Mr. Sandberg said, that when this subject was brought before the Institution two years ago by Mr. R. Price Williams, few Railway Companies had adopted steel rails; but that now nearly all lines used them to some extent. He thought conclusions had hitherto been formed without sufficient experience; but he hoped the statements of permanent-way engineers would supplement the deficiencies of his Paper. Continental railways, as yet, afforded very little experience; and it would be for England to show what had to be done in this important engineering question. On the Swedish lines steel rails were being adopted, though the traffic was comparatively light.

A simple way of ascertaining that the steel employed was sufficiently tough for rails, was to bore a hole in the bottom plate of the ingot-mould, 2 inches in diameter at the top, $1\frac{3}{4}$ inch in diameter at the bottom, and two inches deep; the piece projecting from the lower end of the ingot was broken off when cold, and having been heated to a red heat, was flattened into a cake or plate such as he then exhibited. When cold it was doubled up under a hammer, and its toughness under this treatment decided its suitability as a steel for railway purposes. Afterwards it was sent to the laboratory, and the carbon determined by the Eggertz process. The percentage of carbon and its registered No. were then marked on each piece for further reference. If under the bending-test the cake broke short, the ingot from which it was taken could be used for making springs, &c., which required harder material.

He had been furnished with some particulars respecting the use of steel rails on the London and North Western Railway, from which it appeared that steel rails were laid down at Camden Town in May, 1862, in seven different places, and one pair of rails put down in January, 1863. They were laid so as to form one side of a single line of rails, the opposite side being composed of ordinary iron rails laid down to test their comparative wearing qualities.

The effect of wear upon the ordinary iron rails was shown in the following statement drawn up by Mr. Woodhouse, the Engineer of the Permanent Way:—

"The 1st face of	5	steel rails was wearing as	compared with the	2nd	face of	5	iron rails.
"	4	"	"	3rd	"	4	"
"	5	"	"	4th	"	5	"
"	12	"	"	5th	"	12	"
"	6	"	"	6th	"	6	"
"	5	"	"	7th	"	5	"
"	2	"	"	8th	"	2	"
"	3	"	"	9th	"	3	"
"	5	"	"	10th	"	5	"
"	1	"	"	11th	"	1	"
"	1 (*a.*)	"	"	15th	" in August, 1865, when the opposite steel rail was removed.		
"	1 (*b.*)	was wearing the 23rd face in March, 1867, when the opposite steel rail was accidentally broken, and was taken out.					

"(*a*.) The steel rail removed in August, 1865, was taken up to enable Mr. Bessemer to read a Paper on it at the meeting of the British Association.

"(*b*.) The steel rail removed in March, 1867, was not broken by fair wear and tear, but in consequence of some vehicles getting off the road and causing damage.

"At the time of the removal of the above-mentioned steel rails they were wearing thin, and were bruised on the outer edge. The latter of the two rails was reduced in height by about $\frac{5}{16}$ths of an inch."

All the forty-eight steel rails remaining in the road were still in good condition, and none of them had yet been turned. They were still wearing satisfactorily.

If the number of worn-out iron rails in each case cited in the previous table were summed up, it would be found to amount to a total of three hundred and fifteen, while the number of steel rails wearing on the opposite side, but in good condition, amounted to fifty. So far, therefore, as the experiments had proceeded, each steel rail was found to have worn out, on an average, six iron rails; and on these data the annuity tables had been calculated.

Mr. Edward Williams said there seemed to him some danger of false conclusions as to the cause of the superiority of rails made by the Bessemer process. These rails would wear well, not so much because they were made of steel, as that they were rolled from solid ingots.

Rails, however carefully made by the old process, being built up, were, of course, more likely to laminate than those which were made from ingots which had no layers in them. He was convinced that the question of good or bad iron rails was simply a question of welding, and that the quality of the iron was comparatively of little or no importance, except so far as one description of iron welded more easily than another, and that the kind of iron that welded most easily would make the best built-up rail, because there was the least chance of imperfect welds. A rail made from an ingot would be better than a built-up rail, but whether, price being taken into account, it might not, in many cases, be economical to use piled rails, was another question. He was inclined to think it would be so.

With regard to putting a steel top on an iron rail, it was open to the objection that steel could not, with certainty, be welded on to iron, and there would be danger of the steel head coming off under heavy work.

He thought that what were usually called the best iron rails—rails for which an extra price was paid, and which were carefully watched during their manufacture,—were really the worst rails, for the reason that the iron composing them had to be worked over and over again, and after each working it welded with greater difficulty than before. No kind of iron welded so easily as puddled bars, and the nearer the wrought iron was to cast iron, the better rail it would make. If it were possible to make a rail direct from a puddled ball, it would probably make the best iron rail that could be produced, but, up to the present time, it had not been found possible. The system adopted in the North of England was, he believed, the best for producing really serviceable iron rails. A puddled ball, a rough, spongy sphere of about 15 inches to 18 inches in diameter, was put under a hammer and received a few blows to flatten it. Another ball was put on the top of it, and it was served in the same way; the mass was then hammered into a rectangular slab about 10 inches, or 11 inches wide, and about 2½ inches thick. Two or three such flat slabs were then put together in a furnace, raised to a welding heat, rehammered, and rolled into the slab to form the head of the rail to be produced. This system gave just as much work as was necessary to insure soundness of the slab without overworking it. He had no doubt that this mode of working was much better than roughing down from piles composed of thin puddled bars. Indeed, long experience had proved to him that, whatever system was adopted, it depended upon the capacity of the iron for welding, and the giving it a proper heat, whether or not the rail produced would wear a long or a short time.

He thought the system of supplying exact specifications, and watching the manufacturers of rails, had not succeeded; and he would suggest one which, he believed, would produce much better rails than had been turned out lately, and at a cheaper rather than at a higher price. He would advise that Railway Companies should only apply for tenders to rail-makers of good reputation, that the onus as regarded the durability of the rails supplied should be left upon such makers, and that the Railway Companies should make no secret of the results; in fact, that there should be a periodical return of each maker's rails worn out, and the amount of work they had borne. The more public such returns were made, the better it would be for those who supplied really good rails, and the system could scarcely fail to be a better protection to Railway Companies than anything they now possessed. Of course, the prices paid for the rails should be given as well.

Sir Charles Fox thought the value of steel rails was underrated, inasmuch as it was generally considered as a question of steel *versus* iron. He did not say that the material of steel was not better for the manufacture of rails than iron, as it undoubtedly was so, but he thought that was not a fair exponent of the difference of the value of the two. An iron rail when manufactured, even in the best way, was little more than a bundle of rods; and the top slab might be compared to a piece of hoop-iron lying on the top of an anvil (the body of the rail), when a heavy locomotive passing over it acted as a sledge hammer. If a locomotive wheel were permitted to run over a penny-piece, by its crushing weight it increased its length; but as that would not be the case with the top portion of a rail, because it was penned in lengthwise, it necessarily spread sideways, and became laminated. A steel rail was rolled from one solid ingot, not obtained in the ordinary way of casting ingots by pouring the material from the lip, but from a stopple hole at the bottom of the ladle, by which means no scum would get into the ingot, and it was consequently homogeneous and perfect. It was then rolled into a solid rail having no tendency to laminate, and that was one, and, in his opinion, the main reason why a steel rail was so much more durable than an iron one.

Having had for some years the charge of a long length of permanent way, he had carefully examined many defective rails with a magnifying glass, to ascertain the cause of their failure, and he found, in nineteen cases out of twenty, that the defects arose from lamination of the iron resulting from defective welding. It was, therefore, important to have a better, harder, and more homogeneous material for rails. But he thought that with harder rails engineers would be tempted to increase the load to be placed upon them; and that they had got into a somewhat similar dilemma to the one to which the late Mr. Robert Stephenson used to refer when he said, "It is of little use making improvements in locomotives, because the result is to induce engineers to make still steeper gradients."

Steeper gradients had, however, become a necessity; and, therefore, it was no doubt important to be able to pass heavier engines over such gradients, but in doing so care should be taken in using only such a load as would not be beyond the limit of elasticity of the material of which the rails were made; for if every time a locomotive wheel passed over a rail it sank into it to some small extent (and it undoubtedly did so), and if that sinking were not entirely recovered when the wheel passed on, he need not say the destruction of the rail would not be far distant.

Mr. T. E. Harrison, Vice-President, agreed to some extent with the remarks made by the previous speaker; and representing as he did a Railway Company in the North of England, the chief part of whose rails were purchased from the manufacturers of the district, he had minute observations taken of the wear of those rails, and he might state as the result, that on between 700 and 800 miles of permanent way of the North Eastern Railway the average duration of the last complete set of rails was found to be about fifteen years and a half; and some which were laid down in 1834 were still in use. There were rails made in Wales which had been in use in some cases more than twenty years which were still in excellent condition. In other cases rails had to be taken up after being down only a comparatively short time. On the occasion of the examination of a number of rails taken from considerable lengths of line, which had been down for a long time, Mr. Harrison had advised that a careful analysis should be made; and it had been found that the rails which lasted the longest, contained $\frac{3}{10}$ths to $\frac{5}{10}$ths per cent. of phosphorus, and many of the rails which exhibited the least signs of wearing were such as would be generally considered bad iron. Many years ago large quantities of rails had been purchased in Wales under peculiar circumstances; they were called 'Hudson's' rails; and objections were raised against their being used, because they were manufactured under a contract, without a specification, and it must be admitted that the fracture was that of very inferior iron. They were, however, laid down on a part of the line where the traffic was very heavy; and after fifteen years' wear, many of those rails were still in good condition. This result was in accordance with the views of Mr. Williams and of Mr. Vaughan, of Middlesboro', that the specifications of Civil Engineers showed that they did not thoroughly understand the best mode of manufacturing durable rails. He accorded with that opinion; for when he compared the rails made on a more expensive specification, with a view of getting a more fibrous quality of iron, with Welsh or with North Country rails made without a specification, he found they almost invariably lasted longer than the rails made in accordance with the most elaborate specification. After consultation with two of the Directors of the North Eastern Railway, it was determined to collect samples of all those rails which had been longest down, and to place them side by side with samples of the most unsuccessful, and to have an analysis made of the whole; and then they determined to send to all the manufacturers in the locality, and to ask them to supply each a thousand tons of rails, without giving any specification. They were now in course of manufacture; and the prices at which the manufacturers had contracted to deliver them were below what they would have charged for rails made according to the specification previously used. It was intended to lay down alternate rails from each of the nine manufacturers; and they would be laid where there was the largest amount of wear. If they wore well it was assumed that the manufacturer would be prepared to supply similar rails for the future. The effect of this plan had been to put the manufacturers of the North a little upon their mettle. One sample of rails on the table had been down for twenty-four years: others had been laid in places where eighty trains a day had passed over them during fifteen years. Then there were two samples from Messrs. Bolckow and Vaughan, made without specification, which contained 0·5 per cent. of phosphorus. They were laid near the

Milford Junction, and had not been turned. Many thousands had been taken from the main line and had been laid down on some of the branches, where they would last for the next twenty years. Seeing what could be done with iron rails lasting anything like the period mentioned, the use of steel became unnecessary as a matter of economy. At the same time, on portions of the North Eastern line where there were stations and a great deal of shunting, the rails would not last more than two or three years, and in those cases steel rails had been laid down. A difficulty with regard to the iron rails arose from the test to which they should be submitted. No doubt iron which was best for wear would not stand a heavy blow, and where the rails were submitted to the test of a heavy falling weight they would be found deficient. The difficulty lay in making iron rails of sufficient hardness, and at the same time of sufficient strength for use. He could not refer to a single instance of the breaking of ordinary rails when the line was kept in good order; and the question arose, whether the test of a heavy ball should be applied; if the road was in good order he doubted whether any blow ought to come upon the rail: and even that could be met by putting in a few additional sleepers and shortening the bearings. As a question of economy, with the cost of the additional sleepers and chairs, an iron rail so treated would be cheaper than one of steel. He was an advocate for using the double-headed rail. The North Eastern system embraced a large extent of branches used for coal traffic, on which the partially worn rails were used. There were many miles of those lines on which a new rail had never been laid since the rails were first put down. These branches were maintained by rails culled from the main line, and some of them were used without being turned. Though a rail might be unfit for the main line, it would serve for a less important part of the system; and under such circumstances the double-headed rail was useful. He was not prepared to say that in all cases it was desirable to use it, because the hardest iron might be applied to one head of the rail for wear and a different quality to the bottom web; and a rail thus obtained would stand a heavy falling test; and if the rails were not going to be turned it was a matter of less importance. With regard to the use of steel, he thought if the wear he had mentioned could be got out of the iron rails it would be some time before steel would be used to a large extent; but if the size of the locomotives and the speed of the trains were further increased, steel rails might become a matter of necessity upon the main lines. The rail-makers in the North could make as good rails as they did formerly, by going back to their old mode of manufacture; and it would then be found that the ordinary rail would regain a position which, he believed, to a large extent it had for some time lost.

Mr. W. R. Innes Hopkins, being one of the Northern iron-masters referred to, did not intend to make the rails that he proposed to have tried on the North Eastern Railway according to the formula of any Engineer. He was quite certain that, as Engineers had increased their tests, they had augmented the strength of rails at the expense of their wearing power, and it was a matter of experience that a strong fibrous rail would not stand heavy traffic nearly so well as one with a hard crystalline head. In paying great attention to the wearing power of double-headed rails, they were frequently rendered brittle, and became liable to be broken, but experience showed that very far below the standard now used for testing would give a sufficiently strong double-headed rail to bear the heaviest traffic. Rails that had been laid down for many years, in the North of England, and had stood the traffic well, on being tested, were found to break at one-fourth of the weight frequently prescribed, whereas rails that had become laminated, and had quickly worn out, did not break under the operation of testing. What was technically called 'strong iron,' did not weld readily, and as the weldable property was diminished, the homogeneous character and wearing power of the rail was destroyed. On most foreign lines the Vignoles' form of rail, with a broad lower flange, had been adopted; this gave a greater opportunity for combining wearing power with strength than any double-headed section, because hard iron could be used for the head, and great strength and power of resistance to testing could be obtained in the web and the flange. He considered that the shape of many double-headed rails was far from good; they were too quickly cut in under the head; and many failures were caused by the side of the head breaking off, from not being sufficiently supported beneath. The section of the rail used by the Dutch Government showed a pear-shaped head, which he believed was as good a form as could be devised. There was some trouble at first in 'fishing' this rail, but the Dutch engineers used an arched fish, which appeared, to a great extent, to overcome the difficulty.

Mr. Fowler, Past-President, considered it rather remarkable that Mr. Harrison should have obtained better rails without a specification than when he had given specific instructions; and he could only account for it by supposing that the specification had been drawn for some other rail-making district than that in which the rails were made, for it was impossible to suppose that he would do otherwise than give such directions as would lead to the manufacture of good rails. Mr. Williams stated that the rails should be hard and crystalline, rather than fibrous. No doubt these were desirable qualities, and it was equally so that a rail should not be brittle. He could not agree in the opinion that specifications were useless, and that engineers did not know what they wanted.

On the contrary, he thought that Mr. Hopkins was mistaken, and that engineers did know what they wanted in a rail. Mr. Hopkins might suppose that, because the engineer tested against the possibility of brittleness by a falling weight, therefore he desired to have great ductility: that was a wrong conclusion; but it was important to be assured that the rail was not so hard as to be brittle; and that was the object of engineers in some of their tests. Mr. Harrison's plan of getting nine manufacturers to lay down their rails under the same circumstances would afford an excellent test, and, although without a specification, no doubt he would get good rails laid down; but then it was desirable that he should ascertain exactly the process adopted in the manufacture of those rails, and, after making careful tests, he should analyse the results, otherwise, if the manufacturers were allowed to lay down nine different kinds of rails, and no observations were taken, he would be in no better position than he was at first. In his opinion it was not desirable in the interests of railway proprietors or of the public, that engineers should abdicate their functions; but he would advise them to draw specifications, and to take pains to ascertain the process of manufacture of the iron, and to confer with the manufacturers. In former times he had got rails without a specification, paying an extra price for quality, but his expectations were not realized, and he got worse rails for a higher price.

It would be admitted that no rule could be laid down for the manufacture of rails which would be applicable to all localities. The question must be considered chiefly with regard to the mixture of iron to obtain a certain result. He believed steel would for almost all purposes eventually supersede the use of iron. But, as in the case of all new applications, caution was necessary. There could be no doubt, however, that in certain circumstances, such, for instance, as on short lines for very heavy traffic, the use of steel was most desirable. With regard to its extended use on main lines, each case must be dealt with separately, taking into account the quantity and quality of the traffic, and the varying price of the material. The price of steel rails was falling; and the difference between good iron rails and good steel rails would have a tendency to diminish. At the same time he hoped it would never so far diminish as to lead to the use of an inferior quality of steel rails. He would advise engineers to adopt the plan of having their steel rails carefully tested. The difficulties which led to the manufacture of steel that was too hard were, he believed, being gradually overcome, and existed now in a trifling degree only. The Tables that had been produced were remarkable, but he did not think that the Institution possessed at present sufficient data to induce it to regard them as satisfactory. That good steel rails would last much longer than iron rails no one could doubt; but he had no confidence in a calculation which assumed that steel rails would last from thirty years to eighty years, though Tables, such as those exhibited by the Author, even when the life of steel rails was to some extent assumed, were no doubt useful. There were advantages in the use of steel rails which had not yet been alluded to. Taking the case of a main trunk line, such as the Great Northern, Mr. Price Williams had stated that the life of rails on that railway was eight years.[1] There was no great object in having sleepers which lasted longer than the rails, because few engineers would, on a main trunk line, put new rails on second-hand or half worn-out sleepers. But if steel rails were used lasting over a period of from sixteen years to twenty-four years, it became immediately an important object to make the durability of the sleeper as great as possible, because, in addition to the economy that would result from such an arrangement, there was a material element of convenience in not having the permanent way disturbed more frequently than was absolutely necessary. If, instead of renewing the permanent way every eight years, it became necessary to do so only every sixteen years, a great advantage would be gained. It was well known that when one-eighth of a main trunk line was always in the course of renewal, it considerably interfered with the safe working of the line. Simultaneously with the use of steel rails it would be necessary to introduce a superior quality of timber instead of what was called sleeper timber, which consisted of the tops of trees of an inferior quality. It was probable also that the form of the rail would be changed, and that, instead of the double-headed rail with fastenings composed of many parts, engineers would adopt the Vignoles form; this might be made with steel, with the bottom so wide that there would be no difficulty in having the base as large as that of the largest chairs. His own experience was in favour of a base 6½ inches in width. He considered chairs objectionable; but with a good Vignoles section of rails, a bed of great simplicity, greater strength, and more security would be obtained. That was one amongst the many advantages arising from the use of steel.

Then, again, the question of turning would no longer be considered of importance when the material lasted thirty years. He did not approve of the compound rail with a steel head and an iron bottom, as the welding was sufficiently difficult whether in iron or in steel alone, but that difficulty would be greatly increased by the attempt to make a compound rail of steel and iron. In some instances the use of such rails had been satisfactory, but in others very unsatisfactory; and he would advise Engineers to be content, either with good iron rails, or with good steel rails, and not to attempt a combination.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 353.

Mr. Isaac Lowthian Bell admitted that complete success had not hitherto attended the joint deliberations of engineers and iron-manufacturers.

