 (235·2)	50 (280)
$k = \left\{ \right.$		1,351 (19,215)	1,218 (17,324)	1,137 (16,171)	945 (13,441)
$\sigma =$		0·039	0·043	0·047	0·055

Mr. Schwedler. As both systems of permanent way were satisfactory as regarded vertical loads, it would be desirable, for rough calculations, to take  $k = 1,200$ ,  $\sigma = 0.04$ ; and for a given value of  $P$ , and assuming  $B$ , to determine the values of  $I$  and  $e$ , then after choice of  $I_{11}$  to calculate  $I_1$  and construct the rail in accordance with  $e$ .

In construction the following conditions must be fulfilled that the result might correspond with the calculations:—

1. The rail and sleeper must be fished at the joints, and the fish-plates should have approximately the same moment of inertia as the rail or sleeper, so that the deflection of the permanent way, upon which the action on the ballast depended, might be everywhere equal, and no sagging occur at the joints. If it was possible to make the fish-plates  $4\frac{3}{4}$  to  $5\frac{1}{2}$  inches high, as in Fig. 16 and Fig. 61, where

FIG. 61. FIG. 62.



the form of the sleeper permitted, the rail could be covered by the rail fish-plate only, and the sleeper by the sleeper fish-plate, and the junctions of each part of the structure might alternate. If the form of sleeper was such that the rail fish-plate could not be made so high, as in Figs. 9, 10, 11, and 12, the rail fish-plate alone would not suffice to cover the rail, and the sleeper fish-plate must be made stronger to such extent that the fish-plates together had the moment of inertia  $I_1 + I_{11}$ . In this case rail and sleeper must be fished at the same point, and the form shown in Fig. 10 would result.

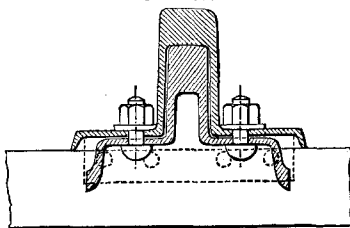
2. The longitudinal sleeper must have approximately vertical turned-down flanges at the edges to prevent the bedding from spreading out under the smooth surface of the sleeper, and to maintain sufficient friction. In the absence of flanges the sleeper sank more readily, the ballast was more easily displaced, and the resistance of the ground diminished, and this necessitated a coefficient  $\sigma$  smaller by about one-half for substitution in the calculation (Figs. 1, 3, 4, 5, 6, 7, 8, 15). On the other hand the coefficient might be increased if the way could be ballasted, outside the rails at least, up to the top of the latter, and the sleepers penetrated deep into the ground.

3. To ensure a good fit between the fish-plates and the rails it was advisable not to make the inclination of the surfaces of contact with the horizon greater than 1 : 4, the fish-plates  $23\frac{1}{2}$  inches long or more, and if practicable to insert between the surfaces of contact at the ends of the rails and fish-plates steel plates 0.04

inch thick, that at these points only contact might be made with the fish-plates, and that at other parts the fish-plate and rail might not touch. The sleeper fish-plates should only be applied underneath, and should be attached to the sleepers by eight vertical bolts. The bolts should have double-threaded screws (Fig. 62), and each of the upper washers for the nuts should be common to four bolts, so that on a change of temperature the bolts might not cant and become strained and loosened.

He considered permanent way made in single pieces preferable on the score of economy, solidity, and stability. The form designed by Mr. Barlow in 1849, Fig. 1, should however be somewhat modified, as shown in Fig. 63, in

FIG. 63.



which the foot was 10 inches wide, the total height 5.9 inches, including the flanges, 0.79 inch, the web and foot flanges 0.31 inch thick, at the corners 0.39 inch, and rounded off, and the head 1.58 inch thick and 2.36 inches. The moment of inertia was about  $I = 1,000$ , the height of the centre of gravity when 0.8 inch had been worn off about 2.76 inches =  $e$ , the weight 92.59 lbs. per metre. Where the ballast was coarse the hollow space might be filled with wood. The buckling of the horizontal flanges might be prevented by short angle-irons riveted below at intervals of 3 feet. The latter obviated longitudinal displacement, and could be used for attaching transverse connections of bar iron on edge at intervals of 12 feet. For curves the rails must be bent on leaving the rolls. Fish-plates of the same moment of inertia, as shown in Fig. 63, and of sufficient length should be attached by eight bolts. The rolling of this sleeper, however, presented difficulties. When rail and sleeper were separate it was economical to give the requisite moment of inertia principally to the rail, and to construct the sleeper more as a plate with flanges under it, as the moment of inertia of the rail, which had only a single web, could be increased with less expenditure of material than that of the sleeper, which in general must be kept low, and was made with two webs, as in Haarmann's system.

The difficulty was that a rail with a great moment of inertia required a similar fish-plate, and this could not be used on account of the projected plate. All that remained to be done in this case was to utilise the strength of the sleeper fish-plate for the rail by

Mr. Schwedler. making the junctions of the rails and of the sleepers coincide. This suggested the form shown in Fig. 64, which had not been carried out in practice, but was a development of Fig. 10, the latter being constructed for Hilf's sleeper. On a considerable length of the Ostbahn a similar system of fish-plates of greater strength, for Hilf's sleepers, had come into use (Fig. 65).

FIG. 64.

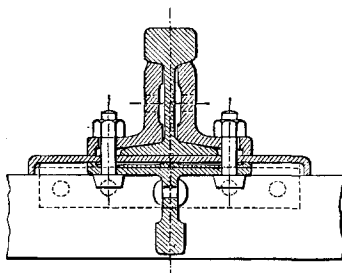
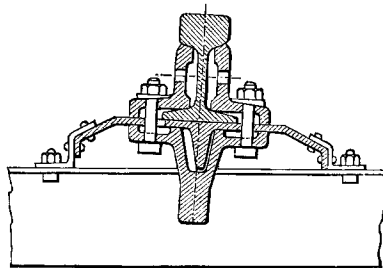


FIG. 65.



Haarmann's sleeper, which had resulted from the intention of increasing the moment of inertia and making use of clamp connections, had been adopted because the rails could have fish-plates 5·11 inches high, and it was thus possible for sleepers and rails to overlap. The wear and tear of the joints was thereby somewhat reduced. The high position of the rail on the Haarmann sleeper, which was only 10·23 inches wide, had been rendered less objectionable by widening the foot of the sleeper to 12·6 inches. Neither the sleeper nor rail fish-plates were shown in Fig. 16, but only the recesses for attaching the transverse connections. The latter, on curves, were not always at right angles opposite to each other as the joints of the inner line in being laid were in advance, until in the outer line a longer rail and sleeper was inserted. To avoid undue strains in this case the transverse connections were attached with only one bolt. This connection, in curves on freshly-laid ballast, was insufficient. The force with which the leading wheel of the locomotive pressed against the outer rail was about  $\frac{1}{3}$  of the weight of the locomotive (half the friction of the total weight of the locomotive  $\frac{Q}{12}$  less that of the leading front

wheel  $\frac{Q}{36}$ ), or, say, 2·4 tons, and the transverse connection in its low position could not support this resistance without considerable deflection. To avoid an increase of the gauge, and to facilitate

the regular formation of the consolidated bed on which the Mr. Schwedler. sleepers rested, tie-rods, as in Hilf's system, Fig. 9, had been used on the Berlin Stadteisenbahn. These, together with the transverse connections, served better to distribute the horizontal pressure between the two lines of rail, and to maintain the gauge as well as the inclination of the rails. The use of transverse sleepers under the joints of longitudinal sleepers (Fig. 9) had latterly been abandoned; it altered the conditions of elasticity of the system, and gave rise to irregularities.

