PAPER No. 280

DESIGN OF RAILS

BY

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History. The earliest Railways were started with iron plates stuck on to wood or stone to serve as rails ; these were gradually replaced by angles with flanges turned either inward or outward. It was in the first half of the 19th century that rails approximating the type we have now in use, flat footed, bull and double headed, were designed and brought into use. Almost every Railway Company then designed its own rails and as this meant cutting of a large number of rolls and consequently heavy expenses to the manufacturers and the purchasers, attempts were made at the end of last century to standardise various sections.

Rails were first made of cast iron, but as the axle load increased they started fracturing and were replaced by wrought iron rails which in turn proved weaker and made room for steel rails.

It was in the United States of America that the "T" or flat footed rail was first designed, while the bull and double headed rails were originally evolved in England. With the passage of time each country developed its own designs. In India the State Railways adopted flat footed rails as a standard chiefly because, weight, for weight of rails, the accessories like bearing plates, etc., would be lighter and mean low cost in carriage for a country which had to import all steel and cast iron articles from abroad.

Chemical Composition. The rails in use in India can be divided into five categories so far as their chemical composition is concerned :—

(*i*) Carbon steel.

(*ii*) Medium manganese steel.

(*iii*) Chrome steel.

(*iv*) High carbon.

(*v*) High manganese or cast manganese steel.

Till a few years ago carbon rails were used for running lines and high carbon or chrome steel rails for points and crossings. A few points and crossings made of high manganese or cast manganese were also imported and put in. In recent years medium manganese steel rails have been purchased for running lines in preference to carbon steel rails. The reasons for this change will be given later.

The chemical composition of carbon rails is permitted to very slightly with the process used and the weight of rails.

The processes by which the rails can be manufactured are :—

(*a*) Basic open hearth or duplex process.

(*b*) Acid open hearth.

(*c*) Acid Bessemer process.

The quantities of various elements are given below :—

Carbon, 0.45 to 0.55 per cent. for (*b*) and (*c*) and 0.68 per cent. for (*a*).

Manganese, 0.90 maximum for (*a*) and (*c*) and 0.80 for (*b*).

Silicon 0.10 to 0.30 for (*b*) and (*c*) and at least 0.05 for (*a*).

Sulphur and phosphorus 0.05 maximum for (*a*) and 0.06 maximum for (*b*) and (*c*). Rails with sulphur and phosphorus content as high as as 0.07 have been imported and used on Indian Railways during the last war.

Dealing with these elements individually :—

Carbon. This has greater influence on the mechanical properties of steel than any other element. As the carbon content increases from ·3 to ·9 per cent. the tensile strength increases from about 73,000 lbs. per square inch to 155,000 lbs. per square inch. Similarly the hardness and yield strength increase. The reduction in area and elongation, however, decrease correspondingly. This shows that the higher carbon contents provides hardness but not toughness which is needed for resistance to abrasion. Higher carbon, therefore, means progressively reduced capacity to withstand abrasive wear. The American Railways have rails whose carbon content is higher than the carbon content of rails mostly in use in India or Europe. The reason for the introduction of this higher percentage was that with the introduction of very heavy axle loads, maximum 44 tons, they required rails which would deflect less. The tractive effort required would be less and the steel would be stronger in tension and compression. The reduced toughness and brittleness introduced thereby is, however, held partly responsible for transverse fissures comparatively more common on American Railways.

High carbon rails with carbon content up to 0.8 per cent. were imported from Canada and laid on Indian Railways during the last war.

Manganese. It is a valuable deoxidising and purifying agent. It converts sulphur into manganese sulphide, and thereby prevents hot shortness. In order to convert all sulphur into manganese sulphide manganese should be five times the quantity of sulphur. Manganese occurs in steel in solid solution of iron and in chemical combination with iron and carbon. This element increases tensile strength and is generally beneficial.

To provide for tougher steel manganese contents were, some years ago, increased on European Railways, as it was believed that with the increase of manganese content the life of rails will be increased. This explains the reasons for the introduction of medium manganese steel rails in India.

Silicon. Silicon is particularly advantageous in steel making process as it acts as a deoxidising and cleansing agent.

Sulphur. Introduces hot shortness.