Although steel in some other form than that generally used up to the present time had been alluded to, he apprehended that, as no practical plan had been hitherto devised and adopted for the manufacture of steel rails upon a large scale, it would hardly be prudent to consider any other than Bessemer steel in the present discussion. Any comparison of economy of course resolved itself into a question of cost and durability. Nothing commended itself more strongly to the mind of the manufacturer than the production of the Bessemer steel, particularly as it was occasionally practised in France, where pig-iron was run from the blast furnace into the converter, and the rail was rolled direct from the bloom, without passing under the hammer. No doubt that was a most ingenious process, and one which might be brought into universal application, but for other difficulties connected with the manufacture of Bessemer steel, which did not obtain in the manufacture of iron. In this last-named operation, the process of puddling separated in a great measure the phosphorus from the iron; whereas it was a peculiarity of the Bessemer process that the phosphorus was condensed in the steel. In selecting iron for the Bessemer process, it was important to consider the composition and the difference in the properties of the various kinds of iron to be dealt with. From his own analyses, and from the Tables of composition given in Dr. Percy's "Metallurgy," it might be assumed that in Cleveland pig-iron there was an average of about 1¼ per cent. of phosphorus; in North Staffordshire, about 1; in Derbyshire, 1; in Bowling, ·51; in South Wales, ·49; in South Staffordshire, ·41; in the Forest of Dean, ·137; in Weardale, ·10: and it was only in hæmatite iron that the phosphorus fell so low as ·047 per cent. He believed that Mr. Bessemer himself held that, by his process, he could not satisfactorily deal with iron containing above ·045 per cent. of phosphorus. The quantity of iron produced in the British Isles, fit for making Bessemer steel, was therefore extremely limited, because the total quantity of hæmatite iron was only about one-fifth of the entire yield of the kingdom. Bessemer hæmatite pig-iron, in consequence of the demand and of the limited make, was worth 80*s*. per ton, whereas Cleveland pig-iron was worth only about 42*s*. 6*d*. per ton. The important question then arose—what other supplies of iron were available for the manufacture of Bessemer steel? The total supply of pig iron in Europe was about eight and a quarter millions of tons. In France, where the manufacture of Bessemer steel was looked upon as one of great importance, there was scarcely a ton of ore fit for the manufacture of iron suitable for the process. At Lavoulte, a small district on the banks of the river Rhone, a small portion of suitable iron ore was obtained; but by far the greater part was made from ore procured from Mokta, in Algeria, which raised the cost of the pig iron to something like £4 per ton. In Belgium, in Westphalia, and in Silesia, there did not appear to be any iron ore fit for the Bessemer converter. Norway and Sweden produced a limited quantity; but not all of that was sufficiently free from phosphorus. He had brought over from Norway a sample of ore, and he had found that the pig-iron smelted from it contained one-half per cent. of phosphorus. The Rhenish provinces raised about five hundred thousand tons of iron ore per annum pure enough for Bessemer iron. Styria and Carinthia also produced a limited supply; but he believed that a yield of two hundred and fifty thousand tons a year was all that could be depended upon from that locality. He had no knowledge of the resources of Russia; but looking at the distance of the ironworks from the shipping ports, he imagined little help could be expected from that quarter. There were no doubt other ores, as in Biscay, but so far as pig-iron was concerned, the result was that, out of the eight and a quarter millions of tons of pig-iron produced in Europe, there was only about half a million of tons suitable for making Bessemer steel.

Then the comparative cost of the manufacture of steel and of iron rails was an important question, not only as it was at present, but what it might be in the future. He thought that rails might be made from pig-iron as cheaply by the one process as by the other, so far as the mere cost of the operation for wages, fuel, and so forth was concerned, and independently of the price of the pig-iron employed. The loss, although considerable in the Bessemer process, took place at a period of the manufacture when the least amount of work had been done; and that was an advantage. He was aware that his opinion of the cost of manufacture was not admitted by the makers of the Bessemer rails. One explanation of the cost might be, that the number of rejected rails manufactured in England was far in excess of the number rejected abroad. He had been assured by a manufacturer in Styria, that he was in the habit of rolling rails for a week at a time without producing a single waste rail; but whether this proceeded from the fact that a superior kind of pig—viz., iron from pure ores, and smelted with charcoal—was used, or from greater fastidiousness on the part of the engineers in this country, he was unable to say.

He had long entertained a doubt as to the amount of confidence to be placed in some of the specifications prepared by engineers; and he still adhered to that opinion, notwithstanding the remarks that had been made. He had some time ago suggested to Mr. Harrison, when the Directors of the North Eastern Railway were considering the question of using a rail of steel costing as much as £12 per ton, whether some improvement might not be introduced in the manufacture of iron rails. The subject was of great importance to Railway Companies, to British iron-masters, and to the country generally, and was one which could only be properly investigated by long and patient observation of those facts which experience in the manufacture, as well as in the use of the rail, could elicit; and hence both iron makers and engineers should co-operate in any attempt to produce a good iron rail; and those who might succeed in accomplishing this would be entitled to be considered as national benefactors, by maintaining the demand for that description of metal produced in such large quantities in this country. Not long ago a rail had been taken up, which had been down for fifteen years on that portion of the North Eastern Railway on which the traffic was the largest. From previous observation, he had ventured to say that it was a bad specimen of iron, so far as purity and freedom from phosphorus was concerned. An analysis of the rail had been made with the following result:—

Silica	·08
Graphite . . .	·07
Manganese . .	·36
Sulphur . . .	·11
Phosphorus. . .	·504
Iron.	98·11
	99·234

Thus showing that it contained almost the amount of phosphorus stated by Mr. Karsten to be the extreme limit. Other rails were taken up which had been in use since 1855. The mean of two analyses of these, made by Mr. Marreco, of Newcastle, was as follows:—

	Phosphorus.	Silicon.	Carbon.	Sulphur.
One specimen contained per cent. .	·513	·079	Trace.	·090
,, ,,	·307	·195	0	·109
,, ,,	·161	·168	0	Not estimated.
,, ,,	·223			

A rail just received, and apparently of serviceable quality, contained ·681 per cent. of phosphorus.

As the same kind of pig-iron might on puddling yield a product varying in quality according to the treatment it received, he had no doubt that rail-makers might produce a hard or a soft kind of iron; in proof of which he laid two samples of iron on the table, puddled from the same pig, one bright and crystalline, and the other fibrous and tough. In France this was actually done in practice, the puddler being paid different prices for the several qualities of iron. Manufacturers in England dared not encounter the risk of making iron which, though strong enough for rails, might still not resist the severe test-blow to which Engineers subjected it; indeed when this power and species of resistance was provided for, a sufficient quantity of No. 2 bar used in the piles, and no mill cinders admitted into the blast-furnace, it seemed to him that a rail specification was considered complete.

Of such importance was the presence of phosphorus considered in France, that when it was found that railway bars were getting too fibrous, mill cinders, or ores containing phosphorus, were introduced, with the view of correcting what was regarded as a disqualification in that kind of iron; so that it might turn out eventually that this hitherto maligned substance might be considered indispensable in a good rail.

With regard to manufacturing steel by some other process, he was not without hope from what he had witnessed, and from careful study, that steel would, by the introduction of new processes, be eventually produced from iron containing phosphorus in amount far exceeding the limits laid down by Mr. Bessemer. Such a discovery, he need not say, would be a valuable acquisition to the manufacturer, to the railway engineer, and to the nation.

Mr. James Deas stated that the North British Railway Company had used solid steel rails for six years, having laid down upwards of 1,100 tons; 500 tons upon main lines, and fully 600 tons in switches and crossings. About one thousand sets of switches and crossings had been put down, and not one of them had yet worn down. Several sets of switches had been in the road for six years, while the switches of iron rails that preceded them had worn out in from six to nine months. Three years ago he had laid 250 tons of steel-headed rails, weighing 75 lbs. to the yard, in 24-feet lengths fish-jointed; they were the first rails of the kind which were made by the Dowlais Iron Company. Out of upwards of nine hundred rails, the steel had separated from the iron in only twenty-five of them, and these rails had been turned and had been left in the road with the iron heads uppermost. The steel was laid flat on the top of the rail, and not turned over the edges, as had been done in the Swedish Government rails designed by Mr. Sandberg.

He had laid down alternately, at the same time, nine solid steel rails and nine iron rails, on the outside of a 12-chain curve. The original depth of the rails was $5\frac{1}{32}$ inches. When they were examined a few days ago, the solid steel and the steel-headed rails had worn $\frac{1}{32}$ inch, whilst the iron rails had worn $\frac{5}{32}$ inch. The inside of the steel-headed rails was, however, worn much more than the inside of the solid steel rails; and this was probably accounted for by the greatest pressure of the flanges occurring at the junction of the iron and steel.

Mr. W. Menelaus said, that to make a rail of wrought iron which would endure satisfactorily, under the conditions not unusual on at least portions of most of the great lines of railway, was commercially impossible. There were inherent faults, first in the quality of the metal itself, and next in the mode of manufacture, which rendered it, in his opinion, impossible to produce a rail of wrought iron which would stand even a reasonable time under the trying conditions to which some portions of the lines must of necessity be exposed. No doubt it was possible to produce perfect homogeneity and sound welding in wrought iron, as for instance in "best-best" tyres; but this could only be done at a great cost, and, beyond all doubt, Bessemer metal could be produced cheaper than this high-class wrought iron. Even granting that wrought iron of great excellence could be produced in large quantities, which he much doubted, even the best wrought iron ever made was far inferior to Bessemer metal, at least for rails. In adopting steel for Bessemer rails there was one great security; bad steel, in the sense of impure steel, could not be made into rails. He frankly admitted that by an error of judgment, or by attempting to make the metal hard and lasting, an overdose of carbon might be given to it, and the rails would in consequence be brittle; but if this mistake were avoided, he held that bad steel could not be made into rails at all. In fact, as a matter of economy, the purer and higher the quality of the pig iron used, the cheaper must be the Bessemer steel rails produced. As far as his experience went, nothing was so bad and so wasteful as to attempt to use pig iron of low quality for making Bessemer metal: if silicon was present in excess there was a bad yield in the converter; and the presence of undue quantities of sulphur and phosphorus caused a great number of waste rails. He had found it best and cheapest to buy the highest quality of pig iron only. His experience of Bessemer metal, however, had been confined entirely to the manufacture of rails, but he had no doubt all steel makers would bear him out in these statements. He believed the only charge brought against the quality of steel rails was their brittleness, as it was called, and he supposed that rails made of Bessemer metal had broken in regular work, even when produced by manufacturers who from their long experience in the trade actually claimed pre-eminence. His opinion was that these hard rails had been made, not designedly, as a matter of economy, but simply by accident, or through an error in judgment; mistakes were less likely to happen now that considerable experience had been gained in working the metal. Excellent iron rails could be made if railway engineers would but treat ironmasters with confidence and would pay a fair price; but when a high class rail was required he was of opinion that, as far as was known at present, there was no material to be compared to Bessemer metal for excellence of quality and moderate cost.

Now as to the union of the two metals in the shape of what were called steel-headed rails. Very unsatisfactory results followed the first attempts to make rails of that description; but no doubt other makers had, like himself, benefited by experience, and now a perfect junction could be insured between the iron in the body and the steel on the heads of rails. He first used plain slabs, and he had made, some years ago, by this method, a quantity of rails for the Edinburgh and Glasgow Railway. Mr. Deas reported that the rails had, so far, stood well, and he still expressed confidence in rails of this description. These rails were made with plain slabs for the tops, and the union of the two metals depended entirely on the weld. After a while he adopted a system for making steel heads, which had been long used in South Wales for iron; that was, giving a mechanical grip to the top slab in the rail-head. The slab of iron was rolled in the form of channel iron, with a rib more or less deep on each side. In the finished rail the steel was thus not only welded to the iron, but it had a good mechanical grip upon it. This plan of rolling the steel slabs in the channel form was a great improvement. All he had arrived at, however, was to get a good grip of the head: but Mr. Sandberg having the management at the Dowlais Works of the manufacture of a quantity of steel-headed rails for the Swedish Government, suggested that the horns or ribs of the channel-formed steel slabs should be deepened, so as to insure a complete envelope of steel for the head; and it was found that, in the rail rolled from the slabs designed by Mr. Sandberg, the steel actually came down into the stem of the rail, and made an excellent sound job.

It was by no means a simple matter to roll steel and iron together, as the two metals required to be worked at different temperatures; but after a little practice the men acquired sufficient skill in the management of the pile in the furnace to secure an excellent junction between the two metals, and in his opinion steel-headed rails, properly made, would be found to stand almost, if not quite, as well as rails of solid Bessemer metal, though of course they would not be reversible, having only one table of steel.

Mr. James Shaw felt from his experience at the Stockton Iron Works, that he could confirm a great deal that had been said regarding iron rails by Mr. Bell, whose remarks should be studied by all Engineers.

Many specifications had come to him from Railway Engineers; and though some of them had exhibited great practical knowledge, others had been so deficient that he had been utterly at a loss how to make the rails. Much had been said about the difference between iron and steel, but he thought that a vast deal depended upon price, upon the judgment of Engineers, and the advice which they gave to Railway Directors. When a manufacturer quoted a price he believed that, as a rule, the lowest tender would be accepted. He knew that the Railway Company desired to get the best apparent rail at the lowest cost, and he might be disposed to believe that some of the conditions were unnecessary. The North Eastern Railway Company had taken the right course in asking a manufacturer to tender. They had said to him, "We will take you into our confidence, although our Engineers have issued excellent specifications, because you know far better how to manufacture rails than we can be expected to do." This example had been followed by a Foreign Railway Company, and the results in both cases were very satisfactory.

The question was one of great importance, inasmuch as it concerned the safety of the lives of the travelling public. He would ask whether it was creditable that there should be issued some one hundred and fifty different specifications. In France that was not the case, and even in America a uniform specification was adopted.

In regard to the manufacture of Bessemer rails a good deal appeared to have been taken upon assumption. As experience of steel rails extended back only some five or six years, it was, he submitted, somewhat rash to assume that steel rails would of necessity last sixty years or one hundred years. Steel rails had certainly the advantage of being more homogeneous, and were therefore less liable to lamination, yet hardly sufficient regard appeared to be paid to other and very important considerations relating to extra cost and the possibility of having bad steel rails as frequently as bad iron rails: he therefore could not implicitly receive the statistics which had been referred to.

Mr. Vignoles, Vice-President, thought, from the statements that had been made by the manufacturers and by all who were best acquainted with the subject, it might be concluded that if a rail from a homogeneous material could be produced the result would be better than if it were produced from a pile. Engineers knew perfectly well what they wanted, although, perhaps, not being practical manufacturers of the material, they might not be able to dictate the best way of arriving at a given result. Besides, they were controlled to a great extent in this country by Directors as regarded expense, and abroad particularly by the assumption that foreign Engineers and managers knew a great deal more than the English Engineers did. Those who had the misfortune of contending with people half informed on technical subjects, which was a dangerous thing, would know how difficult it was to satisfy the requisitions of the foreign Engineers, or of those who controlled them. Within the last few days he had received a communication from the officials of one of the most important Governments in Europe refusing to allow an eminent manufacturer in England to replace rails made by him which had been condemned on unreasonable grounds. In order to resist serious impact, one quality of iron was required, while a different quality was called for where rails had to sustain a load, and those two perfectly dissimilar requisitions were expected to be combined in the same rail. A rail sufficiently homogeneous would combine those qualities to a certain extent. No doubt a steel rail would wear better than one of iron, and a steel-headed rail would wear better than an iron rail; but, in the latter case, the difficulty lay in combining the two. He admitted that the best iron was that which would weld the best; but it had been said that the best iron could be obtained from the puddle ball; and this had not hitherto been supposed possible. He would be willing to adopt the idea of accepting a guarantee from a manufacturer as to the quality of the metal; but he would like to know the price at which the rails were to be produced, and also the mode, and, as far as possible, the result of the wear and tear.

Mr. David Forbes observed, that in all cases homogeneous metal was to be preferred to that which was composed of more or less hard and soft particles; and therefore it became in the first place a question as to how such homogeneous metal could be obtained. Unless iron could be brought into a state of complete fusion, it would not be practicable to get a material having in all parts the same mechanical structure, or the same mechanical composition. As fused iron had not yet been found available, recourse must be had to a compound which was somewhat more fusible and easily manufactured, as, for example, cast steel, which could be produced by the Bessemer, the Siemens, or any other good process. The question became then one of price, and in that respect the Bessemer process at present had the advantage. No doubt good steel could be produced from bad materials; though in the present state of metallurgy not so as to be remunerative. It was quite possible to take the worst cast iron, and to oxidize so much of it as to leave a residue of good steel; but he considered the Bessemer rails had suffered in the estimation of Engineers from the attempts that had been made to use a material which was bad and unfitted for the purpose. He had made some experiments which had been suggested by the opinions of Mr. Siemens, that instead of using a steel rail an iron one containing phosphorus might be employed. The results showed that such a rail would be an extremely dangerous one; since, although at times very strong, such rails were liable to be very 'cold short.' It was found extremely difficult to get the phosphorus so uniformly disseminated throughout the mass as to produce in all parts the same hardness, or the same non-liability to break. The main point was to insist upon the employment of a good raw material for the production of the Bessemer steel.

Mr. H. Conybeare was of opinion that the section of a rail materially affected its duration, and that this was especially the case as regarded the design of the head and of the upper surface or wheel-track. It was obvious that each portion of the rail had its special and definite functions and conditions to fulfil, and a careful consideration of the character of these should supply rules that would regulate with certainty the contours and the dispositions and scantling of the metal in every portion of the section, that would best conduce to the fulfilment of such conditions.

Some years ago, having occasion to design the rails for Irish and Welsh railways, he had collected, with a view to determine the best form of rail, all the sections he could obtain from the Welsh iron-works, and the London metal-brokers; and he compared and collated these with a view to ascertain the extreme range of the variations in practice, and the limits of economy and practicability in manufacture. He also calculated the strain to which each portion of the section was subjected, and considered the conditions it had to fulfil, and the extent to which these conditions were complied with in each example. Having done so, he endeavoured to establish definite rules which should fix absolutely the contour and the proportionate scantling of every portion of the rail section. These he had since carried out in practice, and the results arrived at were exhibited in the following diagrams and Tables. It would be seen that the diagrams, though also applicable either to the T rail or the double-headed rail, referred more especially to what was known as the Vignoles section. Everywhere except in England the double-headed section and the chair road had long been obsolete, and he thought it was much to be regretted that it was not so in this country. It was obviously essential to the perfection of any system of permanent way, that the jointing of the rails to each other, and the mode of attaching the rail to the sleeper, should be of such a description as to ensure absolute uniformity of gauge and of cant, and such as to admit of no jar, shake, or movement, which might loosen the fastenings, and thereby induce hammering and concussion, which must conduce to the disintegration of the bearing surface of the rail, and to the injury of the rolling stock; and judged by this canon, a Vignoles rail, directly fastened by fang-bolts into beds planed by machinery, in rectangular sleepers, was as superior to a road in which chairs intervened between the rail and the sleeper, as the best road of the latter description was to the old stone sleepered and unfished chair road. As regarded the weight of the rails, it was possible to make them too heavy; for modern rails failed not through their deficient strength as girders, but through the deficient homogeneity and hardness of texture in the bearing surface presented to the rails, which induced the lamination and hammering out of such bearing surface under the concentrated pressure and violent impact of the wheels. It was essential that the rails should possess an amount of vertical stiffness sufficient to confine their deflection under the passing load within unobjectionable limits. But any weight or vertical stiffness in excess of what would suffice to fulfil this condition was absolutely injurious; for as a certain amount of elasticity was essential to the durability of the rails, an excess of rigidity invariably tended to destroy the rail surface, by acting as an unyielding anvil placed beneath it, between which and the hammering action of the driving-wheels the bearing surface of the rail was rapidly beaten out into laminæ, and so destroyed; and the heavier the anvil the more rapid was the process of destruction. If extra weight and speed of traffic were to be provided for, improved quality in the material was required rather than increased quantity,—a harder surface, not heavier metal.