Multiple systems had mostly been invented with the object of keeping the rail, as the perishable portion, small, so as to incur slighter losses in renewal. This reduction of the height of the rails was, however, not desirable; under traffic the head was strongly compressed and stretched longitudinally and laterally, and these stresses must be held in equilibrium by the web and flange of the rail. With rails too low deflections soon loosened the connections. The whole resistance was thus thrown upon the sleeper, in which continuity was difficult, if not impossible, to establish by fish-plates of equivalent strength.

In the latter case irregularities were caused in the compression of the ballast, which was then often loosened by frequent repairs, causing still greater irregularities. It was desirable that the transverse connections should not coincide with the joints. Tie-rods alone were insufficient, as they did not ensure the required inclination of the rails. These should unite the two lines of rail, not too far below the top of the latter, so rigidly that with an imperceptible deflection they should distribute the pressure exerted by the wheel-flange (which was not vertical, but might deviate in the ratio 1 : 2 from the vertical) vertically upon the centre of the sleeper, and thus produce a uniform consolidation of the ballast. From this uniform consolidation arose the drawback that the ballast under the sleepers became impervious to water, and the latter collected between the rails, and in frosty weather caused irregularities in the line, and in mild weather, on the other hand, softened the foundations. Hence a good method of drainage, longitudinally by a drain pipe, transversely by gullies of masonry, should be associated with longitudinal sleepers.

This circumstance, as well as the difficulty of removal in altering the permanent way, had deterred many engineers from adopting the system, or had led them to return to transverse sleepers. Nevertheless, where railways were not of a temporary character, and a substantial system of drainage could be established, or where the ballast was of a permanently porous character, even

Mr. Schwedler, after it had been compressed into a state of elastic cohesion, the longitudinal sleeper system, in economy of maintenance and excellence and durability in the equality of the road, had essentially the same superiority over the transverse sleeper system as a firm smooth asphalt road had over wooden paving. The so-called hard running, perceptible by the high pitch of the vibrations, which resulted from the greater coefficient of elasticity of the consolidated ballast, was, on account of the smaller amplitude in the oscillations of the vehicles, less detrimental than soft running on elastic transverse sleepers, when the position of the latter was not quite uniform, and isolated irregularities gave rise to excessive oscillations and shocks which altered the form of the supporting ballast.

To explain clearly the action of the vehicles on the ballast in the longitudinal sleeper system, it would be necessary to go somewhat further into the theory previously indicated, and the measurements which substantiated it.

The differential equation—

$$E I \frac{d^4 y}{d x^4} = -C B y$$

corresponded to the function

$$y = \frac{P m}{2 C B} \cdot e^{-m x} (\sin m x + \cos m x) = \frac{P m}{2 C B} \eta$$

in which  $m = \sqrt[4]{\frac{C B}{4 E I}}$ , and which represented the elastic line of the rail and sleeper. Taken negatively, it also gave the distribution of pressure on the ballast, since  $p = -C B y$ . The second differential of this quantity, according to  $x$ , gave the bending moment of rail and sleeper, taken together,

$$M = \frac{P}{4 m} e^{-m x} (\sin m x - \cos m x) = \frac{P}{4 m} \mu.$$

In practice the variable portion which represented a particular function was denoted by  $\eta$  and  $\mu$  respectively. In Fig. 66 both functions  $\eta$  and  $\mu$  were represented. They were periodical, like the quantities  $\sin m x$  and  $\cos m x$ , which varied between the values  $+1$  and  $-1$ , when  $m x$  was a multiple of  $\Pi = 3 \cdot 14 \dots$  or  $\frac{\Pi}{2} = 1 \cdot 57 \dots$ . The period of  $\eta$  varied from  $m x = 0$  to  $m x = \Pi$ , that of  $\mu$  from  $m x = \frac{\Pi}{2}$  to  $m x = \frac{3}{2} \Pi$ , where each time a maximum was alternately negative and positive. If the distance between two

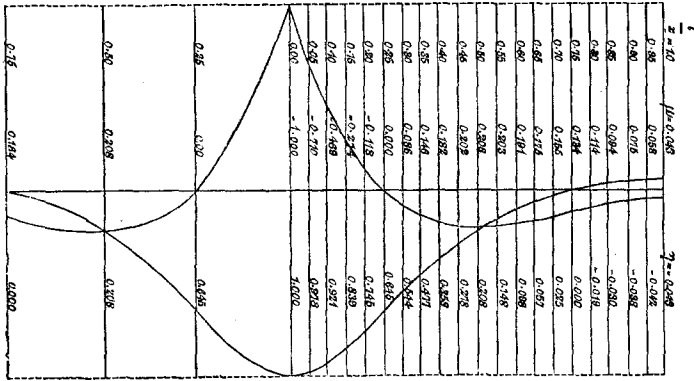
such points was denoted by  $l$ , that was the distance between the Mr. Schwedler.

hollow and crest of a wave, then  $l = \frac{\Pi}{m} = \Pi \sqrt[4]{\frac{4EI}{CB}}$ .

The values of  $\eta$  and  $\mu$  were in every successive interval  $l$ , en =  $0.043 = \frac{1}{23}$  of those in the preceding of the opposite sign. Hence the interval  $o$  to  $l$  in front of and behind the load must be known in order to calculate all the ordinates and plot them symmetrically. The twenty ordinates given allowed the accurate delineation of the curves and their continuation, until sufficiently small values were reached, for the purpose of scaling off all values of  $\eta$  and  $\mu$ , from which  $y$  and  $M$  could be determined.

FIG. 66.

Curve of moments  $\mu = e^{-mx} (\sin mx - \cos mx)$ ;  $ml = \Pi$ .



Elastic line  $\eta = e^{-mx} (\sin mx + \cos mx)$ ;  $ml = \Pi$ .

To obtain the elastic line for several wheels a single vehicle, or a whole train, it was only necessary to draw these curves for every load in the position corresponding to the latter, and then to sum up the ordinates which coincided according to their signs (positive or negative). Or, if the loads were distant from a given point by the lengths  $x_1, x_{11}, x_{111}$ , etc. (taken positively both backwards and forwards), then for this point

$$y = \frac{P m}{2CB} \cdot (\eta_{x_1} + \eta_{x_{11}} + \eta_{x_{111}}, \&c., \text{ and}$$

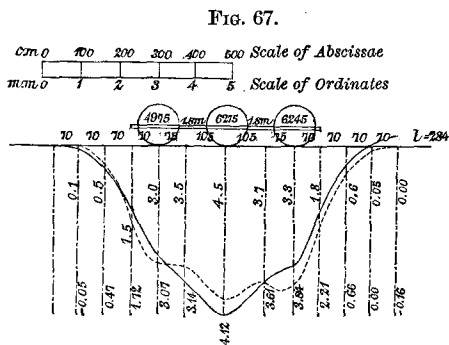
$$M = \frac{P}{4m} (\mu_{x_1} + \mu_{x_{11}} + \mu_{x_{111}}, \&c.).$$

If, for instance,  $m = \frac{1}{91}$ ,  $l = 286$  centimetres (9 feet 4.6 inches),

$$x = 100 \text{ centimetres (3 feet 3.37 inches), then } x = \frac{100}{286} l = 0.35 l,$$

Mr. Schwedler, and according to the above diagram and table  $\eta_{x_1} = 0.447$ ,  $\mu_{x_1} = 0.146$ .

