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Chief considerations affecting the design and usage of Railway sleepers in India

By

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CHAPTER I.

General Considerations.

1. The essential requisites of an ideal sleeper. (*a*) An ideal sleeper should be able to maintain correct gauge between a pair of rails.

(*b*) It should be able to distribute the load over the ballast as evenly as possible and with the minimum disturbance to the ballast bed. For this purpose a sleeper should have the following attributes :—

(*i*) Sufficient strength and stiffness as a beam so as to be able to carry the load without the failure of its material and without undue deformation.

(*ii*) Adequate bearing area so as to transmit the load to the ballast and through it to the formation without causing the failure of either of them.

(*iii*) Adequate resistance to creep. If creep is not stopped, disturbance of ballast bed must take place.

(*iv*) Adequate lateral strength to resist distortion of track under the effect of the lateral flange forces.

Other useful attributes, though of a secondary importance, are the following :—

(*c*) **Lightness of weight.** A light weight sleeper can be economically transported and easily and cheaply handled.

(*d*) Least number of small and loose fittings.

(*e*) Resistance to atmospheric or subsoil corrosion and resistance to the attacks of termites and fungi and to rot. The former is an important attribute for metal sleepers and the latter for wood sleepers.

(*f*) Ability to remain in alignment and retain packing.

(*g*) Means to give a visual indication of the condition of packing.

Under certain conditions or in certain localities, lack of one or more of these secondary attributes may assume a great importance and may rule out the use of the sleeeper altogether.

2. Types of sleepers. Sleepers are of the following two types :—

(*a*) The through, rigid or one piece type.

(*b*) The double block or the semi-rigid type. Here the sleeper consists of two blocks, plates or pots, one under each rail. These blocks may or may not be connected by tie bars.

3. Materials used for sleepers. The following are the materials used for making sleepers all over the world :—

(*a*) Wood, hard or soft.

(b) Steel.

(c) Cast iron.

(d) Concrete, plain or reinforced.

Although, during the last Great War and during this War, concrete both plain and reinforced has been employed as a sleeper material, yet a suitable design which will be able to carry heavy and fast traffic successfully has yet to be evolved. Concrete, therefore, cannot be considered as a serious rival to the wood, steel or C. I. sleepers.

4. **Wood Vs metal sleeper.** The question as to which of the two kinds of sleepers, metal or wood, should be considered superior is still controversial as, besides technical and economic reasons, prejudice has almost invariably played a decisive part in giving preference to one over the other material. Generally speaking, it appears that a wood sleeper is more popular than a metal one. It is considered in America that the former fulfils all the requirements satisfactorily, and it is for this reason that wood sleepers are used almost exclusively on that Continent where, be it noted, economic considerations always play an important part in deciding upon the material to be used.

According to an enquiry instituted in 1935 by a German Association, Greece, Switzerland and Turkey were alone in Europe in having used steel sleepers on a large scale. Of the remainder, the majority used wood exclusively and a few steel sleepers to a small extent. In Germany, according to published statistics of 1936, the proportion of iron and wood sleepers was 1 : 2. It is particularly interesting to note that the two countries, Great Britain and Belgium, possessing an extensive steel industry, but poor in timber, yet employ wood sleepers on their heavily loaded lines almost exclusively. In India, however, the mileages of wood and metal sleepers are almost equal and this in a country which possesses an inexhaustible supply of wood in its extensive forests. The climate in some parts of America is as hot as it is in India, so that conclusions based on American practice should give equally satisfactory results in this country.

5. **Disadvantages of metal sleepers.** The following are some of the main disadvantages of metal sleepers :—

(a) *Corrosion.* Metal sleepers are subject to rapid deterioration by rust or corrosion in warm and moist climates, in soils containing salts of efflorescence, in industrial areas and in tunnels where the air contains acid fumes, on level crossings due to animal droppings and in station yards due to locomotive cinders and any other refuse. It is true that C. I. sleepers deteriorate less rapidly than the steel sleepers. Wood sleepers, on the other hand, are little affected by such atmospheric conditions.