Thus the rails most remarkable for their longevity had been also most remarkable for their abnormal weakness and deflectibility as girders; for example, a length of 25 miles or 30 miles of the original permanent way of the South Western Railway consisted of a 75 lb. rail, laid on transverse sleepers 5 feet apart from centre to centre. The strength of such a rail as a girder was therefore only equal to that of a $57\frac{1}{4}$ lb. rail laid on 3-feet bearings; and as, according to Barlow's experience, the deflection of the same rail, when supported on 5-feet bearings, was to its deflection when the supports were 3 feet apart, as 64 to 24, the flexibility of this rail was threefold that of a 75 lb. rail on 3-feet bearings. Here was, therefore, a permanent way abnormally weak and flexible, its strength being only equal to that of a $57\frac{1}{4}$ lb. rail on 3-feet bearings, and its flexibility at least four times greater than that of a 75 lb. rail on 3-feet bearings. When he last obtained particulars of this permanent way, these rails had been laid down for eighteen years, and were still in perfect order. He believed that more was lost than gained by increasing the weight of even a double-headed rail above 70 lbs. per yard, which appeared to him to be equal to the heaviest traffic; and with cross-sleepers equidistant from centre to centre, and with a section of equal weight per yard, a Vignoles road was stronger and stiffer than a chair road; for the bearing of the rail on a chair was only 3 inches, which reduced the clear bearing only from 36 inches to 33 inches, the square of which was 1,089: but the bearing of the Vignoles rail on machine-planed beds was from 9 inches to 10 inches, according to the width of the rectangular sleepers used, which reduced the clear bearing to 27 inches or 26 inches, the squares of which were respectively 729 and 676; and the strength being inversely as the square with the sleepers 3 feet apart from centre to centre, it followed that the *strength as a girder of a Vignoles rail would be to that of a double-*headed rail of equal weight in a chair road, (the sleepers being the same distance apart from centre to centre,) in the ratio of 1,089 to 729, or of 1,089 to 676, or nearly as 3 to 2. He therefore considered that the weight of a Vignoles rail should never exceed 70 lbs. per yard, nor be less than 65 lbs.: the minimum would be 62 lbs., if dog-fastenings were substituted for through fang-bolt fastenings; but such a substitution was, in his opinion, much to be deprecated.

The section of a rail admitted of three primary subdivisions—the head, the vertical web, and the foot. The same division applied to the double-headed section, merely substituting a second head for the foot. Thus, the principles on which the rail-section, shown in Fig. 2, p. 363, as outlined, applied equally to the Vignoles and the double-headed sections.

The width of the head ranged in practice from $2\frac{1}{2}$ inches to $2\frac{1}{4}$ inches. The former was till lately the rule in England; but the flat-footed rails, which had almost superseded every other form of section on the Continent and in America, and which were rapidly gaining ground in England, were usually only $2\frac{1}{4}$ inches in width of head. In Mr. Brunel's latest specification for a 75 lb. double-headed rail for the Eastern Bengal Railway, the width was only 2·3 inches; on the Grand Russian Railway it was 2·3 inches; on the Cape Railway and Swedish Government lines the same; and the rail of the Kustendjie Railway, of the Royal Swedish, and many others, only 2·25 inches. He considered 2·25 inches the proper width for lines with light and medium traffic, and 2·3 inches the maximum for lines with the heaviest traffic. In fact, it could be demonstrated that nothing was gained by increasing the width above 2·3 inches. If, indeed, the wheel-treads of the rails were horizontal planes, and the peripheries of the wheels truly cylindrical, so that the contact or bearing of the wheel with and on the rail were conterminous with the width of the latter, there would be a manifest advantage in making such bearing surface as wide as possible. But in practice, the contact of the wheel and rail at any one moment was merely that of a cone laid transversely on a cylinder, and such contact, instead of extending the whole width of the rail, would, were the materials unyielding and non-elastic, be a mathematical point without length or breadth; and, after allowing for elasticity, the actual contact at any one moment had been stated by Mr. Brunel never to exceed $\frac{1}{8}$th of an inch in width. He thought this an under-estimate; but, however that might be, it was obvious that the width of actual contact at any one moment could never amount to any considerable fraction of the width of the rail, and therefore that nothing could be added to the width of actual contact, that could in any way diminish the stress of the wheel on the wheel-tread, by increasing the width of the latter beyond the limits he had laid down. By so increasing the width of the rail-head, the overhang or false bearing of the shoulder of the rail over the vertical web that supported it was increased, and thereby, *pro tanto*, the cross strains to which the material of the rail was subjected. The contour of the wheel-tread was obviously the point of paramount importance. It was by the lamination at this surface that the rail perished. It was the weakest link in the chain, and one which, from the peculiar and exceptional conditions of the case, could not be strengthened adequately.

In ordinary cases of engineering, when a structure of given material was designed for the purpose of carrying a load, the amount of such load was first ascertained: secondly, the ultimate strength of the material; and finally, an ample margin was allowed for safety. For example, the ultimate strength of wrought iron being 25 tons per square inch, the load on a wrought-iron girder-bridge was not allowed to exceed 5 tons per square inch. But it was, unfortunately, impracticable to apply this rule to the apportioning of the bearing surface of the rails to the load on the locomotive driving-wheels. The case was a wholly exceptional one in engineering; for not even the smallest margin for safety was practicable. It was impossible to avoid loading the bearing surface to an extent much greater per square inch than the greatest that any such material would be subjected to, if it could possibly be helped; for the point of contact of the wheels with the rail, supposing the material of both to be unyielding and non-elastic, would be not a surface at all, but merely a mathematical point, and the load on the driving-wheels of a locomotive was often 11 tons, the whole of which might at any moment be thrown by a jerk on a single rail.

The only circumstance that could save the bearing surface from destruction under such an emergency was the elasticity of the wheel and the rail, which allowed the periphery of the former to flatten at its contact with the latter, and the rail surface to lap round the contact of the wheel, so as to convert what would otherwise be a bearing point into a bearing surface; and it was desirable to encourage this action as much as possible, by giving the rail as much elasticity and as flat a bearing surface as was compatible with the observance of other essential conditions.

In the case of a railway with a central guide-rail, it was obvious that the wheels of the rolling-stock should be perfectly cylindrical, and the wheel-treads of the rails horizontal planes. In such a case the pressure of the wheel-tyre would be distributed over the entire width of the rail—a condition more favourable to the durability of both tyres and rails than when the pressure on the wheels was concentrated on a scarcely appreciable fraction of the width of the rail—as must be the case when the wheel-tread of the latter had for its contour a circular arc. It should be attempted in ordinary practice to approach these conditions as nearly as the coning of the wheels, coupled with the clearance or play of $\frac{3}{4}$ths of an inch allowed between the flanges and the inner surface of the rails, and also the allowance for the inaccuracy in the gauge and in the angle of the wheel-cant, due to imperfections in the laying and working of a chair road, would permit, by making the radius with which the profile of the wheel-tread was struck as large, and consequently the arc as nearly approximate to a plane surface, as the conditions of the case allowed.

As the wheels were coned to an inclination corresponding to the cant of the rails, such coning would perfectly accord with a flat-headed rail, provided the relative position of wheel and the rail were always kept the same by a central guide-rail; but the play allowed between the flanges and the rails, coupled with this coning to a small extent, and the inaccuracy of gauge and cant incidental to the laying of a chair road, in a far greater measure caused an appreciable amount of angular divergence between the profile of a perfectly flat wheel-tread and the rectilinear profile of the wheel-tyres. Sometimes the latter would bear on the inner edge and sometimes on the outer edge of the former. It was to obviate this that the wheel-treads had been given a rounded contour. The principle was correct; but the amount of such rounding could be demonstrated to be almost inappreciable, and was generally injuriously overdone. The proper amount of rounding to be given to the upper surface of the rail—viz., the radius with which the circular arc forming the profile of the wheel-tread should be struck—admitted of accurate determination. The angle of the arc should be twice that of the maximum angle of divergence between the profile of the cone and the wheel-tread, supposing the latter to be flat.

The amount of the portion of this angle of divergence which was due to the coning of the wheels, and the clearance or play allowed between the wheel flanges and the inner surfaces of the rails, might be thus determined. As the amount of such clearance only allowed the wheels to deviate $\frac{1}{2}$ inch on each side of their central position; and, as the inclination of the side of the cone of the wheel line was only $\frac{1}{20}$th, the utmost limits of such deviation could only raise one end of the axis $\frac{1}{40}$th of an inch, and depress the opposite end to the same extent; and, taking the length of the axis in round numbers as 60 inches, this would only be equivalent to an inclination of $\frac{1}{20}$th of an inch in 60 inches, *i.e.*, of 1 in 1,200, and the angle of deviation of the profile of the wheel from that of the rail head due to this cause would be, of course, the same—that was 1 in 1,200 equal to an angle of 0° 1′ 51″. To this had to be added the angular variation in the cant and gauge of the rail due to the inaccuracies incidental to the laying and wearing of a chair road. The bed of the chair on the sleeper was 10 inches, and the bed was cut to a template; and if the limit of inaccuracy in the cutting and wearing of the bed were assumed to be about $\frac{1}{4}$th of an inch at one end or the other, this would be equivalent to a variation of $\frac{1}{40}$, or equal to an angle of 1° 51′ 1″, and this, added to the angle of variation due to the coning of the wheel and clearance, would make the total angle of divergence A B C and A′ B′ C′ on Fig. 1 equal to 1° 27′ 51″.

Fig. 1.

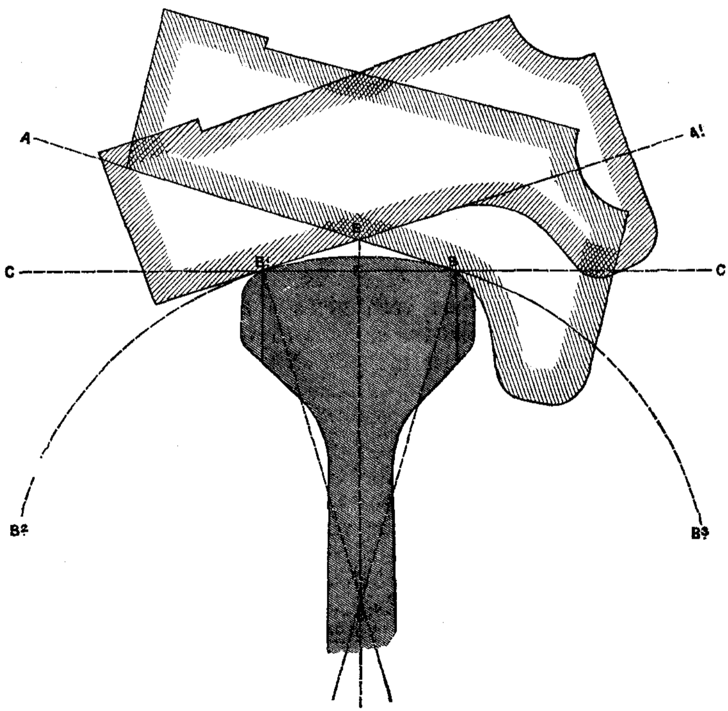
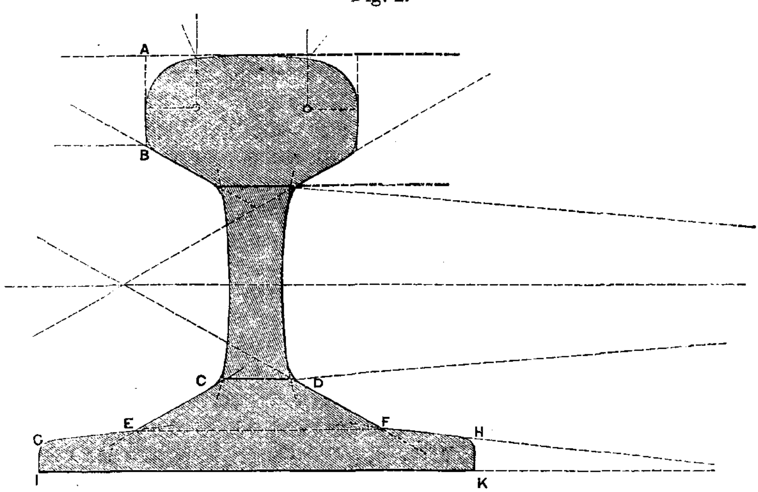


Diagram demonstrating that when B′ B = 1¼ inch, and the head of the Rail is, therefore, 2½ inches wide, a radius of 40 inches will give ample curvature for the wheel-tread.
The angles D B′ B and D B B′ are each equal to 88° 32′ 9″. The angles C B A and C′ B′ A′ are thus each equal to 1° 27′ 51″, and B′ D B measures 2° 55′ 42″.

In this Figure, B′ B represented the bearing surface of a rail, say 2 inches wide, and A B and A′ B′ the extreme positions of the wheel tyre on such a rail, supposing it flat topped; these positions being inclined to the rail surface at an angle of 1° 27′ 51″. To determine the radius with which the profile of the bearing surface of the rail must be described, so as to prevent the weight being ever thrown exclusively on either edge of the rail, and so that each portion of the surface might take its turn equally with the other in bearing the weight, draw through B and B′ the extreme points of contact of the wheels and rail surfaces, the lines B D and B′ D in a direction perpendicular to the lines A B and A′ B′, then the point of intersection of B D and B′ D would be the centre from which the circular arc forming the profile of the wheel-tread should be struck; for it was clear that the profile of the wheel contour would be tangential to this arc in every possible position of the wheels.

The angles E B′ D and E B D being obviously similar angles, therefore B′ D B was equal to twice the angle A B C, or 2° 55′ 42″, and, as the side B′ B of the triangle B′ D B was equal to 2 inches, and the opposite angle was equal to 2° 55′ 42″, the length of the sides B D and D B was 54 inches, which was, therefore, the radius with which the arc forming the profile of the wheel-tread should be struck. If B′ B was equal to only $1\frac{1}{2}$ inch, this radius would be equal to 40·75 inches. This allowed for the inaccuracy of laying and wearing incidental to a chair road, but with a Vignoles rail a much flatter one would suffice. He was, therefore, warranted in adopting 40 inches as the proper radius of the profile of the wheel-tread in all cases.

Fig. 2.



Construction of Rail Section. Half full size.
The wheel tread has a radius of 40 inches.
The vertical web is profiled with a radius of 12 inches.
The upper and lower fish planes are at an angle of 60° to each other.

The radius with which the shoulders of the wheel-tread were rounded off was at first only $\frac{1}{4}$ of an inch: this was found in-sufficient, and the present practice ranged from a radius of ·45 inch to ·7 inch. On the Grand Russian, and in the section adopted by Mr. Samuel, the radius was only ·45 inch. In the rail chosen by Mr. Fowler for the Great Southern and Western Railway of Ireland, and also in the Royal Swedish, the radius was ·5 inch; in the Great Northern of France, ·55 inch; and in the Eastern Bengal Railway, ·6 inch.

The radius of the shoulder should not be less than ·5 inch, nor more than ·6 inch; and, in his opinion, the former dimension answered all necessary conditions, and anything more than that was injurious, as detracting from the width of the wheel-tread.

The flank of the shoulder should be vertical, as the proper function of the metal disposed in this portion of the section was literally to keep the shoulder up to the wheel, and it was obvious that the best disposition of material for this object was to carry down the flanks of the shoulder vertically till they met the upper fishing planes. This disposition of material had also the advantage of providing a better bearing for the fish-plates.

At its lower termination the vertical plane of each shoulder flank was met by the surface intended to receive the upper bearings of the fish-plate.

It was indispensable that the upper and lower bearing surfaces of the fish-plate and rail should fulfil two conditions; first, that they should be plane surfaces; and, secondly, that they should be equally inclined to the axis of the fish-bolt, which should be placed centrically between the upper and the lower bearing surfaces.

The necessity of the fulfilment of these conditions appeared to be obvious. If the surfaces were curvilinear, the principle of the wedge was excluded, and the slightest inaccuracy in the manufacture would prevent the fish from obtaining a fair and continuous bearing on the rail. It was equally obvious that the bolt which pressed these fish-plates into apposition must be centrical, otherwise the pressure upon the upper and the lower bearing surfaces would be unequal, and the fish to that extent defective. The same objection applied to inclining the upper and the lower bearing surfaces of the fish at a different angle; the pressure on the upper and the lower bearing of the fish would in that case manifestly differ in the same ratio as the sines of the angles of their upper and lower bearing surfaces, and the effect would be the same as if the angles being equal, the distance between the upper fishing-plane and the centre of the fish-bolt, and that between such centre and the lower fish-plane, differed in the same ratio.

The functions which the vertical web had to fulfil were simply to maintain the head and the foot of the rail in the same relative position with itself and each other, under any lateral or vertical strains to which they might be subjected in the working of the line. In modern practice the centre thickness of this vertical web ranged from ·55 inch, which was little more than the minimum to which it could be rolled without unduly increasing the cost of manufacture, to ·7 inch. A favourite dimension for the centre thickness of a rib that increased in thickness towards its junctions with the head and foot of the rail was ·6 inch; but ·65 inch, or ·7 inch were common dimensions when the section of the vertical web was parallel throughout from head to foot. He had adopted in these Tables (pp. 367-8) in every case a top and bottom thickness of ·7 inch, and a thickness at the centre of ·6 inch, the profiles of the sides of the vertical web being circular, and drawn through these three points, *i. e.*, with a chord, equal to the depth of the web, and a versed sine equal to ·05 inch, *i. e.*, half the difference between the top and bottom width ·7 inch, and the centre width ·6 inch.

Horizontal lines drawn through the intersection of these arcs, with the prolongation of the fishing-planes, formed the demarcation between the head and vertical web and the vertical web and foot; therefore any one of the forty-one vertical webs in the series given in the Tables (pp. 367-8) might be joined to any of the thirty heads or to any one of the twenty-six feet, and thus about thirty-two thousand varieties of rail section might be formed from such combinations. The re-entering angle between these arcs and planes was filled in by an arc of ·3 inch radius.

The fixing of the angle, at which the fish-planes converged at 60°, was the result of a compromise. Manufacturers preferred a larger angle, so as to give the head the pear-shaped section of the Erie rail: but this increased the foot of the rail, and rendered it difficult to form a good fish, whereas with an angle of 60° as strong a fish might be formed as had ever been made. The only effect on the fish of diminishing the angle from 60° to 50° was that in the latter case an equally strong fish might be obtained with less scantling in the fish-plates and fish-bolts. But no such increase of scantlings would be necessary with the insistent fish.