On the Alsace-Lorraine Railway a measurement of the deflection of the rail of Hilf's permanent way, at a given point, relative to another fixed point some distance off, had been made during the passage of vehicles pushed over it. The dimensions of the permanent way were:— $B = 11.81$  inches,  $I_1 + I_{11} = 659 + 113 = 772 = I$ .

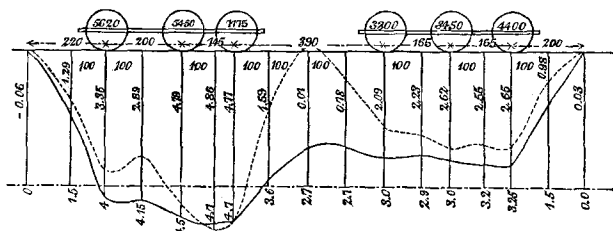


6-wheeled Tank Locomotive.

The weights in the wheels are in kilograms, and the intervals between them are in centimetres.

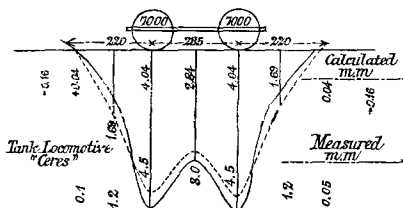
In Figs. 67, 68, 69, 70, the results of the measurements were shown, the loads on the wheels being given. The dotted lines had been calculated by the preceding method. In this case the value  $C = 3$  had been

FIG. 68.



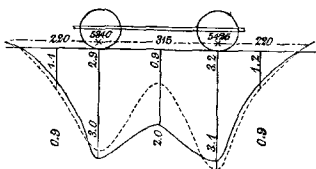
Goods Locomotive with Tender.

FIG. 69.



Tank Locomotive "Ceres"

FIG. 70.



Tender.

assumed, hence  $CB = 90$ ,  $E = 2,000,000$ ,  $\frac{1}{m} = 53.2 \sqrt{\frac{772}{90}} = 91$ ,

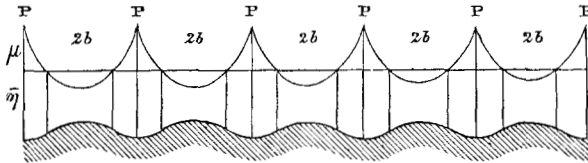
$l = \frac{\Pi}{m} = 286$  centimetres (9 feet 4.6 inches).

In general the agreement between the measured and the calculated ordinates pointed to the conclusion that the theory was correct; in applying it differences occurred only at the few points where the rails rose above the level, as here the weight of the

permanent way was in part less than the required negative pressure Mr. Schwedler. of the ground  $p$ . These differences, however, had little influence on the maximum deflections and moments. The large divergences at points between the wheel-loads led to the conclusion that the reaction of the ballast during compression followed the law of elasticity, but that the recoil took place more slowly, and with less energy. This property of the ballast agreed with that of other solid bodies, compressed rather beyond the limit of elasticity, as the latter only regained their original form after some time had elapsed.

To form a judgment as to the transverse sleeper system, it would first be necessary to demonstrate the results of the theory of elasticity as applied to transverse sleepers. The elastic line  $y$  and the curve of moments  $M$ , for the transverse sleeper, might be derived from the lines shown for the longitudinal sleeper. Let a longitudinal sleeper be imagined, with an unlimited series of equal loads,  $P$  placed alternately at the distances  $2a$  and  $2b$  from each other, and the elastic line and curve of moments of this sleeper

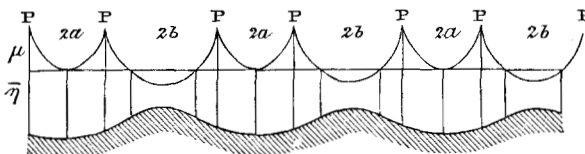
FIG. 71.



calculated by the method of summing up for the respective points  $a$ ,  $a$ , and  $b$ . If the intervals  $2a$  and  $2b$  were all equal to  $2b$ ,  $y$  must be a regular wave line, as shown in Fig. 71, similar to an infinitely long girder, uniformly loaded and supported at equal intervals.

The line of moments consisted of a series of curves bent downwards, which intersected the axis of abscissæ twice between every two loads, where the moment was nil and  $y$  had a point of inflection. If, however,  $2b$  was greater than  $2a$ ,  $y$  ascended higher in the interval  $2b$ , and descended lower in  $2a$ ;  $M$ , on the other hand, was lower in  $2b$  and higher in the centre in  $2a$ .

FIG. 72.



For a certain ratio of  $2a : 2b$  (Fig. 72) it must therefore happen that  $M$  touches the axis of abscissæ in the centre of  $2a$ ; that was,

Mr. Schwedler.  $M$  became nil at this point, and at the same time attained a minimum, whereby the transverse force acting on the sleeper disappeared.

Now, as in these points there was no stress in the sleeper, neither a transverse force nor a bending moment, the sleeper might here be cut through without altering the condition of any other section. The longitudinal sleeper was thus converted into a series of transverse sleepers of the length  $L = 2b + 2a$ , on which rested the two loads,  $P$ , at a distance  $2b$  apart;  $2b$  was the width of gauge. A transverse sleeper of this length, which might be called normal, was so placed that at both ends the lowest position coincided with a horizontal tangent. Of course the greatest pressure on the ballast also occurred there, while the greatest bending moments took place under the loads and in the middle. If the ratio  $2a : 2b$  was greater or less than in the case of the normal sleeper, on cutting through the sleeper in the centre of  $2a$ , a positive or negative moment of resistance would be destroyed, and the further deflection of the sleeper was such as would be caused by the neutralised  $M$ . The lines of deflections and moments hence required in this case a correction, which, added to the ordinates of  $M$ , made  $M$  at the end equal to nil. If, for instance, the neutralised moment at the end had been  $M_0$ , the moments, as represented by the curve of moments at the distance  $x$  from each end, had been diminished approximately by the amount  $\Delta M = M_0 e^{-mx} (\sin mx + \cos mx)$ ; that was according to the law of the elastic line for the longitudinal sleeper. The deflections  $\Delta y$ , on the other hand, increased nearly by  $\Delta y_x = M_0 \frac{2m^2}{C B} e^{-mx} (\sin mx - \cos mx)$ , that was according to the law of the curve of moments. As the curves referred to might easily be drawn from the figures; the combinations and corrections might also be easily determined graphically. For the normal length of sleeper,  $a$  was the portion of the transverse sleeper which projected beyond the rail, and  $ma = \frac{\Pi}{4}$ , or  $a = \frac{\Pi}{4m} = \frac{l}{4}$  might be taken with sufficient accuracy.

The total length of the normal transverse sleeper was therefore  $L = 2b + \frac{l}{2}$ , or

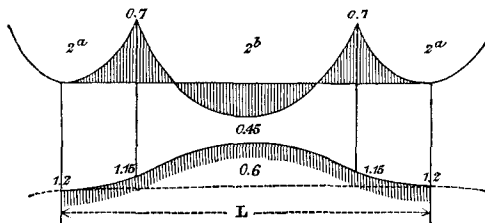
$$L = 2b + \frac{\Pi}{2m} = 2b + \frac{\Pi}{2} \sqrt[4]{\frac{4EI}{CB}}.$$

For  $C = 3$ ,  $B = 25$  (9.84 inches),  $I = 75$ ,  $E = 2,000,000$ , for instance, there resulted  $\frac{1}{m} = 53$ ,  $l = \frac{\Pi}{m} = 167$  centimetres (5 feet 5.7 inches),

$a = 41$  (1 foot 4.4 inches), and  $L = 150 + 2 \cdot 41 = 232$  (7 feet Mr. Schwedler. 7.3 inches).