Phosphorus. Within safe limits is a valuable wear resistant, but beyond 0.05 it introduces cold shortness. The behaviour of rails with increased sulphur and phosphorus content as also of high carbon rails is under observation.

Medium Manganese Steel Rails. The manganese content is increased from 1.1 to 1.4, it has also been stipulated that the combined carbon and manganese content shall not be less than 1.65 per cent.

Chrome Rails. These have been used for points and crossings and on sharp curves. Their use was, however, dropped as they did not appear to be as amenable to welding as the others, and also because they are more costly. As the chrome steel rails are manufactured entirely for the points and crossings all rails that fall within the maximum tolerance of shape or chemical composition have to be excepted. This means that where the chromium content is the maximum the rails would be comparatively brittle, while those with the minimum quantity of chromium will only be slightly better than medium manganese rails. All points and crossings are, therefore, being made of selected medium manganese rails and not chrome rails.

High Manganese or Cast Manganese. The manganese content in these varies from 11 to 14 per cent. Cast manganese rails in points and crossings have been found to be the most lasting. They are, however, extremely costly; from 5 to 9 times the ordinary rails. As the cast manganese points and crossings had to be necessarily smaller in length they rocked more.

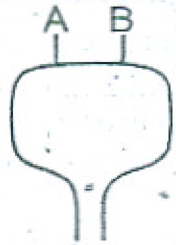
Sorbitic or Heat Treated Rails. A few years ago Sorbitic rails were introduced on the Kalka-Simla Railway. These are heat treated with a view to giving them harder surface and thereby reducing the wear on sharp curves. They are more costly being about one and a half times as much as the ordinary rails. The wear on them is, however, less, though it has not yet been established if the reduced wear justifies the extra expenditure.

Profile of Rails. The function of the foot or what is usually called "flange" in a flat footed rail is the transmission of load to the sleeper. should be broad enough to avoid crushing the sleeper and at the same time strong enough to resist twisting. The size and dimensions of the head are decided on various considerations.

These are :—

1. The width and the thickness should be so proportioned as to permit of efficient rolling of the metal within the head.

2. The table should have a curvature that will provide sufficient bearing area for the wheels tyres of heaviest wheel so as to avoid local crushing and excessive wear while it should not be so flat as to appreciably increase the tractive effort required to pull the train. This is explained as below :—



If A-B is too small it will crush. If it is too large the friction will be excessive, hence greater tractive effort will be required.

3. It should be strong enough to withstand the loads imposed on it, *i.e.*, should not give way at ends.

In the latest design of 90 lb. revised B. S. S. rails the radius of the table is 9". Opinion is divided as to whether this is best suited for our needs. Mr. Sims, who has made valuable contribution to the literature on track work on Indian Railways, has made out a case in his Technical Paper No. 286 that the radius should be 24 inch.

In the design of 90R. B. S. S. the height is $\frac{1}{4}$ inch greater than the flange, the proportion of height to flange being 1.047. On American Railways the proportionate height to base has been increased to 1 : 1.18 on heavy section. Mr. Sims has recommended this proportion to be increased to 1 : 1.1875. The reasons why it has been recommended is :—

(*a*) to afford greater stiffness to the rail.

(*b*) to reduce stresses in fish plates, which in the present designs are excessive and sometimes even beyond the elastic limits.

In the 100 lbs. F. F. rail in use on the Bolan Pass on the N. W. R. the flange is 5 inch and height 6 inch, the ratio of flange to height being 1 : 1.2. This rail has been in use for about 50 years and is known to have stood well. This further strengthen the case in favour of increasing the ratio of height to foot.

The American Railways are now experimenting with a 112 lbs. Section, which they have called torsion resisting.

Its height is 6,$\frac{3}{4}$ inch and foot 5,$\frac{1}{2}$ inch and in this the ratio of height to foot is 1.23. Further with a view to making the load from the wheel fall as centrally as possible the bearing area on the rail has been reduced and radii of fillets increased. The Plate No. 1 shows the rail and the changes made compared with an old Section.