The usual depth of the double-headed rail was 5 inches, but, as already shown, the strength of a Vignoles rail, laid on sleepers 3 feet apart from centre to centre, exceeded that of a double-headed rail of equal section and depth laid on sleepers the same distance apart nearly in the ratio of 3 to 2; and, therefore, to ensure the same strength and stiffness, the depth of the Vignoles rail might be, as compared with that of the double-headed rail, in the ratio of 2 to 3. In practice the depth had hitherto been in excess of this, for convenience in fishing only. The Royal Swedish rail and the Grand Russian rail had each a depth of $4\frac{5}{8}$ inches; the Morayshire, the Kustendjie, the Great Southern and Western of Ireland, and the Swedish Government rails, had each a depth of $4\frac{1}{4}$ inches, while the rails for the Cape were $4\frac{1}{2}$ inches deep, and his own

$65\frac{1}{2}$ lb. section, laid on the West Cork, the Cork and Kinsale, the Cork and Macroom, and the Cork and Limerick Direct Railways, had a depth of 4·3 inches, though for heavy traffic, he made the depth 4·55 inches.

He now came to the foot of the rail. The dimensions of the trapezium, C D F E, (Fig. 2, p. 363) which formed the upper portion of the foot, and the sides of which, F D and C E, constituted the lower fish planes, should be the same for all weights of rail. Its top width, C D, was ·7 inch, its bottom width 2·1 inches, and its depth ·45 inch. From C and D the profiles of the upper surface of the foot extended at an inclination downwards of 1 in 10, till they attained the full width intended to be given to the foot, and from these terminations vertical lines—G I H K—were dropped ·375 inch in depth, for the thickness of the toe, which was fixed by manufacturing considerations, and was the same in all cases, and a horizontal line drawn through I to K completed the profile of the foot.

The width of the foot should be at least sufficient to admit of through fastening, consisting of bolts passing through the sleepers, fixing into fang-nuts abutting on its lower surface. He thought the practice of nailing the rail to the sleeper by exaggerated brads, called dog-bolts, could not be too strongly deprecated. He had found a width of $4\frac{1}{2}$ inches sufficient for fulfilling these conditions; and for the heaviest traffic, it appeared to him that a width of 5 inches was ample. If this width were exceeded, the difficulty of rolling, and consequently the cost of the rail, would be greatly increased.

He was aware that there were advocates for making the foot, or lower flange, very wide in proportion to the depth of the rail, in order to obtain a greater amount of lateral resistance: but regarding a problem of this sort, it might be said *solvitur ambulando*. The Vignoles section had long been in general use, both in Europe and America, and on both continents, after experience gained over a period of ten or fifteen years' working, and on a length of over 10,000 miles of railway, a width of 4 inches had been found sufficient, and was still adhered to. And if a base of 4 inches was thus sufficient with only dog-bolt fastenings, *a fortiori*, must a width of $4\frac{1}{2}$ inches be ample with such superior attachment to the sleepers as was effected by through fastenings, such as fang-bolts.

He exhibited a diagram containing sections of thirty heads of rails, varying in top width from 2·25 inches to 2·5 inches, the bottom width of all being ·7 inch, and in depth of shoulder from ·9 inch to 1·0 inch, the total depth ranging from 1·34 inch to 1·521 inch, and the weight increasing from 25·76 lbs. to 32·39 lbs. per yard. On the same diagram were also shown forty-one vertical webs, varying in depth from 1·9 inch to 2·9 inches, the width at the top and bottom being ·7 inch, and the thickness at the centre ·6 inch, the weight varying from 12·2 lbs. to 18·20 lbs. per yard. There were also shown twenty-six sections of feet, varying in depth from ·898 inch to 1·023 inch, and in width from 4 inches to 6½ inches, and in weight from 24·06 lbs. to 39·43 lbs. per yard. Every one of these heads would fit on to every one of the vertical webs,

Heads varying in Width from 2·25 inches to 2·5 inches, and in Depth from 1·340 inch to 1·521 inch, and in Weight from 25·76 lbs. to 32·39 lbs.

No.	Width in Inches.	Depth in Inches.	Depth to Bottom of Shoulder.	Weight in Lbs.
1	2·25	1·340	— ·9	25·76
2	,,	1·374	— ·925	26·32
3	,,	1·396	— ·95	26·88
4	,,	1·421	— ·975	27·44
5	,,	1·446	1·0	28·01
6	2·30	1·361	— ·9	26·55
7	,,	1·366	— ·925	27·12
8	,,	1·411	— ·95	27·70
9	,,	1·436	— ·975	28·27
10	,,	1·461	1·0	28·85
11	2·35	1·376	— ·9	27·33
12	,,	1·401	— ·925	27·92
13	,,	1·426	— ·95	28·51
14	,,	1·451	— ·975	29·10
15	,,	1·476	1·0	29·69
16	2·40	1·391	— ·9	28·40
17	,,	1·416	— ·925	29·00
18	,,	1·441	— ·95	29·60
19	,,	1·466	— ·975	30·20
20	,,	1·491	1·0	30·80
21	2·45	1·406	— ·9	29·20
22	,,	1·431	— ·925	29·81
23	,,	1·456	— ·95	30·42
24	,,	1·481	— ·975	31·03
25	,,	1·506	1·0	31·65
26	2·50	1·421	— ·9	29·89
27	,,	1·446	— ·925	30·52
28	,,	1·471	— ·95	31·14
29	,,	1·496	— ·975	31·77
30	,,	1·521	1·0	32·39

Constants.

In all cases, the width of the top of the foot, of the bottom of the bead, and of the top and bottom of the vertical web, was ·7 inch, and the profile of the latter was struck with a radius of 12 inches. The fishing planes were inclined to the transverse axis of the rail section at an angle of 30°; the thickness of the metal at the toe of the foot was ·375 inch, from which its upper surface rose at an inclination of 1 in 10. The radius of the wheel-tread was always 40 inches, and that of the shoulder ·5 inch.

Vertical Webs, varying in Depth from 1·9 inch to 2·9 inches, and in Weight from 12·2 lbs. to 18·2 lbs.

No.	Depth in Inches.	Weight in Lbs.
1	1·9	12·2
2	1·925	12·35
3	1·95	12·5
4	1·975	12·65
5	2·0	12·8
6	2·025	12·95
7	2·05	13·1
8	2·075	13·25
9	2·1	13·4
10	2·125	13·55
11	2·15	13·7
12	2·175	13·85
13	2·2	14·0
14	2·225	14·15
15	2·25	14·3
16	2·275	14·45
17	2·3	14·6
18	2·325	14·75
19	2·35	14·9
20	2·375	15·05
21	3·4	15·20
22	2·425	15·35
23	2·45	15·5
24	2·475	15·65
25	2·5	15·8
26	2·525	15·95
27	2·55	16·1
28	2·575	16·25
29	2·6	16·4
30	2·625	16·55
31	2·65	16·7
32	2·675	16·88
33	2·7	17·0
34	2·725	17·15
35	2·75	17·3
36	2·775	17·45
37	2·8	17·6
38	2·825	17·75
39	2·85	17·9
40	2·875	18·05
41	2·9	18·20

BOTTOM FLANGES OR FEET, varying in Breadth from 4·0 inches to 6·5 inches, and in Depth from ·898 inch to 1·023 inch, and in Weight from 24·06 lbs. to 39·43 lbs.

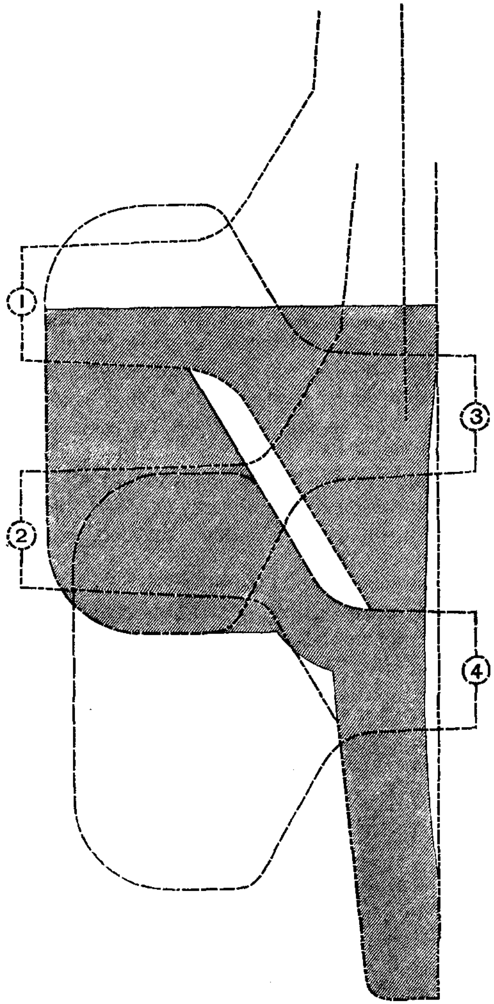
No.	Breadth in Inches.	Depth in Inches.	Weight in Lbs.	No.	Breadth in Inches.	Depth in Inches.	Weight in Lbs.
1	4·0	—·898	24·06	14	5·3	—·963	31·95
2	4·1	—·803	24·64	15	5·4	—·968	32·58
3	4·2	—·908	25·22	16	5·5	—·973	33·22
4	4·3	—·913	25·81	17	5·6	—·978	33·86
5	4·4	—·918	26·40	18	5·7	—·983	34·51
6	4·5	—·923	27·00	19	5·8	—·988	35·16
7	4·6	—·928	27·60	20	5·9	—·993	35·81
8	4·7	—·933	28·21	21	6·0	—·998	36·47
9	4·8	—·938	28·82	22	6·1	1·103	37·13
10	4·9	—·943	29·44	23	6·2	1·008	37·80
11	5·0	—·948	30·06	24	6·3	1·013	38·47
12	5·1	—·953	30·69	25	6·4	1·018	39·15
13	5·2	—·958	31·32	26	6·5	1·023	39·43

the number of combinations of the thirty heads and the forty-one vertical webs was therefore equal to 30 × 41, or 1,230; and every one of these 1,230 combinations of heads and vertical webs would fit on every one of the 26 sections of feet, making the total number of combinations 31,980; the rails so compounded varying in width of foot from 4 inches to 6½ inches; in depth from 4·1 inches to 5·4 inches, and weighing from 62 lbs. per yard to 90 lbs. per yard. The last weight was due to the combination of the heaviest head, the highest vertical web, and the widest foot.

He did not advocate all these combinations or any extreme weight. He only mentioned the number of possible combinations to show that the Tables covered the widest conceivable range of practice. Neither did he advocate, for light or medium traffic, a greater width of head than 2¼ inches, a greater width of foot than 4½ inches, a greater depth than 4·3 inches, or a greater weight per yard than 65½ lbs.; or for the heaviest traffic, a greater weight than 70 lbs. per yard, a greater width of head than 2·3 inches, a greater depth than 4·55 inches, or a greater width of foot than 5 inches.

With these Tables, a T square, and the little template called a "siderodograph" (Fig. 3), any one of these thirty-two thousand rail-sections might be accurately delineated in two minutes. Say an Engineer wanted a rail of the Vignoles section that would comply with the following conditions:—weight from 65 lbs. to 66 lbs. per yard; head to have a width of 2¼ inches, and a weight of 25 or 26 lbs., foot to have the minimum width compatible with through fastenings, 4½ inches, the rest of the weight to be made up by the vertical web; he would look in the Table and find that No. 1 head and No. 6 foot would answer these conditions, and would weigh between them 52·76 lbs., leaving for the vertical web 12·74 lbs. if the rail were to be 65½ lbs. to the yard, and 13·24 lbs.

Fig. 3.



Siderodograph, or Iron Road Delineator. Full size.

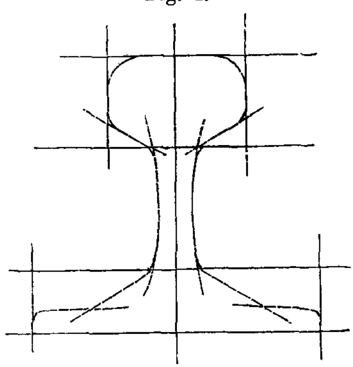
The dotted outline No. 1, shows the application of the template to the lower fish planes, and the junction of the same with the vertical web.
" " No. 2, " " to the toe and lower flange of rail.
" " No. 3, " " to the wheel-tread shoulder and the flange of the rail head.
" " No. 4, " " to the upper fish plane, and its junction with the vertical web.
The concave circular arc at the foot of the template is the profile of the vertical web.

for a 66 lb. rail; and on looking at the Table, he would find that vertical web No. 5 would make the rail 65·56 lbs., No. 6 = 65·71 lbs., No. 7 = 65·86 lbs., and No. 8 = 66·01 lbs.: adopting the last, the weight and height would be—

—	Weight in Lbs.	Height in Inches.
Head No. 1	25·76	1·340
Vertical Web No. 8 . .	13·25	2·075
Foot No. 6	27·00	·923
Total . . .	66·01	4·338

He then with a T square would draw on the board four horizontal lines at the vertical intervals in the second column for the base of the rail, the top of the foot, the under side of the head, and the top of the same, and a vertical line for the axis of the rail; and from this axis he would prick off on each side on the two middle horizontal lines ·35 inch for the top of the foot and the bottom of the head, which would each equal ·7 inch, and other vertical lines for the vertical boundaries of head and foot. On the accompanying diagram (Fig. 4) three lines of construction were

Fig. 4.



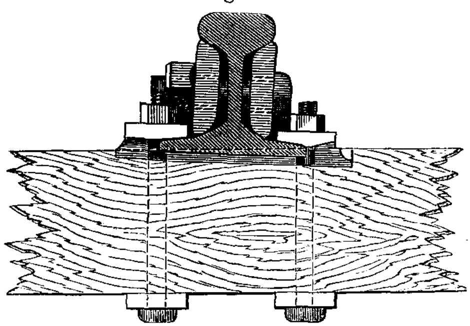
shown as full lines, and the outline of the rail as obtained by the application of the template to such lines of construction was shown by dotted lines. The dotted lines on the full size representation of the siderodograph (Fig. 3) explained the application of the instrument to the various parts of the rail section, and it could be adjusted as desired to the lines of construction (Fig. 4) by moving the T square up and down, and sliding the template along it like a set square.

As regarded fastenings, the only description of joint now employed was the fish-joint; and of this there were two varieties—the suspended and the insistent fish. The former had to perform two functions, the latter only one. The suspended fish had first to act as a girder, by giving vertical strength to the joint between the two rails; the fishes required, therefore, to be as long and deep as possible, to be fastened by four bolts, and to have the bearing edges as nearly horizontal as the fulfilment of other essential conditions permitted, in order to keep the ends of the two rails in accurate apposition, so that the joints might offer no obstacle to the smooth moving of the wheels.

The insistent fish was not required to add to the vertical strength of the joint, such joint being supported by the joint sleepers: the only function it had to fulfil was to maintain the extremities of the conterminous rails in accurate apposition. For this purpose a much shorter and shallower fish than would be required in suspension answered every purpose, and there might be only three bolts instead of four, as the centre bolt, acting immediately at the junction of the rails, had then a greater power of holding them in accurate apposition than it could exert in any other position. Moreover, there was no occasion to sacrifice the section of the rails to the perfection of carrying out the principle of fishing, as the angle of the bearing surface of the fish was comparatively immaterial. The suspended fish was manifestly defective as a mechanical arrangement, when compared with the supported fish, as the object to be kept in view was to approximate as closely as possible to the conditions of a bar of uniform strength. Now it was obvious that a suspended fish-joint could never offer nearly the same resistance to the load as an unjointed rail of the same bearing length; it therefore became necessary greatly to diminish the length of the bearing whenever a suspended joint occurred, and this inequality of bearing length was continued throughout the length of the rail, the bearing gradually diminishing to the joint; and as the resistance was as the square of the bearing, this inequality was manifestly incompatible with any near approximation to the conditions of a bar of uniform strength.

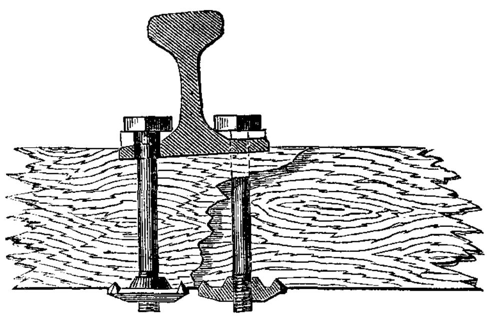
He submitted that Figs. 5, 6, and 7, showed what was the best arrangements for the fished joints and fastenings for the Vignoles rail. It would be seen that the fish was an insistent fish, and that it was a double fish, horizontal as well as vertical; for the wide horizontal under surface of the rail foot was kept in close juxtaposition with the wrought-iron bed-plate which received the ends of the rails, extending the full width of the rectangular joint-sleeper, a width of 10 inches on lines of light traffic, which, if

Fig. 5.



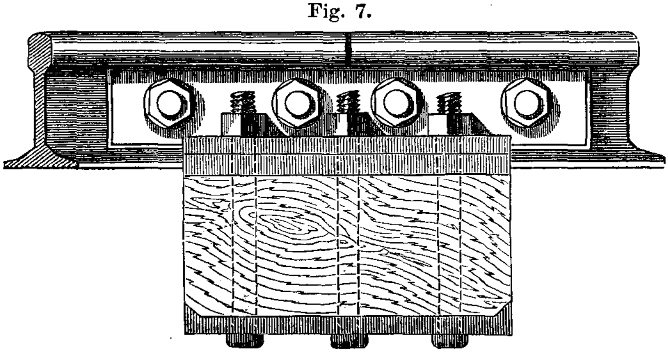
Transverse Section at Joint Sleeper.
The horizontal fish is shown unshaded.

Fig. 6.



Transverse Section at Intermediate Sleeper.

Fig. 7.



Side Elevation of Fish.
The upper horizontal fish is shown above the bed-plate.
Scale for Figs. 5, 6, and 7 :—2 inches = 1 foot.

thought desirable, might be increased to 12 inches on lines of the heaviest traffic. And the ends of these rails were fished to this bed-plate by two horizontal fish-plates with three through fastenings to each centre bolt, being placed at the most effective point, viz., the junction of the rails.

These bolts, three on each side, passed through the sleepers, and were screwed underneath it to a bar $\frac{5}{8}$ inch by $2\frac{3}{4}$ inches, acting as a common nut to the three bolts, thus making the rails practically a continuous bar of uniform resistance, and the sleeper one mass, so to speak, with the rails. Joints of this kind were quite imperceptible when running over the line, and the rails approximated far more nearly to the conditions of a continuous bar of uniform resistance than in the case of a suspended fish.

There might be an advantage in using Parsons' patent bolts for the fish and fang bolts. He had never tried them himself; but their principle was that of equalizing, by fluting the section and strength of the shank to that of the screw-tapped extremity of the bolt, so as to obtain uniform strength and elasticity; this was undoubtedly an improvement.

He always specified for fish-bolts with their inner surface concave, and the corner well preserved instead of being rounded off; by this means the bearing took its grip at the greatest possible distance from the centre of the bolt, and greater leverage was thus obtained to counteract the tendency of the nut to untwist. He had never known such nuts to work loose.

One of the greatest advantages possessed by the Vignoles road, where the rails were fixed directly to the sleepers on machine-planed beds, by means of through screw fastenings, was the absolute uniformity of gauge and cant of rails which was thereby insured, and which rendered practicable a much flatter wheel-tread, and a much narrower clearance than could be attained on a chair line; and these advantages greatly conduced to smooth running, and the preservation of rail surface and rolling stock.