In Fig. 73 the elastic line (being also the curve of the ground pressure) was represented for the normal transverse sleeper.

FIG. 73.



Under average conditions the ground pressure at the ends was approximately—

$$P_a = 1.2 \frac{P m}{2},$$

in the centre

$$P_b = 0.6 \frac{P m}{2},$$

under the rails

$$P_o = 1.15 \frac{P m}{2};$$

the bending moment—

under the rails

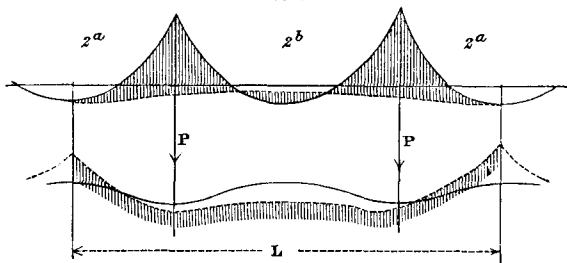
$$M_o = -0.70 \frac{P}{4 m},$$

in the centre

$$M_o = +0.50 \frac{P}{4 m}.$$

If the length of  $L$  was taken as greater than for the normal transverse sleeper, the pressure of the ground at the ends became smaller (Fig. 74), and the condition might be imposed that the

FIG. 74.

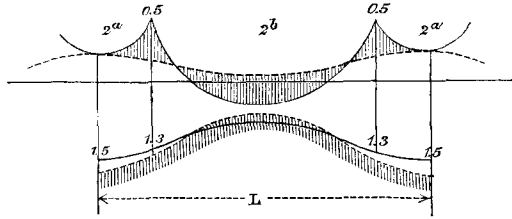


pressure at the ends and in the middle should be equal. This would occur approximately if  $a = \frac{5}{18} l$ , when  $L = 150 + \frac{5}{8} l$ .

Mr. Schwedler. In a sleeper for secondary railways, where  $l = 167$  (5 feet 5.7 inches),  $I = 75$ ,  $C = 3$ ,  $B = 25$  (9.84 inches), there resulted  $L = 150 + 105 = 255$  (8 feet 4.4 inches). This might be called the long transverse sleeper.

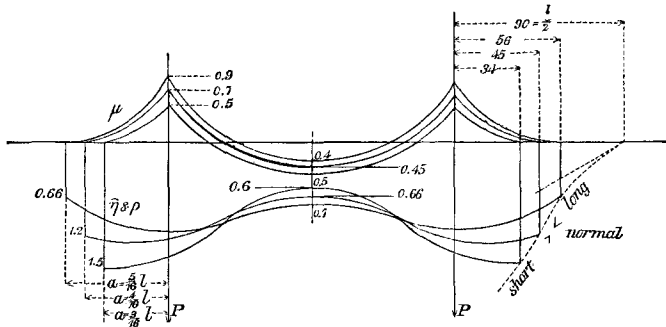
With a smaller length than that of the normal transverse sleeper,

Fig. 75.



the ground pressure at the ends, and the deflection in the middle, increased (Figs. 75 and 76); and the condition might be imposed that

Fig. 76.



$L = 262, 240, 218 \text{ c.m.}$

Diagrams of long, normal, and short transverse sleepers.

the bending moment under the rails and in the centre should be equal. This would be the case for  $L = 150 + \frac{3}{8} l$  nearly. In a special case the numerical values stated in the diagrams of  $\eta_a \eta_c$  and  $\eta_b$ , or  $\frac{P_a}{P m}$ ;  $\frac{P_o}{P m}$ ;  $\frac{P_b}{P m}$  could eventually be corrected, by help

of the condition that the mean ground pressure  $P_{mod.}$  multiplied by  $L$  must be equal to  $2 P$ . It involved, however, no great labour to determine accurately the numerical values by help of the graphical table, Fig. 6, when  $a$  and  $b$  were arbitrarily assumed, and  $m$

and  $l$  known. The exact method was given by the following Mr. Schwedler. formulæ :—

1. Ground pressure at the ends of the sleeper :

$$p_a = \frac{P m}{2} \left[ 2 \eta_a + 2 \eta_{a+2b} + 2 \eta_{3a+2b} + 2 \eta_{3a+4b} + \dots \right. \\ \left. + \frac{1 + 2 \mu_{2(a+b)}}{1 + 2 \eta_{2(a+b)}} (2 \mu_a + 2 \mu_{a+2b} + 2 \mu_{3a+2b} + 2 \mu_{3a+4b} + \dots) \right].$$

(Where  $a, a + 2b$ , &c., should be expressed as multiples of  $l$ , the corresponding values for  $\eta_a \eta_{a+b} \mu_a$ , &c., being then taken from the table, Fig. 66. Their sum, having regard to the signs positive or negative, gave the ordinates shown in Figs. 73, 74, and 75, from which, after multiplication with  $\frac{P m}{2}$  (the ground pressure under the wheel in the longitudinal sleeper system) yielded the value  $P_a$ .

2. Ground pressure under the rail supports :—

$$p_o = \frac{P m}{2} \left[ 1 + \eta_{2a} + \eta_{2b} + \eta_{2a+2b} + \eta_{4a+2b} + \eta_{2a+4b} + \eta_{4a+4b} \dots \right. \\ \left. + \frac{\mu_a + \mu_{2b+a} + \mu_{2b+3a} + \dots}{1 + 2 \eta_{(2a+2b)} + \dots} \cdot \{2 \mu_a + 2 \mu_{2b+a} + 2 \mu_{2b+3a} + \dots\} \right].$$

3. Ground pressure in the centre of the sleepers :—

$$p_b = \frac{P m}{2} \left[ 2 \eta_b + 2 \eta_{b+2a} + 2 \eta_{3b+2a} \dots + \frac{2 \mu_{a+b} + 2 \mu_{3a+3b}}{1 + \eta_{2a+2b}} \cdot \{2 \mu_a + 2 \mu_{2b+a} + 2 \mu_{2b+3a} + \dots\} \right].$$

4. Bending moment under the rail :—

$$M_o = \frac{-P}{4 m} \left[ 1 + \mu_{2a} + \mu_{2b} + 2 \mu_{2a+2b} + \mu_{4a+2b} + \dots \right. \\ \left. - \frac{\eta_a + \eta_{2b+a} + \dots}{1 + 2 \eta_{2a+2b}} \cdot \{2 \mu_a + 2 \mu_{2b+a} + 2 \mu_{2b+3a} + \dots\} \right].$$

5. Bending moment in the centre of sleeper :—

$$M_b = \frac{-P}{4 m} \left[ 2 \mu_b + 2 \mu_{b+2a} + \mu_{3b+2a} + 2 \mu_{3b+4a} + \dots \right. \\ \left. - \frac{2 \eta_{a+b} + 2 \eta_{3a+3b}}{1 + 2 \eta_{2a+2b}} \cdot \{2 \mu_a + 2 \mu_{2b+a} + 2 \mu_{2b+3a} + \dots\} \right].$$

The second portions of the formulæ disappeared for the normal transverse sleeper, as they became nil. In the long and short