This section stands in great contrast to the 90 lbs. 'R' Section in use on the main lines of the North Western Railway. Not only is the proportion of height to foot much greater but the head is 2,$\frac{1}{2}$ inch for the 112 lbs. rail as against 2,$\frac{5}{8}$ inch for 90 lbs.R. The radius of the rail table, fillets and web are also much greater. For comparison a drawing of 90 'R' is also drawn. There appears, therefore, a need for investigating, if the latest rail sections now in use should not be revised with a view to obtaining a stronger and less eccentrically loaded rail.

The wheel tyre of rolling stock operated on most railways has a conical tread, usually with a taper of 1 in 20. The mean amplitude of the lateral oscillation of vehicles with conical tread is comparatively larger than that with the cylinderical tread but the conical tread has the following merits :—

(1) The centre line of the rolling stock has a tendency to coincide with that of the track.

(2) It does not cause violent oscillations.

(3) In curved track, the wheel is in contact with the outer rail at the tread of larger radius and with the inner rail at the tread of smaller radius ; therefore, the slip between wheels and rail is minimized.

If the rail is canted to suit the taper of the tyre, the contact area between tyre and rail head becomes larger and tyre wear decreases. Furthermore the bearing stress between rail and sleeper is distributed more uniformly because the resultant of the vertical wheel loads and the side pressure passes more nearly through the centre of the rail base. Considered from this aspect the cant of the rails and therefore the taper in the wheels will depend on the ratio the lateral flange force bears to the vertical force.

The Japanese Government Railways, the Chinese, and the Railways in Great Britain, Dominions and Colonies, lay their rails with a cant of 1/20, but in the United States most Railways lay their rails with a cant of 1/40 to 1/44, and only a few with a cant of 1/20. The Northern Pacific Railway is the only one which adopts a cant of 1/88.

Length of Rails. Railways in India use 36′, 39′ and 42′ long rails.

Most Railway Administrations in the United States adopt 39′ as the standard length of rail, a few Railways use longer rails, such as 60′ or 66′.

The four-Main-line Railways of Great Britain adopt the standard length of 60′ and only the London and North Eastern uses 90′ long rails on several sections. The Canadian Pacific and the Canadian National have adopted 39′ as standard length of rails.

The Japanese Government Railways formerly used 12-M. (39′) and 10.058 M. (33′) rails as standard lengths, but acknowledging the merits of the longer rail, they have fixed the standard lengths at 25m.(82′) for 37 and 50-kgrm/m (=75lb. and 100lb.) rails and 20m (65′−6″) for 30 kgr./m. (60 lb.) rail. The standard lengths were decided upon after many years' investigations into the various problems concerning the use of long rails.

The rail joint is the weakest at point in the track, and needs most frequent tampings to prevent rail end bater, which causes vibration of rolling stock and uncomfortable riding. Therefore, it has been the ardent desire of the permanent way maintenance officers to reduce the number of joints where conditions permit.

The length of rails is restricted not only by the capacity of the rolling mill and the means of transportation but also the width of the joint gap to be provided for expansion due to temperature changes. The longer rail necessarily needs a larger joint opening which causes violent shocks to vehicles when high speed trains pass over it, resulting in excessive wear of rail ends and ultimate deterioration of the track as a whole. These draw-backs have for long restricted the adoption of comparatively long rails.

It has been proved, however, after various experiments made upon long rails and welded rails, that it is not necessary to provide the full theoretical amount of joint opening as calculated by a formula which ignores the frictional resistance offered to the free expansion and contraction of rails. In fact, rails without any joint openings would be able to resist the axial force due to temperature rise without fear of buckling, till this force reaches a certain limit.

Thus the long rail has come to be utilized by many Railway Administrations, and especially in Europe, where rails as long as ($59'-\frac{5}{8}''$, $78'-9''$ and $98'-5\frac{1}{8}''$) are now widely adopted.
$=18$ m $=24$ m 30 m.

In this respect, the Summary of Question II discussed at the XIth Session (Madrid, 1930) of the International Railway Congress Association states that "the length of medium rails (of medium weight) can, without inconvenience, be increased to 24 m. ($78'-9''$), and research and tests should be continued with a view to increasing the length beyond, (if necessary by means of aluminothermic welding), particularly at special points of the line where the effects of expansion are less to be feared."