The introduction of the Vignoles rail in this country had been greatly retarded by the defective manner in which it was at first, and was still sometimes laid down, viz., on half-round sleepers, and merely secured by spikes, sometimes without even a nick at the end of the rails to prevent them from travelling. No line of Vignoles rails should be passed unless the sleepers were rectangular; for the bearing of their section on the sleeper should be at least equal to that of a chair on its sleeper, and that amounted to 40 square inches. This was somewhat exceeded on a rectangular sleeper of 9 inches wide, which, with a width of 4·5 inches for the rail foot, gave a bearing of 45 inches for each point of support; but when a Vignoles rail was laid on a half-round sleeper, scarcely one-half of the requisite bearing could be obtained, and that only on sap-wood. Another advantage of this system was that with 3-feet bearings, the clear bearing between the supports was diminished, as compared with a double-headed rail, from 33 inches to 26 inches, and the stiffness of the rail thereby increased inversely as the squares, or in the ratio of nearly 3 to 2.

He saw no reason why a steel-headed rail, of the Vignoles section, dovetailed in the manner described by Mr. Menelaus, should not last as long as one entirely of steel at double the cost.

He thought it would be admitted that puddled bars made the most enduring rails; but it was impossible to force iron of this description, with rollers such as were usually employed, into the slender toes of a wide-footed rail. He would submit that this difficulty might be overcome by employing a third roller set transversely to the other two, for rolling the under surface of the foot, an expedient very generally adopted on the Continent in rolling wrought-iron girders of similar section.

Mr. G. B. Bruce said, with regard to the specifications for rails, he was not prepared to throw the blame upon or to give the credit to Boards of Directors or foreign governments, but was rather disposed to take the responsibility upon himself in cases in which he was concerned. So far from the iron-masters having any reason to complain of the specifications of engineers, he thought that they had learnt a good deal from those specifications. The mode of manufacture which Mr. Williams had so graphically described and so strongly recommended was precisely the same which many engineers had long given in their specifications, and which the great bulk of iron-masters had been driven to adopt, by the engineers so requiring the puddle ball to be hammered in the way described. No doubt, the great secret of a good rail was that it should be homogeneous; but that was not the sole condition, otherwise it would only be necessary to fall back upon the old cast-iron rail, which was homogeneous but brittle.

He was ready to admit that in the matter of rails, as well as in many other things, tests were often carried to an injurious extent; but when judiciously applied, they were very valuable. When specifications provided that a rail should not break under a certain falling weight, and yet not bend more than a given quantity,—these conditions secured the possession of the two requisites, hardness and tenacity, so necessary for a good wearing and safe rail.

He was disposed to think that steel rails were not altogether perfect. Out of one lot of 200 tons which he had used recently, five of the rails broke, literally on being thrown out of the wagon; and in the present process of manufacture, individual steel rails were as likely to be defective as iron rails, and could not be implicitly trusted. He had tested some flat-bottomed steel rails, punched in the lower flange, and had observed that when the holes were not near the part on which the weight of 16½ cwt. fell, the rail did not break, though the fall was 20 feet. But if the same rail was so placed that the holes were in the middle between the points of support, the rail broke at a blow with a 5-feet fall. The holes ought to be drilled and not punched in every case when dealing with steel rails.

Mr. R. P. Brereton dissented altogether from the view that good iron rails could not be made if pains were taken; or that it had become indispensable to seek for other materials, such as steel, except for special occasions. There was as yet no sufficient experience of the effect of hard steel rails upon the tyres and rolling stock—by far the most expensive part of the property belonging to Railway Companies. With regard to the deterioration in the manufacture of rails when these had to be turned out quickly and in large quantities, it was not to be expected that they should at the same time be made good. There was no desire to produce a lasting article; and when Railway Companies undertook to make their own rails, they did not make them better than the ironmasters. He had taken the pains to ascertain what had become of about 24,000 tons of rails made in Wales in 1849 for the South Wales Railway, on which there was a large mineral traffic. It was 100 miles in length and was opened in 1850. In the first nine years, out of the 24,000 tons there were only about 1,080 tons lost, or 4½ per cent. of the original quantity; and of the remainder there were at the present time 12,000 tons in use, and wearing out at the rate of about 5 per cent. per annum of the original quantity. This was principally at stations and inclines; and switches and crossings of the same iron were still in use. The life of these rails had already averaged fifteen years, and at the rate now wearing out would ultimately average seventeen. If iron-masters could make such rails years ago they could make them now; but an inducement was required which was not offered.

Mr. T. E. M. Marsh stated that the rails alluded to by Mr. Brereton were made from cold-blast iron, and a great part of it was worked into refined metal. The manufacture was well cared for. Such good rails were not now generally made. A great demand for common rails had been met by cheaper and inferior material and processes. The price had been fixed upon a sliding scale based on the price of common bar iron, which was somewhat lower than the price of rails, the price of the latter being then about 20 per cent. or 25 per cent. higher than that of bar iron at certain works, because it was supposed that rails were more expensive to produce. To this was added from 15*s.* to 25*s.* per ton extra. Thus, assuming bars to have been at £6 per ton, the cost of the rails would have been from £8 to £9 per ton. The rail was made from puddled bars, one of the principal advantages of that process being that the result of the yield of the puddlers might be tested every day, and at any moment. In that way a good welding quality, and a strong, solid rail, could be obtained. The rails referred to were not "cold short." Puddle balls might be badly made, and in fact frequently did inclose chilled cinder and other impurities, which would cause the iron to be crushed off the rail in large pieces.

In some districts it would probably be found better to use puddle balls direct, and not puddle bars; but the quality of the materials, processes, and appliances of the manufactures must be judged of by the engineer.

Mr. Marsh then referred to some samples of rails he had placed on the table:—

No. 1. Rail and piece of slab, made for Mr. Brunel by Messrs. Thorneycroft, in the year 1858; also small experimental lots, made in the year 1848; the top slab being formed out of a single bloom of charcoal iron. The rails were laid on the Great Western Railway, and were doing good service now, where from three hundred to four hundred engines were passing over them daily.

No. 2. Similar to No. 1, made by Mr. A. Hill. The top slab consisted of Bowling iron: used in the year 1858 and subsequently, on lines in charge of Mr. Brunel, for points and crossings, with very good results.

Nos. 3, 4, and 11. Specimens of puddled steel rail, made for railways in charge of Mr. Brunel, illustrating apparently good fracture and uncertain welds; and samples of steel tops separated by wear. These rails were generally unsatisfactory.

Nos. 5 to 9. Specimens of rails made between the years 1846 and 1850 and subsequently, for Mr. Brunel, being of the class referred to by Mr. Brereton, as having been laid on the South Wales division of the Great Western Railway, between Grange Court and Swansea, a distance of 95 miles, where they were subject to the excessively heavy wear of the inclines in the Neath and Swansea district.

The duration of the bridge rails, of which 24,000 tons were laid, was shown in the following statement:—

	Worn out.
From opening of line in 1850 to June 30, 1859	1,081 tons.
„ June 1859 to July 1863	4,598 „
„ July 1863 to February 1864	763 „
„ February 1864 to July 1864	494 „
„ July 1864 to December 1864	784 „
„ December 1864 to July 1865	942 „
„ July 1865 to December 1865	820 „
„ December 1865 to July 1866	888 „
„ July 1866 to December 1866	658 „
„ December 1866 to July 1867	563 „
„ July 1867 to December 1867	557 „
	12,148 tons.

The same quality was also laid on the Great Western Railway, the Wilts and Somerset, exclusive of the Bath branch, the Berks and Hants, on part of the Oxford and Birmingham, and on heavily worked parts of the South Devon Railway, and generally, with few exceptions, on other lines forming part of the Great Western system.

The merits of the various qualities, and the best mode of obtaining good rails, were continuously and rigorously tested by Mr. Brunel, and the best results were invariably obtained from the ironmaster, who did not object to, but invited and approved rigid inspection, and desired to have the benefit of Mr. Brunel's valuable experience, and to satisfy him that all details were carried out to insure good results.

In June, 1853, Mr. Brunel addressed a letter to twelve of the principal ironmasters in these terms:—

"You are probably aware that it is a very general complaint amongst Engineers and Railway Companies that they cannot now obtain with any certainty rails of a good quality.

"There is every reason to believe that a little more care and skill in the selection of the quality of metal, at all events for a portion of the pile forming the rail, and somewhat more care bestowed in the manufacture, would secure a very superior rail to those now generally manufactured, without any very great increase of expense. I am desirous of obtaining, to lay before the Directors of the Great Western Railway Company, proposals for the manufacture and supply of about 4,000 tons of such superior quality to be used as an experiment upon a line of railway where there will be considerable traffic.

"I enclose a specification of the rail required; but I should prefer leaving the choice of means to those whose practical knowledge must be much greater than mine, and I should feel satisfied if I am assured by a respectable manufacturer that he will undertake to use his best endeavours to meet the objections raised, and to make a really good rail. I assume, although this is a time at which you are all very independent of orders, yet that you would be glad to make the attempt to regain the character which I assure you English rails are fast losing, and if you are disposed to make a trial with 1,000 or 2,000 tons, and will state the mode of manufacture you would propose, and the price, I shall feel obliged. The delivery should be immediate, or at all events early."

Extract from Specification, referred to in Mr. Brunel's letter, for Bridge Rails for Great Western Railway, June, 1853.

"One-third in quantity of the whole pile from which the rail is to be rolled is to consist of a slab of a single piece, forming the whole top of the pile, and so placed as to form the upper portion of the rail when finished. This slab shall be made of No. 2 iron, hammered, or of such other defined quality as may be mentioned in the tender and agreed upon.

"The rest of the pile shall be formed of whole lengths of bars, and no rail-ends, or awkward shaped pieces of scrap shall be used."

Mr. J. Strapp had not much experience of the relative values of steel and iron rails on the South Western Railway. Some steel rails had been laid down four years, and during that time about 10,000,000 tons had passed over them without their showing any perceptible signs of wear. At the same time iron rails had been down in the same district eight years, and probably from 19,000,000 tons to 20,000,000 tons had passed over them. He was not prepared to say that iron rails should be replaced by steel rails where they lasted so long. On the contrary, he thought that where iron rails would last over six years, steel rails, at their present price, could not be substituted with economy. He produced two specimens of rails, one of which had been down twenty-five years, on the Gosport branch, about half a mile from a station, over which not more than 4,000,000 tons had passed; the other had been down eight years in Battersea Fields, and over this 17,000,000 tons had passed; the average speed of the trains, in both cases, being about thirty miles per hour. In calculating these weights he had, of course, taken one-half the gross weight of the trains passing over the one line as that due to duty performed by one rail. Time, therefore, was not always a guide to the true worth of rails.

Mr. Peter Ashcroft produced some specimens of rails which had been used on the South Eastern Railway. Some of them had been down twenty-four years. One, an old Dover rail, put down by Sir William Cubitt, had been passed over by one hundred and five thousand trains, as nearly as could be estimated, equal to 13,000,000 tons. This was on the down line, near the Dover Station, so that every train had to pass over it. Another, of which the maker was unknown, was from the Rochester and Gravesend line, and had been down since the year 1845. It was only a 66 lb. rail, and the quality was excellent; there was a large quantity of similar rails still down on that line. Another specimen which had been down since 1865 on the Charing Cross line between Cannon Street and London Bridge, was known to have had a hundred and seventy thousand trains passed over it, amounting to 21,000,000 tons. Only one side of the rail had as yet been used during the two years and eight months which had elapsed since it had been laid down.

He thought the South Eastern Railway Company had benefited very much by leaving, to a great extent, the specification and manufacture of the rails to the manufacturers, subject to a satisfactory guarantee.[1]

Mr. Marsh inquired whether the guarantee had worked satisfactorily. It was a question of what rails had gone back to the manufacturer.

Mr. Ashcroft replied that one manufacturer had supplied 25,000 tons of rails, and the failures had not been more than 1 per cent. On the Charing Cross line, where the traffic was very heavy, one hundred and ninety-three trains a day passing over one line of rails, the failures were as much as 10 per cent. Care was always taken to obtain a sufficient bond of indemnity for a term of not less than seven years; and for five years on the Charing Cross line.

Mr. W. Mills said that a large number of steel rails had been laid on the London, Chatham and Dover Railway. On a length of six miles, originally laid with iron, but which had been relaid with steel rails, he had reckoned the number of trains which passed over three different parts, and had found that in one case 8,500,000 tons had been carried, in another case 8,750,000 tons, and in a third 9,375,000 tons; the rails showed no appreciable sign of wear. Some steel rails, for stock rails for switches, had been laid down at Stewart's Lane, where formerly new iron rails were laid on an average every three-and-a-half months. Those rails had been down three years and three months, and were now in good order, and would probably last another year or more. From this latter instance it appeared, that the power of resisting wear and tear in steel rails amounted to fourteen or fifteen times that of iron rails.

Mr. Joseph Taylor thought it would be a misfortune if the impression arose that the interests of manufacturers and engineers were antagonistic. Their interests must be identical; the only

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[1] *Extract from the South Eastern Railway Company's Specification for Rails.*

"The directors will not object to receive tenders for the 10,000, 5,000, and 1,400 tons of rails respectively, manufactured according to the ironmaster's own specification, provided he can satisfy them of the sufficiency of the material to be used and the mode of manufacture, and enter into sureties for a guarantee of not less than seven years. In any case it is to be distinctly understood that this specification is intended to convey and mean, that when any of the rails are once laid down and being run over, any perceptible lamination, crushing, splitting, or breaking taking place within the period of the seven years (not being fair wear and tear), such rail or rails shall be subject to a total rejection without being turned over, and must be cast aside and replaced by other sound rails at the contractor's cost. Those rails laid down at stations and within the distance signals are excluded from the obligations of this clause, except they are found unsoundly manufactured."

difference being that the engineer wanted the best rail for the least money, and the manufacturer wished to make the best rail he could, and to get the best price for it.

There was room for wider difference of opinion, as to the best means of obtaining the best rails, and the question seemed to be narrowed into that of specifications or no specifications. He was not prepared to say that engineers ought to throw away specifications altogether, and put themselves entirely into the hands of the ironmaster; but it was possible that specifications had been pushed too far. He believed they were framed, in the first place, from the best possible information to be obtained; but he thought engineers shut themselves out from improvement and discovery in the trade, when they adhered for some years to the same specification. There had been some inconsistency in the way manufacturers had been compelled to work. It was only reasonable that, if a manufacturer was required to make a rail to produce certain results, he should be at liberty to make it according to the best of his judgment. Specifications had apparently been directed too much to the production of a high quality of bar-iron, to the neglect of the wearing quality of the metal. The heavy falling test, and the heavy suspending test, tended to produce bar-iron of high quality, but that iron was deficient in hardness and wearing quality. A little hardness might be admitted into the manufacture of rails with great advantage; and yet the rails should be sufficiently tough to resist any impact in the course of the ordinary traffic. Considering the comparative scarcity of steel-producing ore and the high price of steel rails, he thought that, for some time at least, the bulk of the supply of rails must be from iron; and so long as a thoroughly good iron rail could be made for from £6. 10*s*. to £7. per ton, to last fourteen or sixteen years, of which there was no doubt, he did not consider that the days of the ironmaster were numbered.

Mr. W. ADAMS stated that, in the month of October, 1862, 20 tons of Bessemer steel rails were laid down on the North London Railway, over which two hundred and fifty-four thousand two hundred and fifty trains, estimated to weigh 38,137,500 tons, had passed. He had lately measured them and found that they had worn down about $\frac{3}{16}$ths of an inch. He thought that each head might wear down about $\frac{1}{4}$th of an inch, and this gave the means of estimating the durability of the rails. Between thirteen thousand and fourteen thousand rails had since been laid, and he was informed that there had not been a single failure in one of them. Some crossings leading into Dalston Junction had been laid between three years and four years, and the rails were still in good working order.

Mr. ZERAH COLBURN had received a letter from the general manager of the Erie Railroad, enclosing a report to the Chairman of the line, in which he stated that during the month of January upwards of one thousand rails had been broken on that line, and also that he believed the month of February would show a still worse result. Another correspondent had informed Mr. Colburn that within his knowledge, on the Hudson River Railroad, a double line, 144 miles in length, in one day, one hundred and thirteen rails had been found broken, during what was called a 'cold snap.' He had received a letter from a friend in Eastern Canada, three or four weeks ago, where possibly the temperature was lower than on the lines mentioned, and the mercury at the time the letter was written was 41° Fahrenheit below zero. At Toronto there had been unusual cold, and the mercury had ranged from 13° to 17° below zero. He had no reason to doubt the statements as to the breakages of the rails.

Rails in the United States were usually of the Vignoles section, and weighed 64 lbs. to 74 lbs. to the yard. The Manager of the Erie Railroad had asked his directors to authorise him to complete the renewals for this year, to the extent of 25,000 tons, in steel, and not one steel rail had broken, although their weight was only 56 lbs. to the yard, and some steel rails had been down for the last five years. He might add that the Hudson River Railroad was then being entirely relaid with steel rails.

Mr. W. Bragge said, in reference to Mr. Colburn's statement as to the serious disaster on the Erie Railway, for such he called the great destruction of rails, the engineer had stated that the month of February would show a greater destruction of iron rails; but he went on to state that the only portion of the line on which trains could run with safety and speed was that portion laid with steel rails, and that no fault could be found with the 10 miles of track laid with the Bessemer steel rails; of these only one had broken during the winter, and no lamination and very little wear was perceptible. It should be borne in mind by those who were using steel rails, that iron rail-makers had the experience of thirty years or forty years: whereas steel rail-makers had been really at work only since the end of the year 1861. Upon him first devolved the duty of offering steel rails for sale; at that time the steel rail was looked upon with doubt and distrust, and only by offering rails to make into points and crossings, on trial, to be paid for when they had earned their value, was it possible to sell them in England. He claimed for the makers of steel rails, that they had availed themselves of every branch of scientific knowledge which could be brought to bear upon their work; and he contended that the progress of seven years had not been unsatisfactory.

Mr. R. Price Williams observed that on the North London and the London, Chatham, and Dover Railways the life of iron as compared with steel rails was certainly of the briefest, while on the other hand the iron rails on the South Eastern Railway appeared to have shown an amount of endurance almost as remarkable as the highly phosphorized iron rails on the North Eastern Railway.

The consideration of the use of steel instead of iron rails was, after all, an engineering and economical question, which a more extended experience of the superior endurance of steel could alone determine. As far, however, as he could gather, there could be no question as to the preference of steel rails on main lines exposed to heavy traffic and high speeds, where the maximum life of iron rails did not exceed eight years.

The accuracy of the data on which the calculations of the Author's table were based had been called in question; but he had carefully gone through them with Mr. Sandberg, and had found them perfectly reliable. Objection had also been made to the extended period taken for the life of steel rails; he apprehended that the Author had only assumed such as affording the only available means of comparison with iron rails of a proportionably long life, such as might be anticipated where they were exposed to the small wearing action of light traffic. He thought, however, that twenty years' life for steel rails was quite sufficient for all purposes of comparison, as it was evident that where iron rails had a life of even fourteen years, it was cheaper, at the present prices of steel rails, to use that material.