Wood sleepers, however, suffer from inroads of termites and fungi. It may be mentioned that the former do not normally attack sleepers in track where adequate amount of ballast has been used. The trouble due to fungus growth can be obviated by aeration of sleepers at suitable intervals, by using clean ballast which promotes drainage and by suitable treatment of sleepers before use.

(*b*) *Difficulty with insulation.* On electric lines the insulation of rails is easier to accomplish with wood sleepers than with metal sleepers. This explains why wood sleepers are almost invariably used on track-circuited sections of line.

(*c*) *Quality of running.* It is commonly believed that the resilience of the wood sleeper enables it to take the loads with some spring damping effect giving smoother and quieter running. Metal sleepers, on the other hand, are said to run 'hard'. It appears that this opinion is based on mere prejudice. The best sleeper is one which deflects the least under the live load, one which gives the smoothest and the quietest running and is also the cheapest to maintain. The wood sleeper being generally less stiff deflects rather more than the metal sleeper. A track laid with wood sleeper fitted with bearing plates and dog spikes has been found to be noisier than a road laid with the C.S.T. 9 cast iron sleepers, and quieter than a steel trough sleeper road. On this point, there is, however, a diversity of opinion.

(*d*) *Greater weight.* The greater weight of metal sleepers increases their cost of transportation, handling and laying in the track.

(*e*) *High quality of ballast required.* Wood sleepers do not require a high quality of ballast which metal sleepers invariably do.

(*f*) *Breakage due to derailment.* Derailments have, as a rule, much more serious consequences with metal sleepers than with wood sleepers. The wheels of derailed vehicles play havoc with the C. I. plates, bend tie bars and break cotters, making the track unusable over a long distance.

(*g*) *Rail breakage in severe frost.* The track laid with metal sleepers is much more liable to rail fracture in severe frost than one laid with wood sleepers. For example, in a long and severe winter experienced in Germany, 83 per cent of the rail fractures were on steel sleeper track, although there were no special circumstances to account for this unsatisfactory behaviour.

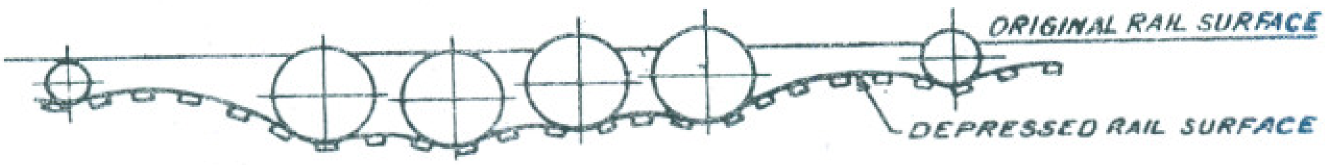
(*h*) *Facility of maintenance.* A track with wood sleepers does not require half as much attention and labour immediately after laying as one with metal sleepers.

(*i*) *Adaptability to one rail section.* Metal sleepers are usually suitable for one rail section only. Contrary to this, the same wood sleeper can be used with flat-footed, double-headed and bull-headed rails of different weights and sections.

CHAPTER II.

Theoretical considerations affecting the design of a sleeper.

1. **Behaviour of the track under load.** In an ordinary track, the sleepers behave as elastic supports which depress under the load and recover completely when the load is removed, provided that the ballast has not been displaced or the formation has not failed while under the load. It was originally believed that the wheel runs in strictly horizontal path and it is the track that comes down to meet it and rises again behind it. From this it followed that the rail bent between the wheels and not between the sleepers as shown in the sketch.