As an experimental measure, in about two miles of track laid with steel trough sleepers and 90 lbs. F. F. R rails, 3 rails each of 42′ length were welded together by Aluminothermic Process in 1939. Observations taken on this track in summer 1944 showed that the rails moved by about two-third of the theoretical expansion as the temperature rose, coming back to the old position with the drop of temperature. The joint sleepers moved by almost an equal amount with the rails. No noticeable lateral or vertical movement took place.

Observations were also taken in summer 1945 when 10 expansion spaces in these long rails of $126'-\frac{3}{4}''$ each were jammed with closely fitting liners. A continuous rail length of 1387′ was thus obtained. The expansion spaces at the ends of this rail were about $\frac{3}{8}''$. Although the temperature rose by 60°-F, the expansion spaces of about $\frac{3}{8}''$ at the ends of this rail did not even close up. The theoretical expansion for this length for a rise of $60°F = 6{\cdot}841''$ while actually the average expansion at the ends was 0 246″. It was also noticed that only the ends of the rails moved, the intermediate portion remaining stationary. The rise in temperature led only to the development of internal compressive stresses.

Assuming that no initial temperature stress exists at 80° F, the internal stress due to a rise of 60°F would come to :—

$$\frac{30{,}000{,}000 \times 60 \times \cdot 00000685}{2240}$$
$$= \frac{685 \times 6 \times 3}{2240} \qquad = \frac{1233}{224}$$
$$= 5{\cdot}5 \text{ tons per square inch.}$$

If, therefore, long welded rails are to be used they should (*a*) be efficiently anchored, and (*b*) have higher yield points under compression so as to overcome the risk of buckling.

Foreign Railways, particularly in Germany, have laid welded rails of 1580′ length with $\frac{5}{16}''$ gaps at the ends.

The introduction of long welded rails would mean more comfortable riding and reduce maintenance cost.

The old rails on the Indian Railways are about 24′ long. The modern practice is to put in 42′ long rails. The decision to use longer rails has mostly been guided by the consideration of reduction in maintenance cost and increase in the riding comfort. There is, however, another factor which needs consideration when deciding on the length of the rail.

The length of a rail should be such that there is no resonance between the oscillation due to rail joints and the self oscillation of vehicles. No detailed experiments appear to have been performed in countries other than Japan to determine the self oscillation of vehicles and to apply the results so obtained in deciding the length of rails.

The Japanese found that the periods of free vibration were 0·4 second for locomotives, 0·6 to 0·7 for coaches, 0·3 for empty wagons and 0·5 second for loaded wagons.

Track Stresses. No paper on the "Design of Rail" can be considered complete without a consideration of the stresses and their effect on the design. The subject is, however, very vast and has been dealt with in many technical publications and would require volumes to deal with satisfactorily.

A research on this subject was conducted on American Railways in 1914-18 and later on was followed up on the Indian Railways. The results of investigations made on the Indian Railways are summarised in the Technical Paper No. 245. In more recent years, valuable research was made from 1935 to about the beginning of war by Messrs Gelson and Blackwood of the North Western Railway under the direct instructions of the Railway Board.

No useful purpose is, therefore, served by dealing with this subject in a sketchy manner, the only way possible in this paper. It may, however, be stressed that the rails do not behave as beams supported on sleepers acting as rigid supports. On the other hand, the formation, ballast and sleepers behave as a continuous elastic support to the rail.

Further the stresses in the rail increase rapidly with the increase of speed. The two important factors effecting this increase are (*a*) the counterbalancing of driving wheels, and (*b*) speed. The other factor to be considered is the steam effect due to the transmission of the driving force by the connecting rod.

In the designs of engines, therefore, if the track stresses are to remain within reasonable limits, the counterbalancing of wheels should be satisfactory from the trackman's point of view.

Lateral and Torsional Stresses in Straight Track. In addition to the vertical forces, lateral and torsional forces also act on the rails. Those tend to overturn the rails and lead to uneven distribution of stresses. For example the stresses on the outside of the flange is 1·1 to 1·3 times the average stress in the rail base.

Stresses in the Rail on Curved Track. When trains run over a curved track at speeds lower than that for which the outer rails is superelevated, the load on the inner rail is greater than the load on the outer rail, and as the speed increases the excess load moves to the latter.