He was unable to comprehend why Mr. Bell, at the outset of his interesting account of the iron rail manufacture in the Cleveland district, should lay so much stress upon the superior advantages afforded by the process of puddling, in getting rid of the phosphorus, when it appeared from his subsequent remarks that the presence of this substance in certain proportions was essential to the production of a sound and durable iron rail. That an excess of phosphorus did conduce to the hardness of iron rails there could be no question; but he thought most engineers who had experience of cold short iron would confirm the opinion, that such additional hardness was obtained at the greatly increased risk of sudden and perhaps disastrous breakage of iron rails.

He was disposed to think that the efforts alluded to, as being made to produce sound iron rails out of highly phosphorized Cleveland iron, would prove unsuccessful; if, however, any practicable means could be devised for getting rid of the phosphorus, and of producing good steel out of Cleveland iron, the discoverer would undoubtedly confer a great benefit, not only upon that district but upon the country generally.

He had prepared a tabular statement with the view of showing, that when compared with the present and future advantages to be derived from the substitution of steel for iron rails, the difference in first cost was not of the importance that might at first be imagined.

TABULAR STATEMENT, showing how an ANNUITY of 10*s.* 5⅛*d.* per Ton will Recoup the difference between STEEL and IRON RAILS (£6. 10*s.* per ton) in a period of 20 Years.

Dr. Cash advanced at 5 per cent. Interest, £6. 10*s.*	Principal Recouped.	Interest.	Annuity, £0·5215795.	Cr.
	£.	£.		£.
To 1 Year's Instalment	0·1963130	0·3252665	To 1 Year's Annuity	0·5215795
2 " "	·2064010	·3151785	2 " "	·5215795
3 " "	·2167295	·3048500	3 " "	·5215795
4 " "	·2275585	·2940210	4 " "	·5215795
5 " "	·2389400	·2826395	5 " "	·5215795
6 " "	·2508870	·2706925	6 " "	·5215795
7 " "	·2634255	·2581540	7 " "	·5215795
8 " "	·2766010	·2449785	8 " "	·5215795
9 " "	·2904330	·2311465	9 " "	·5215795
10 " "	·3049540	·2166255	10 " "	·5215795
11 " "	·3202030	·2013765	11 " "	·5215795
12 " "	·3362125	·1853670	12 " "	·5215795
13 " "	·3530280	·1685515	13 " "	·5215795
14 " "	·3706755	·1509040	14 " "	·5215795
15 " "	·3892135	·1323660	15 " "	·5215795
16 " "	·4086745	·1129050	16 " "	·5215795
17 " "	·4291040	·0924755	17 " "	·5215795
18 " "	·4505605	·0710190	18 " "	·5215795
19 " "	·4730830	·0484965	19 " "	·5215795
20 " "	·4967430	·0248365	20 " "	·5215795
	6·4997400	3·9318500		£10·4315900
Principal . . £6·4997400			As per Contra.	
Interest . . 3·9318500				
10·4315900				

Annuity required for 1 mile single line, £62. 11*s.* 9*d.*
(Iron rails and steel rails, 75 lbs. per yard.)

It would be seen that by dealing with the difference in cost between iron and steel (£6. 10*s.* per ton), as a deferred annuity, the small annual payment of 10*s.* per ton, during a period of twenty years, would recoup the principal with interest at 5 per cent. during that period. He might mention that on the main line of the Great Northern, where the average life of an iron rail was only eight years, the cost of renewals of the rails alone amounted on an average to £1 per ton per annum. It was evident, therefore, that under such circumstances the adoption of this principle of deferred annuities would ensure a saving of at least 50 per cent.

Mr. BIDDER, Past-President, had never in the course of his practice pretended to dictate to the manufacturers how iron should be treated; but he had always endeavoured to obtain the best quality. Engineers were often overruled by their masters, the Directors; and there was apparently only one species of test they were capable of appreciating, and that was the lowest price. Whether as regarded locomotives, or steam-boats, or the manufacture of rails, he should consider it simple affectation to assume that he, as an Engineer, had such a knowledge of details that he could dictate the mode in which they should be constructed or produced. He knew one instance of the position he desired to lay down, where in the case of some steam-ships, the result was that when a sum of about £120,000 had been spent in six steamers, five had never been used at all; and the only one that was used did not make a single voyage without loss. As regarded iron rails, every manufacturer, urged by his own particular interest, directed his attention to the mode of manufacture most suitable to his own locality and the material he had to deal with. Now wherever Mr. Bidder was permitted to have his way, he specified what he wanted, the test, the power of the metal, and its other qualities; and then he said to the manufacturer that was what he required, and those were the tests which he should apply; and he then advised the acceptance of the tender after judging of the character of the men who tendered. He necessarily inferred that they were men satisfied with their own mode of manufacture, and that he might rely upon them to make the iron in the way they stated. By that means he had a much better surety than if he had tried to force upon them a mode of manufacture to which they had not been accustomed.

With regard to rails, all views as to the peculiar class of metal suitable for rails had been, from the first initiation of railways, subject to violent anomalies. He remembered a time when everybody assumed that only cast iron was fitted for rails, when all at once it turned out that wrought-iron rails were much more durable. It must be borne in mind that, on a railway, no rail could be broken by pressure. Take a bearing 3 feet long, and an engine 30 tons in weight, rolling over it at a speed of 40 miles an hour. It was well known that in 3 feet a rail would bend more than $\frac{1}{4}$ of an inch before it would break; but if there were no rail at all, at 40 miles an hour the wheel of an engine would not deflect the $\frac{1}{8}$th of an inch from gravity; therefore, if a rail deflected more than $\frac{1}{8}$th of an inch, no further pressure from the engine could occur. But what had to be dealt with in rails was impact and rubbing; the latter being the most serious question. He did not know how a test for the grinding of a locomotive wheel could be applied, unless by means of a huge grindstone; and that would not give the exact effect.

Mr. Bessemer had been a great benefactor to railways and metallurgy in general: he had given an impulse, the effect of which could hardly at present be foreseen; but he believed the result would be to produce eventually a cheap and good rail. He did not care so much about its tensile powers, but rather its capacity to sustain the grinding impact of a locomotive engine, running at the rate of 40 to 50 miles an hour.

At the present day the popular cry was to close the capital account of companies. But if it were proved beyond doubt that a rail which cost £14 per ton was the one to be adopted in lieu of the present rail at £7 per ton, who was to provide the extra £6 or £7 per ton? On railways which were not in a condition to pay any dividend at all, if the capital account were closed, and rails were introduced which would eventually produce great economy, he was afraid the result would be equivalent to confiscation; for suppose some 10,000 tons of rails, at an extra cost of £70,000, were laid down, and this sum were to be taken out of the preference dividends, that would prevent their receiving any dividend for the time being; and that he would call confiscation.

Mr. T. A. Rochussen stated that the Author of the Paper had mentioned the mode of welding first brought into operation at Hörde, in Prussia. The Plan C (Plate 14) was first adopted in the year 1851, when the coal and mineral traffic had increased to such an extent, that the ordinary iron rail did not suffice to resist the increased weight. The puddling of fine-grained iron led to the puddling of steel, which not only was applied to rails, but it gradually became a staple manufacture of the country. About two years previously he had produced two rails manufactured according to that process; and only two or three days ago he had an opportunity of inspecting some of the same rails at Oberhausen, where they had borne a traffic of 42,000,000 tons. The rails weighed 56 lbs. to the yard, yet only one side was worn; the other was untouched, and these rails would probably not be turned for another six months. That welding process had been carried on now for more than seventeen years, and was still largely in operation; compound rails were used to a greater extent than both solid steel rails and solid iron rails together. The difficulty of welding was greater with Bessemer steel than with puddled steel; and it had been found necessary to increase the weight of steel in the slab, so as to throw the weld into the web, as represented by Plan A (Plate 14). This process was only applied to the Vignoles section of rail; since there would be no saving in having the reversible opposite head in steel, leaving simply the small piece of iron between. It was very difficult to get the iron web from the steel head in the old rails.

He thought that the fracture of American rails, which had been mentioned, was due in a great measure to their unfavourable section, which was too shallow.

The Hörde works, in Prussia, had gone further than introducing the weld of steel and iron. They had for a number of years made different systems of iron angle-bars, with steel heads suspended between them. One system, which he exhibited, had been used for some time on the Brunswick Railway, and was a most advantageous mode of supporting a limited amount of steel by a larger web of iron.

Mr. Benjamin Baker observed that, in testing an iron rail against one of steel, of lighter section, but of equal stiffness, care should be taken that they were representative rails of equal average quality; so that a hard steel rail might not be tested against a soft iron one. He thought engineers had ample data to enable them to predict what the durability of such rails would be. The maximum stress on the rails could readily be ascertained, since it would be equal and opposite to that on the springs of the engine, the varying deflections and corresponding pressures of which might be noted in the ordinary working of the engine, at different rates of speed, over various portions of the line; the stress being known, the strain and deflection might be accurately computed. The comparative stiffness of similar sections of steel and iron rails was known to average as 4 to 3, and the strength as 5 to 3. It followed from this that the stiffness of Mr. Fowler's 84-lbs. section, if rolled in iron, would be equalled by a steel rail of similar but reduced section, weighing $72\frac{1}{2}$ lbs.; and the strength would be equalled by a 69-lbs. steel rail.

With the section of rail adopted by Mr. Fowler, at 5 feet bearings, the solid rails bore a deflection on an average of $10\frac{1}{2}$ inches; those with drilled holes, only $2\frac{1}{2}$ inches; while those with punched holes snapped with less than $\frac{3}{8}$ths of an inch deflection. Those rails were manufactured by the Dowlais Company from tough steel, of exceptionally uniform quality, the tensile strength varying very little in any experiment from 35 tons per square inch; and the breaking weight applied at the centre of the 5-feet bearings averaged 29 tons for the solid rails, $19\frac{3}{4}$ tons for the drilled rails, and only $13\frac{1}{2}$ tons for the punched rails. To break those rails in a testing machine, at the rate of sixty per minute, would require 52 effective horse-power for the solid rails, and less than one horse for the punched ones; and the knocking about which the respective rails would sustain, without injury in ordinary working, would be nearly proportional to those amounts. The ultimate deflection of the punched rails was identical with that of cast-iron rails of similar section; hence, in one sense of the word, they were equally brittle. A curious fact, bearing upon the position of holes in the flanges of rails, was worth noting. In the rails above mentioned, the two holes at each sleeper were placed 4 inches apart, measured on the centre line of the rail, and on alternate sides of the web, so that the loss of section was that due to one hole only. Now theoretical considerations indicated that the resistance of the rail would be increased by making another hole opposite the existing one, notwithstanding the double loss of section. It seemed rather an odd way of strengthening a rail, to punch a hole $1\frac{1}{8}$ inch diameter through its weakest part; but after making every correction, theory indicated a gain of 10 per cent., and this result was corroborated by direct experiment. It was found upon trial that, whilst with one punched hole the rails broke under $13\frac{1}{2}$ tons' pressure, with two holes, placed opposite each other, of similar size, they sustained $14\frac{1}{2}$ tons.

Captain H. W. Tyler had been accustomed for many years past to hear constant complaints against the manufacture of rails. It had been said that the manufacturers had lost the art of making rails—that the introduction of the hot-blast had enabled them to work up inferior ores—that it was impossible to obtain either good material or good workmanship—and that, in fine, good durable rails, such as were formerly supplied, were not to be got at any price. It was also said that rails were wearing out in this country in six months, in situations where they formerly lasted for years; and that those sent out of this country for foreign consumption were worse than those manufactured for home consumption. He had quite recently read a letter, from the other side of the Atlantic, from a gentleman of great experience, who did not believe that English manufacturers could now make durable rails, and who thought that there was no remedy but the employment of steel. Last summer he saw steel rails being laid down on lines in the United States, which cost, including transport and a very heavy duty, about £25 per ton. Only a few weeks ago, he had inquired into an accident in the Penge tunnel of the London, Chatham, and Dover Railway, which was occasioned by the failure of a rail, certainly very badly made, the top of which had fallen away in six pieces, and he saw many near it failing in a similar manner. During a recent inspection of the Grand Trunk Railway of Canada, he found that rails laid down within the last few years had been failing to an extraordinary extent, and that portions of the line relaid with new rails were obliged to be again renewed in from three to five years, while the older rails were still necessarily kept in the track.

Now he had been carefully considering this question, both in England and in America; and particularly with reference to Canada—where, in consequence of the severity of the climate, rails of good quality were still more required than in England. The road was there in a perfectly rigid condition, for, say five months in the year, and the thermometer sometimes $-40°$, with the frost penetrating 5 feet into the ground. But under those circumstances the durability of the rails was very various; some of them lasting six times as long as others, under the same description of traffic. He found this was not a question of price; for strangely enough the cheaper rails had lasted longer than those for which a higher price had been paid, in some cases at the suggestion of manufacturers, to ensure greater durability. The failures appeared to be irrespective of the specification, and of tests applied. The principal defect was undoubtedly imperfect welding; and those rails which had worn best were generally those which showed on their fractured sections coarse crystals, and what would be called inferior quality. He did not believe that all the defects of manufacture which had been witnessed or experienced were due to faulty specifications. In truth, the engineers had generally consulted the manufacturers in drawing up those specifications. The difficulty had been to obtain durable rails under any specification. And when the number of specifications was complained of, for he had heard a manufacturer saying the other day that he possessed copies of two hundred and fifty different specifications, it must be remembered that a different specification was necessary in the case of each manufacturer, and of each section of rail, and was allowable in the case of each engineer.

In regard to tests, he believed that harm had been done by requiring manufacturers to make rails subject to the test of too heavy a falling weight. He had heard rails spoken of as being extra good because they would stand 17 cwt. falling 25 feet. Such rails were no doubt defective in other essential qualities.

In answering the question how to get a durable rail, it must be first determined what was required in a rail. A rail had often enough been compared to a continuous girder: but it was much more; for while it was required, like a girder, to resist compression principally in its upper, and tension chiefly in its lower chord, it was further required while deflecting very slightly, to wear gradually away under traffic on its upper flange, and to resist such wear and tear to the utmost. He by no means agreed in comparing the action of the wheel and the rail to a hammer and anvil, because when the rolling weights inflicted a blow, they did so with the intervention of springs. When the rails were shallow, or wanting in depth, the blows became more serious, and failures by crushing at the ends, even when the joints were fished, were more apt to occur; but when the section was deep, and deflection was immaterial, the fish was more perfect, and a rolling, crushing action was the principal effect to be encountered.

In regard to the best form of rail, whatever the reason might be, it was certain that the double-headed section of rail was mostly adopted in England: while on the continent of Europe and America, such a section was only exceptionally seen. There were two principal reasons for the adoption of the double-headed section: rails of that section had a broader base by means of chairs, and they might be turned so as to wear out four instead of two edges. But, on the other hand, there were strong reasons against their adoption. They were raised higher over the sleepers, having the chairs below them: an amount of metal was put into the chairs which might with greater advantage be put into the rails: they could not, as a matter of manufacture, be made equally durable and serviceable in both heads: and when turned, they were more or less defective, and unserviceable.

With the Vignoles rail, on the other hand, the engineer and the manufacturer might combine to make a hard durable head without fear of a rail that would break in the track, because they could at the same time use fibrous material in the lower flange: and with this section all risk of loose keys was avoided, and there was also the advantage of fewer parts.

It was a prevalent idea that the Vignoles rail was not a good form of rail for traffic at high speed, but he could not, himself, see the objection. He believed, on the contrary, that when deep in section, with a good broad base, and laid on square cross-sleepers at a proper distance apart, it formed the safest permanent way that could be constructed for any speed.

In regard to quality, that to some extent depended upon the form. As he had already said, a harder and more brittle head could be used with the Vignoles than with the double-headed section. Any rail, whatever might be the quality which would not crush from bad welding, would last for a considerable time. He had an aversion to steel-topped rails, knowing that the steel and the iron welded at different heats, and believing that under the most careful system of manufacture, a large proportion of steel-topped rails must, sooner or later, fail from the separation of the steel from the iron. He had seen numerous cases, in different situations, where the steel had come off bodily, and he conceived that even the steel tops, which were originally well united, must be liable, in consequence of being rolled out under the traffic, sooner or later, to separate. He therefore thought that the statement in the Table was deceptive. The general question of the relative advantages of steel, as compared with iron, granting that the manufacturers would still make good iron, was simply one of price. Every one must admit the advantage of a homogeneous rail, the structure of which rendered lamination impossible; but it was not every Railway Company that could afford to pay a high price for steel rails for other than exceptional parts of their line.

He believed that, while guarantees were good in their way, and particularly in England, when rails could easily be returned to the makers, there was one method which would be better in the end than specifications or tests, and that was the unreserved publication of the results. If all engineers would combine to collect and record the price, the wear and tear, and the durability of each sample of rails from the various makers, and to publish their records annually with the reports of the companies, the manufacturers would be subjected to a wholesome competition with each other, which could not but be attended with the best effects.

Mr. J. A. Longridge said that the first malleable iron rails were made by his father at the Bedlington Iron Works. There was a strong contest in those days as to the comparative merits of malleable-iron rails and cast-iron rails; and the principal objection against the malleable-iron rails was that they laminated and exfoliated. Engineers were then in favour of cast-iron rails in preference to wrought-iron, and among them was George Stephenson. The first wrought-iron rails were laid on a private railway for conveying coals to the Bedlington Iron Works; and to George Stephenson's credit it must be said, that when he saw that although they did bend they recovered their form again, he at once recommended their adoption, instead of cast-iron rails, although he had a pecuniary interest in the latter. The manufacturers could still make as good, or better malleable-iron rails than were produced at that time, or when the London and Birmingham Railway was in course of construction; and if the manufacturer was not bound by absurd tests on the one side, and by a specification which might suit one iron but would not suit another, and the sort of rail that was wanted was clearly stated, an excellent rail could now be produced for a fair price. A weight of 3 cwt. falling from a height of 20 feet on the rails was equal to an accumulated shock on the rails of 3 tons. Supposing the weight on a driving-wheel of a locomotive engine to be 7 tons, and that at a joint in the permanent way one rail stood $\frac{1}{4}$ of an inch above the adjoining one, then the velocity with which that would fall would accumulate a shock on the rail of $\frac{1}{7}$th of a ton, instead of 3 tons, as in the case of the falling weight. He thought, therefore, that such a falling weight was an absurd test. He did not deny that the dead-weight test would give a certain result; but he was sure that almost any rail would amply support whatever weight might come on it as a dead weight. He did not agree with Captain Tyler that the form of the Vignoles rail was advantageous, because crystalline iron could be put where it was in compression and fibrous iron where it was in tension. That was very true if a rail was supported simply between two joints, but inasmuch as a rail was a continuous girder, in a certain position of the load the top of the rail was in tension and the bottom of the rail in compression; therefore if fibrous iron was required in one part it was required also in another. Yet rails were all so amply strong, that it was not a question of the strength of a rail, but of its durability. Iron rails should not be condemned because they wore out, but an attempt should be made to reform the rolling stock. The enormous weight put on the driving-wheels crushed the rails; and he thought conical wheels fixed to the axles should be discarded, as being very injurious to the rails: the better system would be to have every wheel revolving independently. Mr. Cross had tried this plan on the St. Helen's line with perfect success. He did not approve of the conical wheel, because, even if the wheels were revolving independently, one portion of the wheel-tyre must be sliding. Take the ordinary cone of the wheel, and the ordinary width of its bearing on the rail as only $\frac{3}{4}$ of an inch: then with a train of 100 tons moving at the rate of 20 miles an hour, there would be a grinding action equal to $1\frac{2}{3}$rd horse power; and if the train moved at the rate of 60 miles an hour, it would be equal to a grinding action of 5 horse power.[1] This must have a prejudicial effect on the wear of the rails. If they were simply subjected to a rolling motion, they would last for an indefinite period; and he was sure it was mainly due to the conical form of the wheels that the grinding and wearing motion took place: and this was increased by putting gravel and sand on the rails when they were at all greasy. He thought that steel tyres, which were now being adopted, working on steel rails lessened the adhesion, and

[1] The formula for this was—

$$\text{Horse-power} = \frac{w\,v\,b}{33{,}000\,f\,.\,n\ \text{D}}.$$

When w = total weight of train in lbs.