Mr. Schwedler. sleepers they gave the correction previously mentioned. It should be remarked that the load P, in the case of the transverse sleeper, should not be made equal to the pressure on the locomotive wheels (7,000 kilograms), but be smaller, as, in consequence of the rigidity of the rails, the neighbouring sleepers assisted in carrying the load. If the pressure of the wheels was taken as R = 7,000 kilograms, or 5,000 kilograms, then—

$$P = R \frac{n+1}{n+3} \text{ where } n = \frac{\lambda^3}{3 E I_1} \cdot \frac{2 C B}{m \{1 + \eta_{2a} + \eta_{2b} + \eta_{2a+b} + \dots\}},$$

where I was the moment of inertia of the rail, E, the modulus of elasticity of the material of which it was made, and  $\lambda$  the distance of the sleepers from each other. The values of m, B,  $\eta$  related to the sleeper. For R = 7,000 and  $I_1 = 900$ , C = 3, B = 25 centimetres (9.84 inches) ( $\sum \eta$ )<sub>o</sub> = 1.16,  $m = \frac{1}{58}$ ,  $\lambda = 100$ , E = 2,000,000, the value of n = 1.61, and P = 4,102 kilograms (9,043.3 lbs.).

If the coefficient of elasticity of the ballast was greater, say C = 8, then  $m = \frac{1}{45}$  ( $\sum \eta$ )<sub>o</sub> = 1.05, n = 3.2, P = 4,760 kilograms (10,493.87 lbs.) for the Prussian iron transverse sleeper of normal length, L = 240 centimetres (7 feet 10½ inches),  $I_{11} = 105$ .

For the cross-sections of the latter with reference to the preceding calculation, a pressure P = 5,000 kilograms (11,023 lbs.) for a wheel-pressure R = 7,000 kilograms (15,432.2 lbs.) had been assumed.

If the old Rhenish iron transverse sleeper, the Vautherin system (Fig. 21) was made the subject of calculation, the data would be L = 230 centimetres (7 feet 6½ inches),  $I_{11} = 81$ , B = 22 centimetres (8.66 inches), weight 35 kilograms (77.16 lbs.) each, and the values assumed C = 3, E = 2,000,000; the results would then be  $C B = 66$ ,  $\frac{1}{m} = 56$ ,  $l = 176$  (5 feet 9.2 inches), ( $\sum \eta$ )<sub>a</sub> = 1.32 ( $\sum \eta$ )<sub>o</sub> = 1.24; ( $\sum \eta$ )<sub>b</sub> = 0.59; ( $\sum \mu$ )<sub>o</sub> = 0.7, ( $\sum \mu$ )<sub>b</sub> = 0.5.

$$M_o = \frac{5,000 \times 56}{4} 0.7 = 49,000 = \frac{I_{11} K}{e} (42,529 \text{ inch-lbs.});$$

$$K_o = \frac{49,000 \times 3.7}{81} = 2,238 \text{ kilograms per square centimetre} \\ (31,831 \text{ lbs. per square inch}).$$

$$M_b = \frac{5,000 \times 56}{4} 0.5 = 35,000 (30,379 \text{ inch-lbs.}) = \frac{81}{3.7} K; K_b = \\ 1,602 (22,785 \text{ lbs. per square inch}).$$

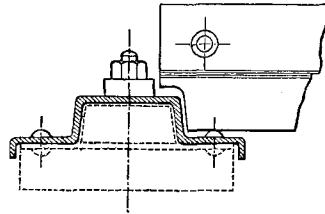
$$p_a = \frac{5,000 \times 1.32}{56 \times 2} = 59; \sigma_a = \frac{59}{22^2} = 0.122.$$

$$p_o = \frac{5,000 \times 1.24}{56 \times 2} = 55; \sigma_o = \frac{55}{22^2} = 0.113.$$

$$p_b = \frac{5,000 \times 0.59}{56 \cdot 2} = 26.3; \sigma_b = \frac{26.3}{22^2} = 0.055.$$

Considering that in the case of longitudinal sleepers the constant for the ground  $\sigma$  was taken at 0.04, and that with  $C = 3$  no greater strain than 1,200 kilograms per square centimetre (17,068 lbs. per square inch) was assumed for the iron, the values obtained,  $K = 2,238$  and  $\sigma = 0.122$ , must be deemed unfavourable, as the sleepers would be partly bent and partly subside. An increase of width to  $B = 27$  centimetres (10.63 inches) would only reduce  $K$  to 1,982 (28,190 lbs. per square inch), and  $\sigma$  to 0.077. For the newly ordered iron transverse sleepers,  $T_{11}$  had therefore been increased to 105, thereby maintaining the required economy. Fig. 78, similar to the Haarmann pattern, was the result. The upper plate was 11 centimetres (4.32 inches) wide and 0.9 centimetre (0.35 inch) thick. The centre of gravity lay 3.8 centimetres above the lower flanges, which were 2 centimetres (0.79 inch) deep. Their weight was about 110.23 lbs. each. At the ends and in the middle vertical transverse ribs were riveted on. The length was that of a normal transverse sleeper  $L = 240$  (7 feet 10½ inches)—

Fig. 78.



$$\frac{1}{m} = 57.8, l = 182, (\Sigma \eta)_a = 1.168; (\Sigma \eta)_o = 1.161;$$

$$(\Sigma \eta)_b = 0.58, (\Sigma \mu)_o = 0.728, (\Sigma \mu)_b = 0.502; P = 5,000 (11,023 \text{ lbs.})$$

$$M_o = \frac{P}{4m} (\Sigma \mu)_o = 52,597 = \frac{105}{3.8} K; K_o = 1,900 (27,024 \text{ lbs. per square inch) below.}$$

$$= \frac{105}{2.6} K; K_o = 1,315 (18,703 \text{ lbs. per square inch) above.}$$

$$M_b = \frac{P}{4m} (\Sigma \mu)_b = 36,267 = \frac{105}{3.8} K; K_b = 1,313 (18,675 \text{ lbs. per square inch) below.}$$

$$= \frac{105}{3.8} K; K_b = 906 (12,886 \text{ lbs. per square inch) above.}$$

Mr. Schwedler.

$$p_a = \frac{P m}{2} (\Sigma \eta)_a = 55 \text{ kilograms}; \quad \sigma_a = \frac{55}{25^2} = 0.088.$$

$$p_o = \frac{P m}{2} (\Sigma \eta)_o = 52 \quad ,, \quad \sigma_o = \quad = 0.083.$$

$$p_b = \frac{P m}{2} (\Sigma \eta)_b = 25 \quad ,, \quad \sigma_b = \quad = 0.040.$$

An increase in the width of the sleeper to 27 centimetres (10.33 inches) would in this case also merely reduce the preceding quantities to 1,874, 1,230, 1,300, 860, 0.068, 0.065, and 0.039 respectively. From this it appeared, that, preserving the same degree of economy, the transverse sleeper permanent way did not give such favourable results as the longitudinal sleeper system. In the section shown in Fig. 78 the intention was, while obtaining a large moment of inertia, to keep the centre of gravity as low as possible, to reduce the stress K. As constructed with the flanges, although the latter were but 1.5 centimetre (0.59 inch) deep, this had only partially succeeded. Nevertheless the form was in so far good, that the greatest stress was confined to the edges; and, in case of the latter being wrenched, the wide footplate sustained the maximum stress, and the conditions became more favourable. By strengthening the footplate and reducing the upper plate, with equal economy and preserving the same value of  $I_{11}$ , a lower position of the centre of gravity would be attained and the coefficient K reduced; in which case washers for the rail bearers would be necessary. The latter could, however, be advantageously used to give the inclined position to the rails, now done by bending the sleepers.