The ratio of the lateral to the vertical bending stresses differs according to the design of locomotives, *i.e.*, according to the total wheel-base, distribution of wheel loads, distance between drivers, rigidity of the frame, amount of curve superelevation given, and the running speed. The maximum values measured on a test track are shown below :—

		Ratio of lateral bending stress to vertical bending stress (%) Maximum values.	
Radius Metres (degrees.)	Rail	Steam locomotive	Electric Locomotive
219 m. (6°)	Inner rail	60-80	30-50
	Outer rail	40-70	40-65
175 m. (10°)	Inner rail	50-85	30-80
	Outer rail	40-85	45-60

Generally speaking, the maximum lateral bending stress occurs under the driver which gives the maximum vertical bending stress. The maximum bending stresses in the curved track are greater than those on the straight.

Effects of Spacing of Sleepers. It was believed that if stresses in rails were high ; closer spacing of sleepers should be resorted to and in fact the old schedule of maximum, minimum and recommended dimensions said that " with close spacing of sleepers a less weight per yard is permissible."

This is a wasteful and expensive-advice and should not be followed unless circumstances like war, etc., would make heavier type of rails unavailable.

It has been explained already that a rail does not bend between sleepers but between wheels. The deflection of the track is therefore a function of rail, sleepers, ballast and formation bed.

The bending moment M_o in inch tons under an isolated load P is

$$M_o = P.\ \sqrt[4]{\frac{E.\ I}{64\ U}}$$

Where

M_o = bending moment in rail at point of wheel load due to single wheel load.

P = wheel load on rail at the point which will be used as the origin of abscissas,

E = Modulus of elasticity of steel,

I = moment of inertia of section of the rail,

U = an elastic constant which denotes the pressure per unit of length of each rail necessary to depress the track (rail, tie, ballast, and roadway) one unit, for the system of units ordinarily used, it will be expressed in pounds per inch of length of rail required to depress the track 1 in, U represents the stiffness of the track, and involves conditions, of tie, ballast and roadway, it is termed the modulus of elasticity of rail-support.

The value of U varies with the stiffness of rail, sleeper spacing and dimensions, depth of ballast, solidity of roadway, condition of sleepers etc., but if all other factors are constant the value of U varies with the sleeper spacing and is directly dependent on the number of lineal inches of rail supported per linear inch of sleeper support. That is the bending moment and consequently rail stress is inversely proportional as the fourth root of the sleeper spacing. Calculating for an isolated load it is found that by decreasing the spacing from 33" to 20" the load may be increased by 13 per cent. (This is for wagon axle loads only, for locomotive or bogie axles, the permissible increase of load will be less). On the other hand an increase of weight of rail permits almost exactly 2 per cent increase of load for every lb. added to the weight per yard of rail sections of 50 lb. and upward.

If the average capitalised value of a sleeper is Rs. 16 it would cost Rs. 20,000 to obtain an increase of 13 per cent in permissible load on 50 lb. rail by decreasing the sleeper spacing, so far as the rail stresses are concerned ; whereas with rails at Rs. 120 per ton it would cost Rs. 2,000 only to put in 60 lb. rail instead of 50 lb. and obtain an increase of 20 per cent of load. It is clear that the most economical way of carrying heavier loads is to increase the weight of rail.

The case for closer spacing of sleepers arises when (*a*) as said before, rails are not available, or (*b*) reduction in speeds is enforced at the same time as sleeper spacing is decreased (*c*) the ballast is crushing and (*d*) the formation is giving way under excessive loads.

Professor C. E. Inglis carried out mathematical investigation in conjunction with full-scale experiments with a view to studying the manner in which the running of a pair of wheels and axle along a straight railway track is affected by characteristics such as the elastic yielding of the ballast, the stiffness of the rail, the lack of continuity at a rail joint, wheel-loads and speed. He came to the conclusion that by the use of a stiffer rail a reduction can be achieved both in the range of the vertical movement of a wheel moving slowly along a continuous length of rail, and in the depth of the pot-hole it creates at a rail joint. These observations have been further confirmed by the experiments performed by Messrs Gelson and Blackwood in India, where they found that a heavier rail gave very much smoother running than a lighter rail on the same Section.

Further with a heavier rail, the maintenance costs are reduced, because the life of the sleeper and other track materials is increased thus making it economical, in spite of its higher initial cost.