,, v = velocity of train in feet per minute.

,, b = breadth of surface of tyres in contact with the rail.

,, $\frac{1}{f}$ = coefficient of friction.

,, $\frac{1}{n}$ = degree of conicity of tyres.

,, D = diameter of wheel in feet.

that the weight on the driving-wheels would have to be increased. Therefore he maintained that wrought-iron rails should not be discarded. The proper course to pursue was to reform the rolling stock, to distribute the weight on a greater number of driving-wheels, to have wheels revolving independently, and to abolish the conical wheel.

Captain H. W. Tyler observed that Mr. Longridge had stated that it was necessary to provide for tensile strain in the top flange as well as the bottom flange of a rail. Now, in any case in which a weight was applied on each side of a sleeper, the top flange of the rail no doubt would be more or less in tension; but in reality and in practice the distance between the engine-wheels, and especially the driving-wheels, was at least 5 or 6 feet, while it was commonly more; whereas, the distance between the sleepers was only $2\frac{1}{2}$ feet or 3 feet; therefore there could never be a weight supported on both sides of any sleeper at the same time. When the rails were sufficiently deep, and when the sleepers were sufficiently near together, the deflection of a rail under passing loads was imperceptible; and any strains which could be produced in tension on the upper flanges of the rails over the sleepers were practically immaterial, and were not to be compared to the strains in tension on the lower flanges between the sleepers.

Mr. John Boyd thought that if engineers abolished tests they would not get rails as good as those now obtained; although the falling-weight test was perhaps excessive at the present time. He did not think the mode of manufacturing rails had been sufficiently considered. It was certain, that by a proper mixture of iron in the puddling furnace a better rail could be obtained than by making use of any one quality of iron; for instance, by a mixture of Cumberland 'red short' hæmatite iron with Welsh iron, and also with Cleveland iron, both of which were 'cold short.' Sir Charles Fox once told him that he saw rails from England being delivered in America, and several of them broke when they were thrown down. He had formerly known the Scotch foreman who was superintending the delivery, and he said to him, "What a pity it is your Railway Companies don't give £1 a ton more, and get better rails than these." The reply was, "Weel, Sir Charles, they are just as guid as the bonds we gie for them." Before giving a judgment on the wear of the rails, it should be known how these rails which only lasted three or four years were paid for. If engineers did not specify the mode of manufacture, they should at least specify the description of iron of which the pile should be formed; and he would suggest that the top and bottom slab of the whole length and breadth of the pile should be formed of No. 2 hammered 'all mine-refined' iron, and the intermediate slabs of the whole length of the pile laid so as to break joint, of puddled bars, and that the quantity of cinder in them should never exceed one-sixth of the whole burden on the furnace, and that no crop ends should be used, and the thickness of the slabs be so arranged that all parts of the pile should be reheated simultaneously.

He was of opinion that moderate, and particularly falling tests, should not be discontinued; and that care should be taken that the bulk of all the rails really were equal to the quality of the tested rails; as it was notorious that rails said to have stood the test stipulated for by the East Indian Railway Company's Engineer at the maker's works had not borne the same tests at Rotherhithe; and in his opinion the reputation of engineers and the safety of the public required that tests should not altogether be abolished.

He submitted the analysis of West Cumberland hæmatite Bessemer pig iron, which was extensively used by the makers of Bessemer steel throughout the kingdom for rails and other purposes. He advocated the use of a mild steel rail, as having most adhesion.

"REPORT UPON THE WEST CUMBERLAND 'BESSEMER' PIG IRON, BY DR. NOAD, F.R.S.

"*Laboratory, Kinnerton Street, Dec. 10th,* 1867.

"DEAR SIRS,

"I now have the pleasure of reporting on the last sample of Bessemer Iron which you sent me for analysis. I consider it to be first-rate iron; the quantity of silicon being by no means excessive, and sulphur and phosphorus wholly unimportant.

I am, dear Sirs,
Yours very faithfully,
(Signed) HENRY M. NOAD.

"*Messrs. West Cumberland Hæmatite Iron Co., Workington.*"

ANALYSIS.

	per cent.
Graphite	3·850
Silicon	1·728
Sulphur	0·030
Phosphorus	0·044
Manganese	0·072
Titanic acid	0·152
Iron	94·124
	100·000

"REPORT UPON THE SAME, BY DR. TOSH.

"*Chemical Laboratory, Maryport, Dec. 9th,* 1867.

"The specimen of pig iron received on the 27th ult. has been found to have the following composition:—

	per cent.	
Carbon {as graphite	3·989	4·485
Carbon {combined	·496	
Silicon	1·767	
Sulphur	·008	
Phosphorus	·025	
Titanium	trace.	
Manganese	·219	
Iron	93·724	
	100·228	

"From the above results I have no hesitation in saying that this iron is of excellent quality.

"Considered with regard to its adaptability for Bessemer Steel making, it is in every respect one of the best irons which I have examined.

(Signed) EDMUND G. TOSH, Ph.D.

"*Messrs. West Cumberland Hæmatite Iron Co., Workington.*"

Mr. F. D. BANISTER gave some details of the wear of rails on the Brighton Railway, and illustrated his remarks by a tabular statement. On the first 12¾ miles of the line from the London end towards Brighton, which carried the South Eastern and the Brighton main and local traffic, a length of 7 miles being a quadruple, and the remainder a double line, the total expenditure in rails for ten years, from 1856 to 1866, had been £20,865, or £159. 13*s.* 10*d.* per mile per annum; giving a per-centage on the original cost of £12·11, and showing a life of 8·10 years. In the suburban district, from Victoria to Norwood, on the West End and Crystal Palace line, the expenditure per mile per annum was £77; the total expenditure in ten years, £8,097; the per-centage of these on the original cost per mile per annum, £9·31, and the life of the rails 10·73 years. On the remainder of the main line, from Red Hill to Brighton, the expenditure per mile per annum was £72. 7*s.* 4*d.*; in ten years, £21,712; giving a per-centage of wear of £8·53 per mile per annum, and a life of 11·71 years. On the coast lines, Brighton to St. Leonards, and Brighton to Portsmouth, the results were nearly the same—expenditure, £40 per mile per annum; total expenditure, £15,000; and a per-centage of £4·94 per mile per annum on the original cost. There were some curious results on local lines. On the line between Wimbledon and Croydon the expenditure in rails in ten years had been £11. 6*s.* 8*d.* per mile; total expenditure, £511. On the coast line, from Lewes to Newhaven, which had been in use for twenty years, the expenditure for the last ten years had been only 14*s.* 10*d.* per mile per annum for rails. That showed that those rails were remarkably hard; they had worn very well, but more broken rails had been found there than on any other part of the system. The general result of the ten years' wear was an expenditure for rails of £78. 4*s.* 11*d.* per mile per annum,

LONDON, BRIGHTON, AND SOUTH COAST RAILWAY.

AVERAGE COST per MILE per ANNUM, and other Details respecting the MAINTENANCE of WAY and WORKS, for TEN YEARS ending 31st December, 1866, including RENEWALS both of WAY and BRIDGES, but exclusive of STATIONS and SIGNALS. Materials Net.

Length. Miles.	Length. Chains.	From.	To.	Wages.	RAILS.	Sleepers.	Chairs, &c.	Renewal of Bridges.	Total.	Original Cost of Rails £7 5s., less Cr. for Old £3 12 6. Net Cost £3 12 6.	Amount expended in Rails in Ten Years. Net.	Life of Rails in Years.	In Ten Years' Wear of Rails, per cent. on Net Cost.	Tonnage per Annum.	Remarks.
				£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£.	£.				
12	65	B. Arms, Junc.	S. Nest. .	374 18 5	159 13 10	55 6 2	49 7 8	11 0 0	650 6 1	17,100	20,865	8·19	12·20	2,096,640	Seven miles quadruple, the remainder double line. Average speed 35 miles per hour.
29	60	Red Hill .	Brighton .	172 3 4	72 7 4	59 12 8	51 14 8	. .	355 18 0	25,436	21,712	11·71	8·53	898,560	Double line. Speed 35 miles per hour.
32	53	Brighton .	St. Leonard's	121 16 4	42 11 8	43 13 3	38 18 9	56 9 8	303 9 8	27,926	13,844	20·17	4·95	318,240	Ditto. Ditto 30 ditto.
41	43	Ditto . .	Portcreek .	105 1 10	38 0 6	50 14 3	38 10 0	44 9 6	276 16 1	35,514	15,966	22·24	4·49	555,440	Ditto. Ditto 30 ditto.
9	27	Croydon .	Epsom .	143 2 2	79 15 7	56 6 8	31 13 4	. .	310 17 9	7,983	7,169	11·13	8·98	861,120	Ditto. Ditto 30 ditto.
10	13	Norwood .	Victoria .	332 5 8	77 0 11	31 8 7	17 8 7	. .	458 3 9	6,688	8,097	10·73	9·31	3,781,920	Ditto. Ditto 30 ditto.
			Average .	208 4 7	78 4 11	49 10 3	37 18 10	18 13 2	392 11 10	. .	. .	14·03	8·07	1,418,653	
6	4	Croydon .	Wimbledon	67 0 0	8 10 0	11 6 8	6 13 4	. .	93 10 0	2,586	511	. .	. .	411,840	
9	9	Keymer .	Lewes . .	157 2 2	9 8 10	43 13 4	18 4 5	102 2 0	330 10 9	7,791	858	. .	. .	336,960	
5	47	Lewes .	Newhaven	103 9 1	0 14 10	37 16 4	10 10 10	79 5 5	231 16 6	4,777	48	. .	. .	299,520	

and a per-centage on the original cost of £8·07, the average maintenance of works over that portion was about £392. 11*s.* 10*d.* per mile; so that the per-centage for wear of rails upon the £392. 11*s.* 10*d.* was nearly 20, and the average life had been fourteen years. He might mention that between the Bridge over the Thames and the Victoria Station the rails originally laid by Mr. Fowler were of iron; they lasted two years, and had been twice renewed, but they had now been replaced by rails of steel. On a portion of the line near Bricklayers' Arms Station, in the summer of 1864 he had laid down 400 yards of steel rails, manufactured by Sir John Brown and Co. Over that portion on the down line the whole of the South Eastern and Brighton traffic had passed, being 16,500,000 tons, in three years and eight months. Those rails had been carefully measured, and he found that the wear had been a little more than $\frac{1}{16}$th of an inch. The iron rails adjoining were worn out in about sixteen months, with a traffic of about 6,000,000 tons, the speed in both cases being 30 miles an hour.

Mr. W. Bridges Adams observed that in the question of rail manufacture, the engineer was the designer of the form, strength, and quality required, if he were a veritable constructive engineer, while the manufacturer was the producer of what would sell and make most profit. The ironmaster preferred pigs, "the sow and pigs" in cast iron; next, heavy round bars, then square bars, then the section of a parallelogram, then the parallelogram channelled to make a rail; but improved forms he called fancy iron, and eschewed them, if he could, till a sufficient pressure was put upon him by the fear of losing trade. The quality prized in Bessemer rails was homogeneity. Whether they were steel or iron, was not a settled point. Mr. Bessemer himself did not decide whether they were steel or iron. Probably they were steel, from the fact of their breaking uncertainly, and, as shown by a sample on the table, the same bar breaking within a foot of the upper edge, where it was turned down under the engine-wheel as though it were a piece of lead. A good rough test for steel would be hardening and tempering a portion for a spring. Steel must be used either hardened and tempered equally, or annealed throughout. If neither of these processes were resorted to, it would be irregularly hard and soft, and would infallibly break. This was probably the reason why the maxim had grown up—"keep them soft." Bessemer rails in their best form were homogeneous iron, and would of course rub away under heavy friction, like any other homogeneous iron equally soft; but they would not laminate, as iron—not being homogeneous—was liable to do. Iron rails were made by what was called piling, *i. e.* iron in short lengths of differing quality, covered over with scale, everywhere except at the ends, where they were not intended to be united. These piles were full of hollow scale-cells, to which the air got access while in the furnace, and when rolled out they were a mere series of fibres and ribands, separated by scale, in straight lines; and if farther rolled out, they would still be straight fibres, and not gnarled in curves like the grain of oak or elm, or like tinplate or sinuous iron, or like double thin steel, piled and curved and re-piled, or Damascus sword blades, or the original puddle bloom from the furnace. It seemed desirable with single-headed rails to obtain a hard granular top and a fibrous bottom to the rail, and it was possible to obtain blooms of those opposite qualities at the pleasure of the puddler. There was a process of uniting two such blooms without any scale between them, and therefore of rendering them homogeneous. They required to be flattened under the hammer into oblong slabs, with good surfaces and squared edges, and then to plane the two surfaces which were to be united to a close fit. Placed together, and heated in the furnace to a welding heat, they would roll out homogeneously. But when the best rails were produced, the question arose as to the most judicious mode of applying them in line. A sample rail of the bridge form from the South Wales line, after being down for many years, appeared as good as ever. But it had been laid on a continuous longitudinal timber, and was boarded on the top, to make the iron cross the fibres of the wood; for it had been found in practice that with the rails parallel to the fibres the longitudinal logs split. The rail was perfectly granular, and had it been used with intermediate chairs, it would probably have broken. Chairs formed anvils to rails, and notched them below while they were bruised above by the wheels. Neither had fish-joints yet been perfected. Some elasticity must be given, not positive play, but a vibratory elasticity, and a true joint connection.

Increased speeds had to be provided for, multiplied three-fold for 7 and 8 tons' load on each driving-wheel, instead of two, and for increased length of wheel-base growing from 7 feet and 8 feet to 16 feet and 30 feet, and constantly increasing curves on the lines of rails. In short, long rigid parallelograms were being driven round very sharp curves, the wheels at a tangent with the rails. What the amount of grinding was might be gathered from the reversal of a double-headed rail. It at first presented a series of square-edged notches, $\frac{1}{2}$ inch deep: at the end of a week the edges were taken off; in another week the metals became small curves, then large curves, and gradually the rail became a level plane. If the wheels rolled instead of sliding, they would simply roll over the curved surfaces; but as they slid, they became a planing-machine, and cut off the projecting metal. To get rid of the friction, it was necessary first to radiate the axles so that the wheels would always be in parallel planes to the rails, whether on straight lines or on curves, or double reverse curves. Then to form the carriages with curved spring-ends instead of side-buffer rods, to use short openings between the vehicles, closing the trains to lessen resistance, and prevent the vehicles riding on each other's backs in collision, to use continuous breaks, self-acting by gravitation, like steelyard levers—the normal condition to be pressing against the wheels, lifted by guard or driver, and instantaneously in action on inclines, in case of a coupling breaking. When these things were done, the engine-power might be reduced, and the weight of the engines or the load of the train might be increased. Tank engines were used, because they could run with either end forward. Tender engines, if properly coupled, making one bending machine of engine and tender, would do the same. At present, in order to obviate a vicious design, the driver screwed up the engine and tender rigidly together; and a long stiff body was thus formed, which was apt to get off the line, and which indeed would not keep on at all but for its weight. The question of light engines and vehicles was important; but when the surplus resistance was removed the trains might be lightened. Light trains should be used for light branch traffic; but with traffic unlimited, the loads on the engine driving-wheels should be what the rails and lines would bear without being crushed, and the train-capacity should be in conformity. If tank-engines were used for long journeys, the load of water, which was a diminishing load, should not be placed near the driving-wheels, but as far away as possible. Any tender-engines could be altered to run tender foremost as steadily as a tank-engine; and two engines could be efficiently coupled together to work as twins, with water-tanks for short distances, without injuring lines or rails.[1]

Mr. E. A. Cowper had prepared a Table showing roughly the different modes of manufacturing steel and iron, simply for quick comparison of the number of operations in each of the processes. In the old practice the iron used always to be refined before being puddled, but that process was now generally omitted, from economical motives, though he was afraid in some cases it was but false economy, and that the frequent very short life of a rail was partly due to it.

According to the old process for making steel there was of course the cementing, the melting in pots, the hammering the ingots, and the rolling, in addition to the refining and puddling. The melting of steel in quantities of about 40 lbs. each in separate pots was a most expensive process, the wear and tear of the furnace on such small quantities was very great, and it was therefore impossible to make cheap steel rails on that plan, though it was admirable

[1] *Vide* "Railway Practice and Railway Possibilities," by W. Bridges Adams, London, 1868.

for tool-steel and other expensive kinds. He had put Lowmoor as the name of a process, although it was practised at other places.

TABLE showing the Number of Operations in each of the Various Processes for Making IRON and STEEL.

	Old Practice.	Modern Practice.	Lowmoor.	Marshall.	Krupp.	Bessemer.	Siemens.	
							Scrap.	**Ore.**
IRON.	Smelting. **Refining.** Puddling. Hammering Balls. Rolling P. B. Piling. Rolling.	Smelting. Puddling. Hammering or Squeezing Balls. Rolling P. B. Piling. Rolling.	Smelting. Puddling H. I. Hammering. **Breaking and Selecting.** Piling. Hammering. Rolling.	Smelting. Refining. Puddling. Hammering Balls. Rolling P. B. **Cleaning.** Piling. Rolling.		Smelting. **Melting in Air Furnace.** **Blowing in Converter.** Hammering Ingots. Rolling.	Smelting. Puddling. Hammering Balls. Rolling P. B. **Melting in open Hearth.** **Examining.** Hammering Ingots. Rolling.	**Melting in open Hearth.** **Examining.** Hammering Ingots. Rolling.
STEEL.	Cementing. **Melting in Pots.** Hammering Ingots. Rolling.	**Melting Cast and Wrought Iron in Pots.** Hammering Ingots. Rolling.			Smelting. Puddling. Rolling. **Hardening.** **Breaking and Selecting.** **Melting in Pots.** Hammering Ingots. Rolling.	Same as above.	Same as above.	Same as above.

The pigs were first taken and puddled to produce hard iron—iron with about ·15 per cent. of carbon in it; the ball was then hammered thoroughly into a thick flat cake; it was not rolled at the same heat, but it was thrown on one side to cool. It was then broken up and selected, and he believed that the process of examining each piece and selecting the iron was one of the causes why it had won such an excellent name for tyres and for other things where iron was required to be hard. By these means it was known that every part was hard; there was no question of one puddler bringing out a soft ball and another a hard one, and the iron being all mixed or 'piebald.'

Then came what was commonly called the 'Marshall' process. In this there was the smelting, the refining, the puddling, the hammering the balls, and the rolling the puddle-bars; then the 'cleaning' of the iron, which was a species of 'milling,' and consisted in putting the small pieces of iron, cut into short lengths, into a cylinder, with a quantity of sand and water, and turning them round and round until they were thoroughly cleansed from all black scale: afterwards this bright iron was piled and rolled, and 'blacks' in the iron were thus avoided.