It was a peculiarity of transverse as compared with longitudinal sleepers, that the former were always loaded at the same point (Fig. 22), while in the latter the load rolled. With longitudinal sleepers, therefore, the ground was uniformly compressed and consolidated by continuous uniform rolling, while with transverse sleepers it was only plastically pressed, and thereby assumed the form of the elastic line of the transverse sleeper. Hence in transverse sleepers, the coefficient of elasticity could not well be taken as greater than 3, because in fresh ballast the shape when set was formed. The accuracy of the calculation for the maximum deflection was little affected by this, but the sleeper did not rest firmly under the rails, nor probably the ends, if the pressure of the wheel was not the maximum pressure. In the transit of passenger carriages the so-called easy running arose from the hollow beneath the sleepers.

The greater the hollow the more easily was the line displaced. A remedy consisted in deeply bedding the sleeper, but then, as

in Haarmann's system (Fig. 23), the horizontal component of Mr. Schwedler. the flange pressure on the curves of the line produced a greater deflection of the sleeper in soft ballast, in consequence of the high level of the rails. Thus the firm bedding of the sleeper was neutralised by the high position of the rails. The hollow space under the ends of the sleepers increased with the height of the rails above the latter, the reduction of the length of the sleepers and the softness of the ballast. It would be an improvement if the ballast were previously compressed, or long transverse sleepers used. The latter would rest uniformly in the middle and at the ends, and only have the hollow space (in this case desirable) under the rails, which would combine security of position with easy running.

The best method of attaching the rails to the cross sleepers had not yet been settled; it would seem, however, that with iron sleepers, as compared with the spike-attachment for wooden sleepers, too much was often attempted. In Prussia the Rhenish system of attachment (Figs. 21 and 22) was mostly used, for rails with flanges of from 4 to  $4\frac{1}{8}$  inches. It would be desirable so to arrange the attachment, as to exclude the possibility of its working loose, and enable the sleepers to be covered with ballast up to the head of the rail.

If the usual wooden sleeper with  $L = 250$  (8 feet  $2\frac{1}{2}$  inches), a depth of 15 centimetres (5.9 inches), and a width of 25 centimetres (9.84 inches) was compared with the iron cross sleeper, it would be seen that the ballast could slip out of place against the smooth under-surface with greater facility, on account of the absence of flanges. With the same coefficient  $\sigma$  the wooden sleeper was therefore at a disadvantage. Its moment of inertia was  $I = 7,000$ , the modulus of elasticity  $E = 120,000$  kilograms,  $CB = 3 \times 25 = 75$ ; hence  $\frac{1}{m} = 81$  and  $l = \Pi 81 = 254$ . With the normal length,  $L$  should be  $= \frac{150}{2} + 254 = 277$  centimetres, having a length of 250 centimetres, it consequently belonged to the short sleepers, which were strongly deflected at the ends, lay hollow, and sustained the greatest ground pressure. A rough calculation gave the following results:—

$$p_a = \frac{5,000}{2 \times 81} \times 1.5 = 46 \text{ kilograms (101.41 lbs.)} = \sigma \times 25^2;$$

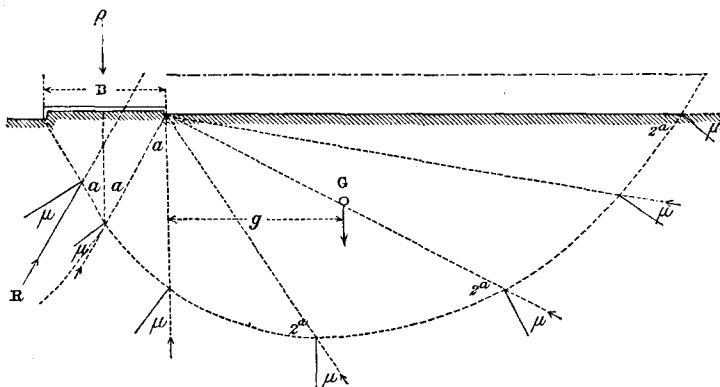
$$\sigma_a = 0.073.$$

$$M_o = M_b = \frac{5,000 \times 81}{4} \times 0.5 = 50,625 (43,920 \text{ inch-lbs.}) = K \frac{7,000}{7.5};$$

$$K_o = 54 \text{ kilograms per square centimetre (768 lbs. per square inch).}$$

Mr. Schwedler. It was desirable that  $p_a$  should be rather less, while  $K_a$  might be somewhat greater. An improvement would take place with a slight reduction in the height and increase of the length and width. It appeared from this that wooden transverse sleepers compared with those of iron, were, as regarded the coefficients  $K$  and  $\sigma$ , not unfavourable, only they did not oppose the same resistance to longitudinal displacement as iron cross sleepers with three transverse ribs (one in the middle and two at the end), and, on account of the absence of flanges, did not hold the ballast firmly together. In further discussing the theoretical aspect of the ballast bed, and the equation  $p = B^2 \sigma$ , as a basis to start from, a homogeneous material, without cohesion and more or less rough, would be taken. It was usual to measure the roughness by the angle of repose  $\mu$ , so that the coefficient of friction within the material was  $tg. \mu = \rho$ . If the sleeper was laid on the horizontal surface of the material (Fig. 79), and the latter was sufficiently consolidated,

FIG. 79.



on the sleeper being subjected to a vertical load a wedge (prism) of ballast would be immovably held together by the flanges; the point of the wedge formed the angle  $2a$ . According to the well-known theory of earth-pressure,  $a = \frac{\Pi}{4} - \frac{\mu}{2}$ . The reaction on the surfaces of the wedge was  $R$ , forming with the normal the angle  $\mu$ , and acting on the lower third of the surface. It was determined by the equation  $p = 2 R \cos a$ . Now if the wedge were to displace the earth on either side, a slip surface must result, the conjugated slip surfaces of which passed through the edges of the sleeper and produced the series of planes shown in Fig. 79. The resultant

cylindrical slip surface formed with this series of planes, which Mr. Schwedler indicated the outer lines of pressure, the angle  $2\alpha$ , so that the direction of pressure deviated by the angle  $\mu$  from the normal to the slip surface. If the mass of earth thus bounded had the weight  $G$ , and its centre of gravity were at the distance  $g$  from the edge of the sleeper, then, as the outer lines of pressure exerted no leverage, the moment about the edge of the sleeper would be—

$$Gg + R \frac{B}{3} \cdot \cos \alpha - p \frac{B}{2} = 0,$$

whence 
$$p = \frac{2Gg}{B} + \frac{2}{3} R \cos \alpha = \frac{2Gg}{B} + \frac{p}{3},$$

or 
$$p = \frac{3Gg}{B}.$$

From an accurate drawing  $p$  could thus be directly ascertained. If the edge of the sleeper lay at a depth,  $h$ , under the surface of the ground, the layer above the cylinder of ballast to be displaced must be added to the weight  $G$  and  $Gg$  become greater. The analytical calculation of the value of  $p$  derived hence gave—

$$p = \frac{B^2}{8} \gamma \cdot \frac{e^{3\rho\alpha} \cdot e^{3\rho\frac{\pi}{2}} + e^{-3\rho\frac{\pi}{2}}}{\sin^3\alpha \cdot 3\rho + \frac{1}{3\rho}} + \frac{3Bh\gamma}{8} \frac{e^{2\rho\left(\frac{\pi}{2} + \alpha\right)}}{\sin^2\alpha},$$

where the second portion represented the influence of the depth to which the sleeper was sunk in the ballast ( $e$  was the basis of the hyperbolic logarithm).