The results of investigations made by Japanese Government Railways are given in Table VIII. Table IX gives ratio of track materials renewed every year and Table X the ratio of total expenditure per year for rails of different weights.

TABLE VIII

Ratio of the track maintenance labour for rails of different kinds.

Tonnage carried per year (tons)	Weight of rail		
	30 kgr/m 60 lbs.	37 kgr/m 75 lbs.	50 kgr/m. 100 lbs.
	%	%	%
1,000,000	100	87	78
2,000,000	100	87	78
3,000,000	100	86	77
4,000,000	100	86	77
6,000,000	100	85	76
8,000,000	100	85	74
10,000,000	100	84	73
12,000,000	100	83	72

TABLE IX

Ratio of Track material renewed each year.

Materials.	Weight of rail 30 kgr/m 60	37 kgr/m 75	50 kgr/m 100
	%	%	%
Ballast	100	52	24
Sleepers	100	78	69
Fish-plates	100	24	1
Track bolts	100	50	8
Spikes	100	85	70

TABLE X

Ratio of total expenditure per year for rails of differents weights.

Tonnage carried per year (tons)	Weight of rail including depreciation charges interest, etc 30 kgr/m 60	37 kgr/m 75	50 kgr/m 100
	%	%	%
1,000,000	100	92	94
2,000,000	100	90	90
3,000,000	100	88	87
4,000,000	100	87	84
6,000,000	100	85	81
8,000,000	100	84	78
10,000,000	100	83	76
12,000,000	100	82	75

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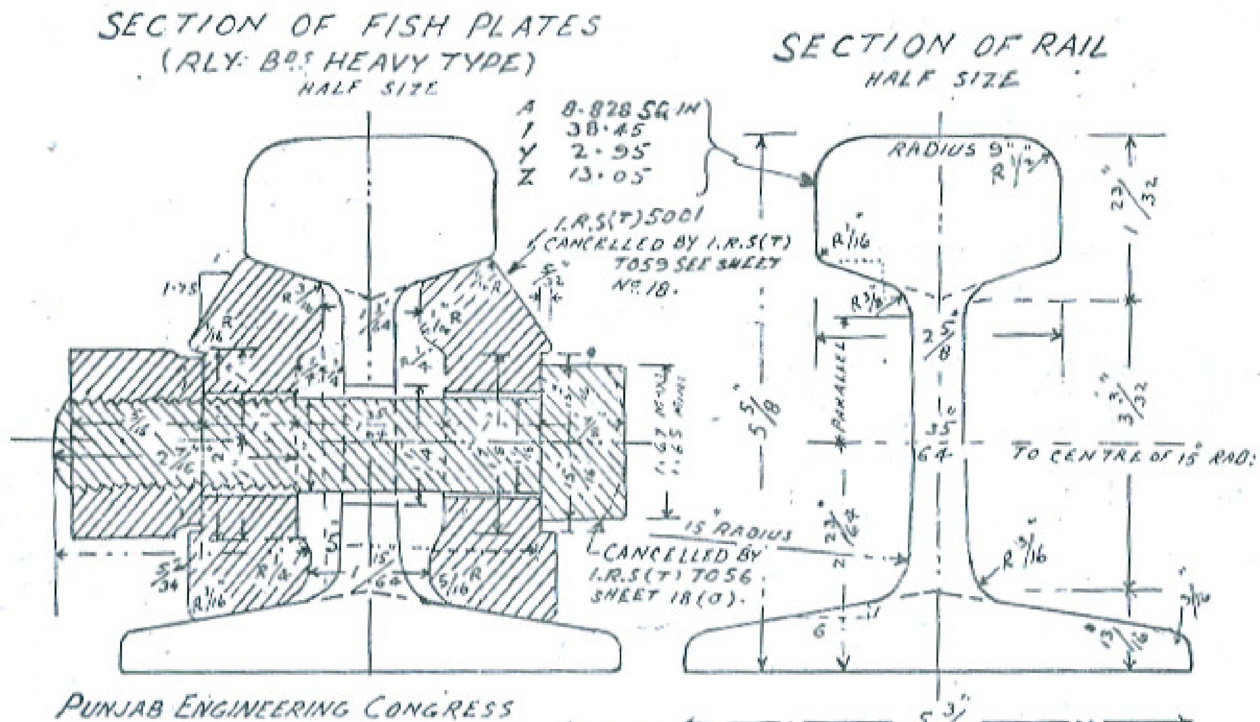

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A NEW FLAT-BOTTOM RAIL SECTION.