In Krupp's process of making steel the metal was first puddled, then rolled into bars about 0·9 inch or 1·0 inch square, and thrown into cold water, which of course hardened the steel from end to end. It was then broken up into short lengths, so that every piece of 3 cubic inches was examined at both ends, and it was examined and selected according to quality. The pieces were then put, like the cemented steel, into pots, melted, cast into ingots, hammered, and rolled. A sort of military discipline was exercised in bringing the men with the melted steel in the pots up to the bath, or pond of metal, by the sound of a bugle; and sometimes more than a hundred pots full of steel were got together for one cast. Krupp, however, now used Bessemer steel largely; and he had many Bessemer converters at work, although he did not exhibit any steel at the Paris Exhibition by the name of Bessemer steel. Much depended upon the manganese and other ingredients put into the pots with the steel in this as well as in other places.

In the Bessemer process there was the smelting the pigs, the melting, the blowing, the casting, the hammering, and the rolling. The blowing was the chief process, and by it either wrought iron or steel of various degrees of hardness could be produced. The use of a certain quantity of spiegeleisen was of great importance.

Last on the Table were Mr. Siemens' two processes. In the first plan for making steel, from puddled bars or scrap iron and cast iron, the wrought iron, having of course been smelted, puddled, hammered, and rolled, was simply melted down in a bath of melted cast iron, in the hearth of a furnace having an intense heat, but no oxidizing flame, and the ingots were cast from this large bath of melted metal.

In Mr. Siemens' second plan the iron ore was brought into a state of 'sponge of iron' by the heat to which it was subjected in a non-oxidizing atmosphere, or one in which some carbon was present, though not enough to convert it into cast iron: the iron was not in any way exposed to a 'cutting flame' or 'burnt,' but the drops of metal were absorbed, or, so to speak, dissolved out of the 'sponge of iron' by the small quantity of melted cast iron at the bottom of the hearth. There was, therefore, in this process only the melting, examining, the hammering into ingots, and the rolling; thus by either the first or second process there was obtained a perfectly homogeneous cast steel, or wrought iron, without any blacks or bad welds caused by piling or lapping up of cinder in the ball, as in puddling.

He thought Mr. Bessemer was quite right when he, some years ago, said that no perfect metal could be produced without its being melted; and now there was a furnace that produced such an intense heat, that tons of steel or wrought iron could be as perfectly melted as the little drops of steel of 40 lbs. weight were in the steel pot-furnace of former days, and yet without any burning of the iron or steel. He thought each of the processes named in the table depended greatly for its success on some one point being attended to. Thus, in the old process, 'refining' was of great use in preparing pure 'plate-metal' before puddling; while the practice of 'breaking and selecting' in the Lowmoor and Krupp processes was admirable. The old plan of melting in pots was, and still continued to be, a very expensive process; whereas the Bessemer plan not only made steel and wrought iron very direct from cast iron, but gave the power of casting large ingots cheaply, though without the means of examining the metal in the process. In Mr. Siemens' plan there was certainly the advantage of being able to examine and test the metal under operation, and either to increase or diminish the quantity of carbon, so as to make 'high' or 'low' steel or wrought-iron at pleasure; and from the casting of such large quantities of metal at a time, and the economy of fuel in the furnace, excellent metal could be turned out very cheaply.

Mr. F. Stileman stated, through the Secretary, that the total annual cost for maintenance and renewal of the permanent way of railways was above 9 per cent. of their gross receipt, and in the year 1866 amounted to £3,466,668. This expenditure showed an increase of £507,709, or 21·6 per cent. over the expenditure of the year 1863, the increased mileage for the same period being 13·22 per cent.

The estimated tonnage of rails laid in main lines was 2,438,520 tons: taking the life of iron at ten years, it would require 243,852 tons, at a cost of £7 per ton, equal to £1,706,964 to be expended annually; if renewed with steel rails, lasting double the time, 121,926 tons would be required at £11 per ton, equal to £1,341,186, showing a saving of £366,778 per annum, or nearly 1 per cent. of the gross railway receipts.

Mr. Brunlees observed, through the Secretary, that the rails on main lines were, generally speaking, more deficient in bearing surface than in quality. Their tops were too narrow for the weight of engines now employed, hence they became laminated, and were crushed long before they were worn out. If rails were made with a top double the present width, or of the same width as the tyres of the wheels, the crushing power of the wheel thus diffused would be reduced to one-half, consequently the life of a rail would be doubled. To make such a rail, a weight of about 30 lbs. per yard would have to be added to the 80 lb. rail; but the additional cost would only amount to one-third of the additional cost of laying down steel rails at 80 lbs. per yard. He had, therefore, no hesitation in saying that the saving which a wider topped rail would effect in the wear of tyres would alone very shortly pay for the additional weight of metal; whereas, if steel rails with only the ordinary width of head were used, the wear of tyres would be considerably accelerated. To maintain a good line, and a fair top on the rails, more lateral strength was required, and this would be gained in the wider rails. There would also be a considerable saving in maintenance, and that sometimes oscillating, sometimes trembling motion, due to the weakness of the road and the wear of the tyres, would be completely done away with. No doubt there were special places where steel rails might be used with advantage, but, generally speaking, iron rails of good quality and of greater section, combined with a judicious distribution of the weight on the locomotive wheels, would meet a greater number of present desiderata than could be supplied by the use of steel.

Mr. Joseph Mitchell expressed his opinion, through the President, that the flat-bottomed form of rail might be the best, if of steel, laid irrespective of expense, on a continuous bearing: but he doubted the superiority of that form of rail when laid on cross-sleepers, for it thus became, in fact, a girder between two points 3 feet apart.

It was inferior as such to the double-headed rail, as it had less depth, being for a rail weighing 75 lbs. per yard about $4\frac{1}{4}$ inches in depth; whereas the double-headed rail was generally $5\frac{1}{4}$ inches deep, and was formed like a girder, with its effective strength on the upper and lower sides; the cross bearing also was only 5 inches, as compared with the bearing of the chair, which was 10 inches.

If the flat-bottomed rail was made higher than $4\frac{1}{2}$ inches, it was apt to deflect with the weight of the trains. No doubt it was the cheapest, but not much, the saving not exceeding £70 per mile.

Although the double-headed rail, with its numerous fastenings, still required improvement, yet, in practice, it had been found to be the best, or it would not have been continuously relaid, and otherwise so universally adopted by all the principal engineers throughout the kingdom up to this time.

Again, good ballast was an important element in securing a sound and cheap permanent way. If a line was not well ballasted and the ballast of good material, the rails would never wear equally, however superior might be the quality of the iron. If the ballast was soft or clayey, the pressure of the trains would make the rails sink in wet weather, and thus create irregularities which, with the repeated concussion of the engines, tended much to destroy and damage them. Now, on a large portion of the railways he had made in Scotland, extending over 280 miles, not only was there good gravel ballast, but the embankments and cuttings were mostly gravel. The consequence was that the motion of the trains was so smooth and easy as to be a matter of general remark. The rails on the first section opened, which were double-headed, had been down thirteen years, and he had no doubt they would last six years longer.

He thought sufficient data had not been obtained to afford a satisfactory conclusion on this subject, and he suggested that permanent-way Engineers might be asked to divide the lines under their charge into sections of 10, 20, or 30 miles, or such other distances as were subject to similar traffic; and to report on the nature of the ballast, the size of the sleepers, the form and weight of the rails—and, if possible, the makers' names, the average number of trains, and the average tonnage passing over those sections per annum; also the quantity and cost of ballast per mile, the cost of wages per mile, and the number of sleepers and rails renewed in each year.

By a return of this nature, an accurate estimate of the cost of the maintenance of permanent way under every variety of circumstances, might be obtained, and thus proprietors of railways might know, by comparing the maintenance of one railway with another, whether those they were interested in were maintained in the condition and at the expense they ought to be.

Mr. J. M. Heppel suggested, through the President, that rails should be tested directly for durability. Suppose, for example, a pair of rails 10 feet long to be laid down, and a pair of wheels carrying 10 tons to be kept, by a small fixed engine with a crank motion, continually rolling backwards and forwards over them till they exhibited symptoms of failure. It seemed to him that this would nearly represent the actual condition under which the wear and tear took place; and at any rate, as a comparative test between different specimens, would give very useful information. In this way in about a month an amount of tonnage might be passed over equal to that by which the best rails were worn out. No doubt the tendency of such a test would be to stimulate the production of hardness at the expense of ductility; and to counteract this, some test for the latter, such as a blow from a falling weight, would have to be added.

He thought that if manufacturers were requested to tender on their own specifications, but guaranteeing a certain resistance to impact, and a certain tonnage passed over at a given speed, in the way just mentioned, all their special experience would be utilized, and there would be a considerable amount of security for the result.

He was aware that some difficulty would arise in submitting to test a sufficient number of specimens without undue expenditure of time and money. Still it might be managed; and if the results to be expected were as valuable as they appeared to him likely to be, a considerable outlay in obtaining them would be well repaid.

Mr. W. M. Neilson suggested, through the President, that rails should not be tested at the works of the makers, but at a public testing-machine, under responsible management, to which rails might be sent for undergoing the test process. Experience would give those who managed this machine facilities for discovering the different qualities of rail submitted to them. Suppose four rails to be tested together, by four wheels hooped with ordinary tyres, suspended by a lever pendulum frame, the wheels to be loaded to the required weight, and so carried by a spring as to give such a shock to the rails as might be found desirable. The lower end of the lever, by touching projections in its motion, would cause the side oscillating motion: and the amount of adhesion might be measured by buffer springs at the ends of each of the rails. A simple attachment to a small steam engine would give the requisite motion to the machine, which would, of course, be kept constantly at work; the number of oscillations and pressures on the buffer springs being recorded by a tell-tale.

The motion of the wheels round the axis might be regulated by springs or weights, suspended by chains leading from pulleys over the centre of the pendulum frame; but the reverse motion of the wheels might not be a too severe element in the test.

Mr. Sandberg said the discussion had been such as to render any reply on his part almost unnecessary. However, he should like to direct attention, first to the steel-headed rails, and next to the Annuity Tables. His object in alluding to the steel-headed rails arose from the difficulty which existed in foreign countries in usefully employing the worn-out iron rails. In countries round the

Baltic and the Mediterranean, they had been re-rolled with iron slabs, but of late Bessemer steel had been applied for the heads. He never expected to obtain perfect homogeneity, nor to get the same wear out of the steel-headed as out of the solid steel rails; and, therefore, in the Annuity Tables the former were represented as lasting only half as long as the latter. If the worn-out iron rails could be converted into solid steel rails by Mr. Siemens' plan, it would certainly be a great advantage for railways, not only in this country, but in the colonies and indeed wherever far removed from the seat of manufacture. These steel rails would, of course, have to be equal to the Bessemer rails in quality and price; and if Mr. Siemens could succeed in making them as cheap and of equally good quality, he would not for a moment continue to defend steel-headed rails.

As to the Annuity Tables, some objection had been made to the eighty years taken as the life of solid steel rails. According to his view, compound interest was an important feature in arriving at a just comparison between the values of the three descriptions of rail, and he had no other means of expressing their relative capacities of enduring wear than by giving their life in years. He thought that sufficient experience had been adduced in this discussion from different railways to prove that solid steel rails lasted on an average six times as long as common iron rails, though he admitted that iron rails could be made of a quality far superior to that usually employed; but in such a case they might cost more than steel rails; and therefore in the comparison he had made he had taken common iron rails, without extra price, or any guarantee, or extra specification. There had been fifty instances mentioned on the London and North Western Railway, where solid steel rails had lasted six times as long as iron rails; instances of the same kind had been stated on the London, Chatham, and Dover Railway; and on the North London, in about forty instances, as far as their experience had extended up to the present time, steel rails had lasted four or five times as long as iron rails. All these steel rails were still in use, and in good condition. As regarded steel-headed rails, he had received a favourable statement from the North British Railway; and that day he had heard from Mr. Ashcroft that some of those rails made for the Swedish Government referred to in the Paper (Plan B, Plate 14), and described in the discussion by Mr. Menelaus, had been laid a few months on the South Eastern Railway at London Bridge Station. Mr. Ashcroft had given a very favourable report concerning them. However, more experience was needed to prove that they would last three times as long as common iron rails.[1]

[1] Mr. Ashcroft has stated in a letter to the Author, dated May 18th, 1869, that trains computed to have weighed upwards of fifteen millions of tons had passed over the steel-headed rails between March, 1868, and May, 1869. These rails were laid in the London Bridge yard of the South Eastern Railway, and he had been sur-

Mr. Bell had expressed a fear as to the supply of pig iron for the future make of Bessemer rails. The same opinion was entertained by the Swedes five or six years ago, when the Bessemer process was introduced. They had actually tried to prove that nothing could be done without Swedish ore. However, very little of the Swedish pig-iron which had come over to this country had been employed for Bessemer steel rails; and there was no doubt that the English hæmatite would be sufficient for some time to come.

With regard to the statement that the pig iron made from Norwegian ore at Newcastle contained 0·5 per cent. of phosphorus, Mr. Bell had admitted that the statement applied to ore from a lately-opened mine, and that it was not applicable to the great bulk of Norwegian ore. His own opinion was, that if the English hæmatite ore should not prove plentiful enough, the ores from Sweden, Norway, Bilboa, Elba, and America, were sufficient to provide for any future want of pig iron for the Bessemer process.

As to the tests of iron rails, very few Railway Companies had adopted any more severe than those Governments with which he was connected: that had arisen from the severe climate in the Scandinavian countries, the ground being often frozen 3 or 4 feet deep, and offering in winter little or no elasticity. The speed had to be reduced considerably in the winter, to save both the road and the rolling stock. Although it was well known that greater wear could be obtained from rails containing a large per-centage of phosphorus, such as those from the Cleveland district; yet the greater strength, and consequent safety, of the Welsh iron had been taken into consideration, and most of the supply for Scandinavia had been procured from the Welsh districts. There had been no breakages of rails on the Swedish lines, but the Russians had during the severe frost of 1866 a great number of rails broken; the number amounting to two hundred a week during the most severe part of the winter. These Russian rails had been made in this country, nearly of the same section (Vignoles') and weight as the Swedish rails; but the test for the rails destined for Russia was only half as severe as that for the rails for Sweden, the latter being a 15-cwt. ball falling 7 feet on the rail, supported on bearings 4 feet apart.

The statement that steel rails in Canada were not injuriously affected by cold so much as iron rails, was what might have been expected. Steel was less subject to the influence of cold than iron,

prised to find that they had resisted so perfectly, (there being no apparent failure whatever in them,) when it was considered that they weighed only 66 lbs. per yard. Opposite to these rails there had been laid some iron rails, weighing 82 lbs. per yard, manufactured by an eminent firm; the latter exhibited evident signs of early failure. It should be noted that all these rails were laid on a curve and on a gradient of 1 in 100, and where the breaks of every train were applied to stop at the platform.

especially when phosphorus was present in the iron. But steel rails had broken when the weather was temperate, in ordinary wear, and even in unloading from the trucks, as had been remarked by several speakers. These rails had been examined, and in the generality of cases they had been found to contain too much carbon. Still there had been several cases in which steel rails had been broken, without being too hard, or containing too much carbon, but from excess of silicon. Formerly it was believed that the silicon was eliminated in the Bessemer process before the carbon was carried off, forming a cinder, which acted on the carbon in the same way as in the puddling furnace. There was now reason to believe that, where there was much silicon present, and very little carbon, the latter disappeared before the silicon, and some silicon was left which rendered the steel brittle. Steel rails had been broken on the Belgian State Railway, and, when they were analysed, there was found to be no excess of carbon, but so large an amount of silicon as 0·6 per cent. In another instance as much silicon as carbon had been found in the metal. These facts had been confirmed by Director P. Tunner, of Vienna, who had communicated the fact to Dr. Percy in a letter, from which he had the privilege of reading the following extract:—

"At the iron-works at Neuberg, in Styria, the Bessemer metal is carefully assorted after every cast, and is separated into seven series, or different degrees of hardness. The brands to be marked are ascertained on the one hand mechanically, by welding, working, and hardening, by the tensile strength and elasticity; and, on the other hand, chemically, by the Eggertz carburation process: it is only when the same result is obtained by these two methods that the numbers denoting the degree of hardness are marked. A very great difference has been ascertained between the results of the mechanical and those of the chemical methods, in the quality of some Bessemer steel, which was made about eight days ago from pig-iron made by charcoal with ¼th its weight of coke. By the first method No. 3 was indicated, that is to say, a very hard steel difficult to weld, but otherwise of good quality. By the other test it proved to be No. 6, that is to say, it had a hardness next to that of wrought iron. In consequence of this very remarkable difference a chemical analysis became necessary, which showed that the steel in question contained only 0·3 per cent. of carbon, but 1·0 per cent. of silicon. It therefore appeared that silicon might occur in steel as a substitute for carbon, and it is particularly remarkable, that it was found in a hard steel. This fact further proves that it is not always true that by the Bessemer process the silicon is first eliminated, and then the carbon. That some proportion of silicon may exist in steel has been long known; and Schafheutl maintains that some silicon is a necessary constituent of steel. But that with 1·0 per cent. of silicon and only 0·3 per cent. of carbon, it is possible to obtain a hard steel, seems to be a new observation worthy of attention."

This confirmed what had been lately found in this country, namely, that the silicon and carbon disappeared simultaneously, and not, as was formerly believed, the carbon first and the silicon afterwards. Therefore, as an excess of silicon had the same influence on the hardness of the steel as an excess of carbon had, and as the amount of the former was more difficult to regulate in the process of steel-converting than the latter, which could be judged of by the flame, he thought it might be concluded that, until further experience was gained, Bessemer rails would require to be as carefully tested as those made from iron. In concluding his remarks, Mr. Sandberg took the opportunity of thanking those gentlemen who had taken part in this discussion, for the valuable information which they had brought forward. That information formed a most useful contribution to the knowledge of the manufacture and wear of rails, and would doubtless tend greatly to the benefit of both the manufacturer and the consumer.

Mr. Gregory, President, said it must be pleasing to the Members of the Institution to find light thrown upon professional subjects, not only by different minds but by different nationalities. The last subject under consideration was a Paper by an American Member. The Paper that had now been read was from a Scandinavian Member of the Institution, and he was sure all who had heard it would agree that it was one which merited the thanks of the Institution.

Note by the Author.

Since the foregoing Paper was read, the price of steel rails has been reduced beyond expectation. At the present time (June, 1869) the cost of solid steel rails, at one of the principal works in this country where both kinds of rail are made, is £10 per ton as against £7 for iron rails. As Mr. Bessemer's patent will expire next year, the reduction of the royalty now paid, will gradually have the effect of bringing the price of steel rails nearer to that of iron rails; but it seems doubtful whether any sudden reduction of price will ensue. Under these circumstances there can be no doubt as to the expediency of employing steel rails, even on railways where the traffic is light; but, of course, the heavier the traffic the greater will be the economy of substituting steel for iron.

During the last twenty years the price of iron rails has been gradually reduced to one-third of their original cost, but this reduction has unfortunately been accompanied by the production of an inferior quality of rail—a subject alluded to by several speakers in the discussion. It is to be feared that to some extent a similar effect may possibly follow the anticipated reduction in the price of Bessemer rails; and it will therefore become more than ever necessary, for the public safety, that the consumer should carefully examine the quality of the material which he receives.