If the second part was ignored, and the material assumed to be sharp sand, which had an angle of repose of 3 to 4, then  $\rho = \frac{3}{4}$ ,  $\mu = 37^\circ$ ,  $\alpha = 0.46$  length of arc,  $\sin \alpha = 0.4462$ , and if  $\gamma = 1,600$  kilograms per cubic metre (1.2 ton per cubic yard), or  $\frac{1,600}{10^6}$  per cubic centimetre, then

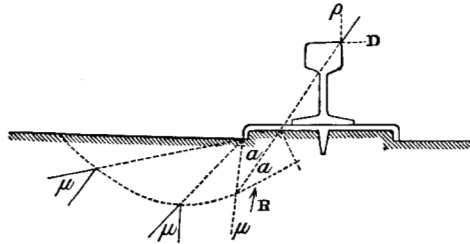
$$p = \frac{B^2\gamma}{8} \cdot 400 = B^2 \cdot 0.08,$$
 hence  $\sigma = 0.08$ , the limit of displacement. With the coefficient of friction  $\rho$  of the material, the value of  $p$  altered considerably; thus—

for 
$$\left. \begin{aligned} \mu = 30^\circ, p &= \frac{B^2\gamma}{8} \cdot 126; \sigma = 0.025 \\ \mu = 45^\circ, p &= \frac{B^2\gamma}{8} \cdot 1,800; \sigma = 0.360 \end{aligned} \right\} \text{as the limit of displacement.}$$

Mr. Schwedler. The roughness of the material used for ballast was consequently of great influence on the stability of the sleeper, on the one hand, and on the determination of dimensions on the other.

Besides, the pressure must act vertically and centrally on the sleeper. With an inclined pressure (Fig. 80) the wedge of earth, through the apex of which the line of pressure passed, and which was symmetrical to the latter, decreased rapidly, as did also the cylinder G, whereby displacement was greatly facilitated. The

FIG. 80.



object of tie-rods and transverse connections in the longitudinal sleeper was to resist the horizontal components of pressure, and the moment resulting therefrom, and of directing the pressure vertically and centrally with regard to the sleeper. In the transverse sleeper system this was effected by the rail and sleeper.

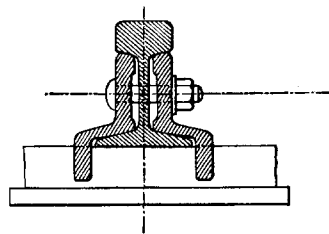
It only remained to speak of the individual supports. No doubt a round plate 50 centimetres in diameter, with a vertical rim turned downwards (flanged), was capable, if the ballast was sufficiently compressed, of sustaining a load of 5,000 kilograms (say 5 tons), and elastically transmitting it to the ground. Indeed, the running might be easier than with stone supports, as under the iron plate a small hollow would form in the middle, into which the centre, which alone should be loaded, sank gently. Instead of the smooth plate, one similar to that used for aneroid barometers would be not unsuitable. The plates would be laid horizontally, and furnished in the centre with inclined washers as supports for the rails. Now, although such plates might, on account of their considerable area, appear sufficiently rigid against side-pressure, still, for the purpose of maintaining the gauge and inclination of the rails, transverse connections of some stiffness could not be omitted. The thickness of the plates, which might be 0.2 inch or less, could not at present be theoretically determined; it was, however, important that they should retain a certain degree of elasticity. A similar

tendency appeared in the compressed transverse sleepers exhibited at the Paris Exhibition of 1878; these were narrow between the rails, wide outside the latter, and dished with a flange all round. Mr. Schwedler.

The reaction of the ballast was not uniformly distributed over the width of a sleeper or plate, but was smallest at the edges, and increased towards the middle proportionally to the distance from the edge. The plate only opposed the minimum of resistance during the manipulation in laying and ballasting; the bending moment was nil at the edge and increased towards the middle, as, for instance, in a plate supported at the centre and loaded pyramidally with earth. Where, in the case of longitudinal sleepers, their moment of inertia was of no importance, they might also be considered as a series of individual supports; or as a series of cross sleepers, specially arranged under each rail, which had, therefore, a width of 0·4 inch, and length of 11·81 inches, and were loaded in the middle. The calculation of the thickness was obtained by substituting, in the formulæ for the transverse sleepers,  $2b = 0$  and  $2P = p$  ( $p$  to be taken from the longitudinal sleeper). The thickness must then be taken as uniform, so that the moment of inertia remained constant. Following up this method a step further, a strip of corrugated plate iron,  $11\frac{3}{4}$  inches or more wide, might serve as a longitudinal sleeper, in which every corrugation would be regarded as a small transverse sleeper for a single rail. The necessary rim of the longitudinal sleeper thus formed might, perhaps, be made by pressing down the corrugations during manufacture.

The rails for the transverse sleeper system of permanent way should, in the first place, have good fish-plates to replace the moment of inertia of the rail, as in the longitudinal system. It would be advisable to recess the fish-plates at the ends, so that they might rest on two cross sleepers and lay firmly between the latter to prevent the rails shifting (Fig. 81). Suppose the load  $P$ , from a wheel bore on the centre between two sleepers, the interval of the latter being  $\lambda$ , then the bending moment under the wheel, would be, with regard to the elasticity of the sleepers, nearly equal to that to which a length,  $\lambda$  of rail, freely supported at the ends, would be subjected, or  $M = \frac{P\lambda}{4}$ , as the advantage of continuity was partly neutralised by the elasticity consequent on soft ground.

FIG. 81.



Mr. Schwedler. On hard ground,  $M_e$  approximated to the value  $\frac{P\lambda}{4} \cdot \frac{37}{53} = P\lambda$  0·173, the strain on the rail being diminished. If the rail for longitudinal sleepers  $\frac{I}{e}$  was compared with that for transverse sleepers  $\frac{I_1}{e_1}$ , with the same load  $P$  and the same stress  $K$ , there followed,

$$K = \frac{Pe}{4I} \sqrt[4]{\frac{4EI}{CB}} = \frac{Pe_1\lambda}{I_1^4},$$

$$\frac{I_1}{e_1} = \lambda \frac{I}{e} \sqrt[4]{\frac{CB}{4EI}},$$

$$I = 700, e = 5\cdot7, C = 3, B = 32; \sqrt[4]{\frac{CB}{4EI}} = \frac{1}{88},$$

$$\frac{I_1}{e_1} = \frac{\lambda I}{88e}.$$

*i.e.* when the distance between the sleepers was 88 centimetres, (34·65 inches) both rails would have the same moment of resistance; with a greater distance the moment of resistance of the cross-sleeper rail must be correspondingly larger.

With regard to economy, the centre of gravity of the rail when worn out must be at half the height of the section of the rail. This also formed the basis of the calculation.