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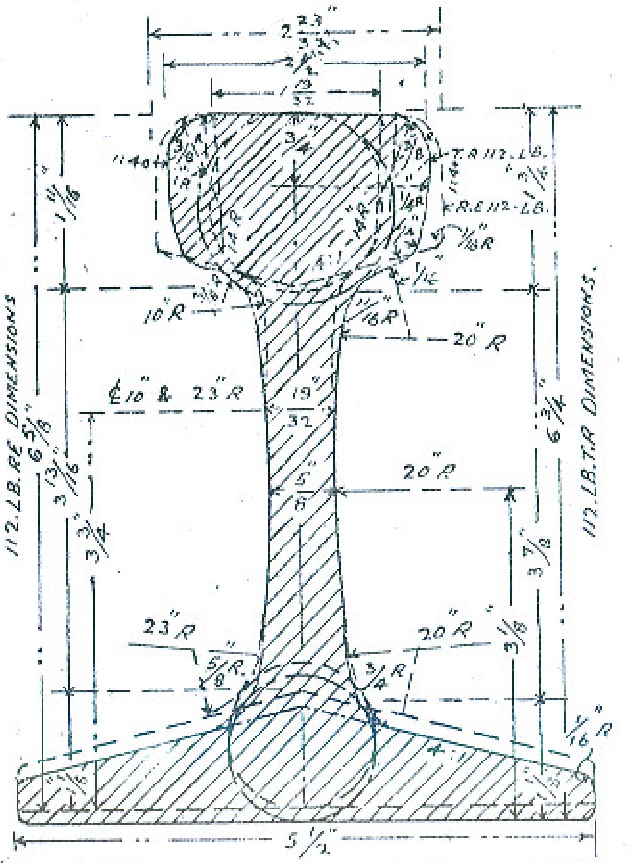
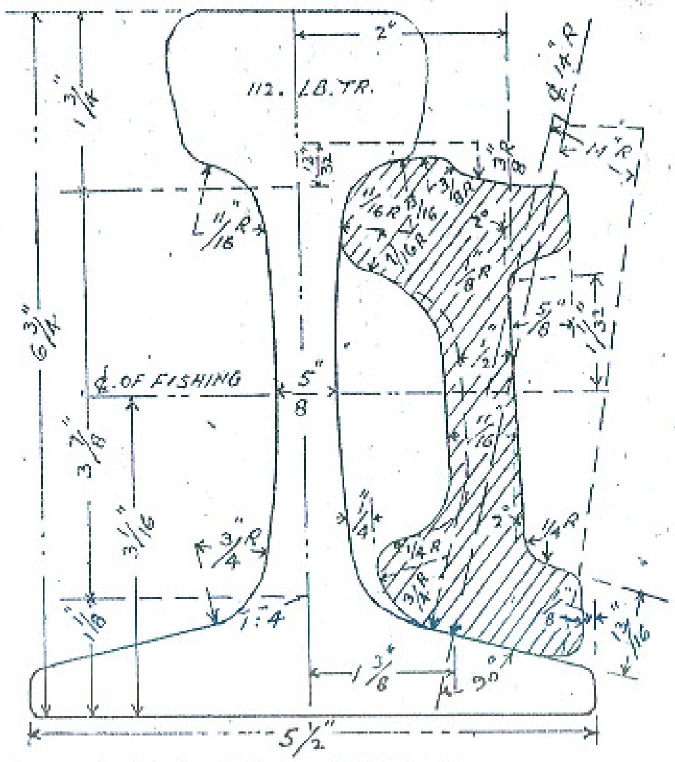
LEFT: NEW 112 LB. TR. RAIL (SHADED) IN COMPARISON WITH STANDARD R.E. SECTION

BELOW: NEW 112 K M B TYPE OF FISHPLATE OR JOINT BAR.



(Copied from page 305 of Railway Gazette September 29. 1944.) N.W.R., H.C.E 1525.



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