A width of head of  $2\frac{5}{8}$  inches should, with respect to the wear caused by the wheels, be the minimum; to resist breakage the depth of head should be at least 1 inch; the web to resist inclined pressure say  $\frac{3}{8}$  to  $\frac{7}{16}$  inch; the flanges  $3\frac{1}{2}$  to  $3\frac{5}{8}$  inches wide, with a depth of  $\frac{1}{16}$  inch for longitudinal sleepers, and 4 to  $4\frac{1}{8}$  inches wide, with a depth of  $\frac{3}{4}$  inch for iron and wooden transverse sleepers. With reference to the fish-plate bolts, and the friction of the fish-plates, the surface of contact of the latter with the head and flange should have an inclination of 1:4. The depths of head and flanges were measured from the point of insertion of these inclinations. The depth of web was determined by the required moment of inertia. According to the amount of traffic a packing plate of from  $\frac{3}{8}$  to  $\frac{3}{4}$  inch should be added for the whole 9 metres' (29 feet 6·34 inches) length of the rail when soft homogeneous steel was used. From the above there resulted, for rails with longitudinal sleepers, a height of about 4·32 inches, and for rails with transverse sleepers a height of 4·72 inches, when worn out.

Mr. Smythe. Mr. A. J. HAMILTON SMYTHE observed that, in discussing the practical value of the various systems of metallic permanent way,

it might fairly be premised that no system was likely to be generally used that required a special section of rail. Steel rails had been laid so extensively within the last few years, and their probable duration on the lines of moderate traffic, which composed the majority of railways, was so long, that it was hardly to be expected that they would be replaced by rails of other sections as necessary parts of any systems of metallic permanent way, however good.

Much the same line of argument, so often used in discussing the relative advantages of transverse and longitudinal systems of wooden sleepers, appeared to apply to the case of metallic sleepers, and seemed to have led to the same result. The Author's statement that there could be no tendency in sleepers to shift endways on straight lines or easy curves was contradicted by experience. Where the ground was soft, or the ballast scanty, even straight roads laid with a heavy rail on wooden sleepers were frequently getting out of line, notwithstanding the greater friction of wood than of iron on ballast. Judging from this experience there seemed good reason for the Continental practice of closing the ends of the iron sleepers to increase the resistance to endways shifting.

The Author also doubted the advantage of burying the sleepers in the ballast; but considering the inferior bond formed between iron and ballast as compared with wood and ballast, it seemed all the more important for obtaining a steady road that iron sleepers should be well embedded in the ballast, and that in order to obtain a noiseless road as much ballast as possible should be laid over them.

Notwithstanding the quoted objection of Mr. Grüttefen to the horizontal feet of the Vautherin sleeper, they appeared to have the advantage of enabling a considerable weight of ballast to be imposed on the sleeper, and also to resist its tendency to rock on its longitudinal axis, which was found troublesome even with rectangular wooden sleepers, on account of the consequent displacement of the packing. The system of fastening devised by the Author appeared to be the simplest yet introduced as regarded laying in and removing the rails, but the bowed clip underneath the sleeper must interfere with firm and even packing at the point where this was essential. As regarded curving the transverse sleepers to obtain the tilt, it was obvious that straight sleepers were handier to stack and transport; but apart from this it was difficult to believe that curved sleepers could be depended on to keep the tilt and gauge true under heavy traffic, unless the packing were abso-

Mr. Smythe. lutely perfect. No doubt the use of tilt plates added to the probability of the road chattering ; but if used wider than the rail base they would have a counterbalancing advantage in distributing the pressure of the rail over a greater area of the sleeper, thus preserving the surface of the latter to a considerable extent.

Mr. Vautherin. Mr. J. VAUTHERIN explained that the non-success of the Belgian trials in 1868 was due, firstly, to the insufficient thickness of the metal (the sleepers only weighed 12·5 to 13 kilograms per lineal metre, say 25 to 26 lbs. per yard), and, secondly, to the sleepers having been too short. The engineer of the Belgian Grand Central Railway thought it practicable to reduce the length of the intermediate sleepers to  $86\frac{1}{2}$  inches, and even to  $82\frac{1}{2}$  inches ; so that the track took a series of double wave-lines in plan. Calling *a* the joint sleeper of 2·4 metres ( $94\frac{1}{2}$  inches), the order was *a, b, c, c, b, a, b* and *c* representing lengths of  $86\frac{1}{2}$  and  $82\frac{1}{2}$  inches respectively. It was the short intermediate sleepers that broke. The justice of this conclusion was proved by the fact that in 200 kilometres of iron-sleeper track laid by the Belgian State Railways fractures had not occurred, and the same applied to the Dutch and German sleepers. The Author had not mentioned the employment since 1868 of the Vautherin sleepers, on 100 kilometres of the Algerian lines of the Paris and Lyons Railway. Mr. Demoly, the engineer of that company, had attentively studied the question of iron sleepers, and made a very interesting report on it. (See p. 70) This report, dated 9th July, 1880, was followed, on the part of its Author, by the ingenious and efficient modifications of the original fastenings, as described elsewhere. Mr. Vautherin's most recent English patent was not yet issued, but he submitted the German specification, and also drawings of the fastenings. He would add that the section adopted by the Bergisch-Märkisch Railway (Fig. 20) had his entire approbation, and was, indeed, adopted by himself in his first patent as an alternative, especially intended for use with coarse ballast. In conclusion he believed that the use of iron sleepers would have been sooner popularised outside Germany if it had not been at first endeavoured to produce them at a price as low as that of wooden sleepers, which had obliged the use of sections too slight for their work.

Mr. Wright. Mr. ROBERT WRIGHT had adopted the sleeper referred to by the Author (Fig. 22) in 1878, and there were now about fifty-five thousand of these sleepers in use in the main lines ; and tenders had been issued for twenty thousand more. These sleepers answered very satisfactorily ; there was no sign, or hearing, of chattering of parts, nor did he expect such, the clips and bolts

holding all firmly together. The tilt, or sole-plate, allowed the sleeper to lay so much the deeper in the ballast; and this was of much importance in Holland, where, in a great measure, hill sand had to be used for ballast. Curved sleepers, with their ends projecting upwards and exposed in summer to expansion from heat, followed by loosening of the ballast, and the middle of the sleeper taking a bearing on the ballast, and thus causing a rocking in the length of the sleeper, were, he thought, not to be compared with the advantages afforded by straight sleepers. The inspectors and gangers on the Dutch Rhenish Railway were in every way pleased with the sleepers, and found that a firm road was obtained after about twice good packing. He considered that the sole-plate gave strength to the sleeper where it was most required, and that it prevented the rail from wearing into the sleeper. The "Organ für die Fortschritte des Eisenbahnwesens," "Verein Deutscher Eisenbahn Verwaltungen,"<sup>1</sup> contained an article on the subject of curved sleepers, in which the writer, for various reasons condemned their use. In the same periodical it was stated,<sup>2</sup> that according to the experience obtained on the Rheinische railway in Prussia, the cost of labour in maintenance of the iron and steel permanent way compared very favourably with the old wooden-sleeper system. In regard to the longitudinal systems, since 1869 several hundred yards of Hilf's had been in use under his charge in the main line, subject to a moderately heavy traffic. It was the cheapest for maintenance, in regard to materials, of any road of which he knew; but it had the drawback that it continually crept in the same direction as the train, and thus gave extra labour in bringing back again from time to time. Haarmann's longitudinal system had been adopted for the steam tramway from the Hague to Scheveningen, and it made a first-rate smooth tram-road. He was inclined to think that Mr. Webb's sleeper would prove very suitable.

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15 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,  
in the Chair.

The discussion upon Mr. Wood's Paper on "Iron Permanent Way" occupied the whole evening.

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<sup>1</sup> 1881, pp. 137, 139.

<sup>2</sup> 1881, p. 205.