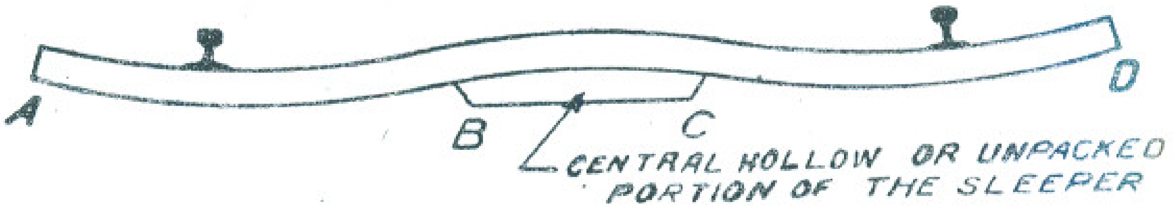


Researches by Prof. Inglis show that a wheel travelling along a continuous rail with uniformly spaced sleepers does not travel in a horizontal path but develops a slightly undulatory movement due to the alternating hard and soft spots at and between the sleepers respectively. With very yielding ballast the movement is not so marked but there is a critical speed, well within the normal speed ranges, at which this motion is greatly increased. On the other hand, with exceptionally incompressible ballast the running will not be so smooth though the critical speed is hardly, if ever, attained under normal working conditions. The behaviour of the wheel at a rail joint is, however, just the reverse. At high speeds the downward movement of the wheel at the joint may be less than when the wheel velocity is smaller due to the downward motion having a limited acceleration depending on that due to gravity and the power of the springs. The load on the sleepers just beyond the joint, however, is greatly increased and accelerations as high as ten times that due to gravity may be obtained on an unyielding foundation, and slightly less with an average ballast bed. Tests show that most serious vertical movements are obtained at rail joints.

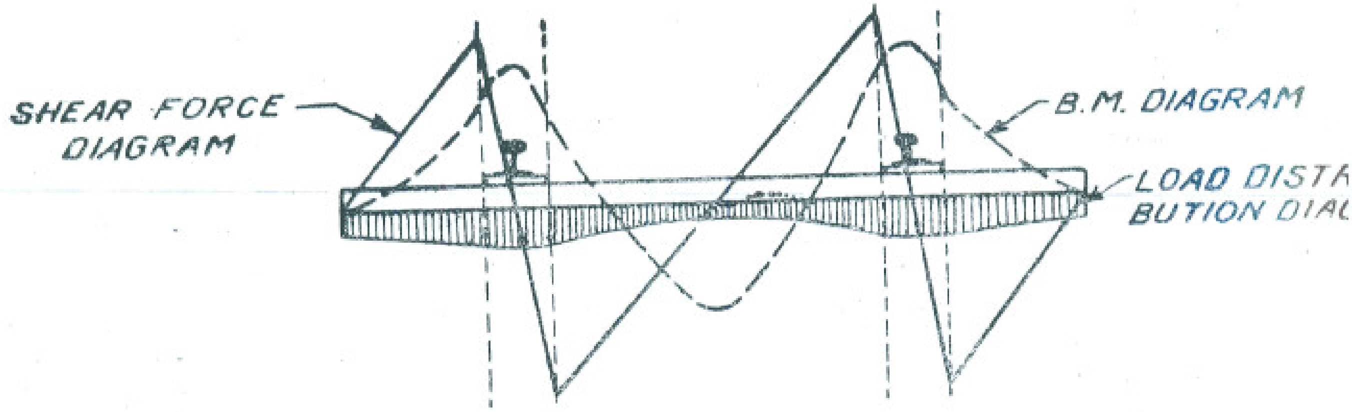
Before a track can be designed on a rational basis, it is necessary to determine the vertical acceleration of the wheel at the joints and at the middle points of a rail, by a suitably designed recording accelerometer, for various types of track in India. Research work on these lines was about to be started in India but due to outbreak of War, it had to be postponed.

2. **Behaviour of a sleeper under load.** A sleeper under load behaves very much as shown in the sketch below :—

It may be assumed that the sleeper is supported on the two rails and is loaded by the ballast reaction. Under average conditions of packing, it is safe to suppose that the distribution of the load is more or less uniform over the lengths AB and CD of the sleeper which are packed,

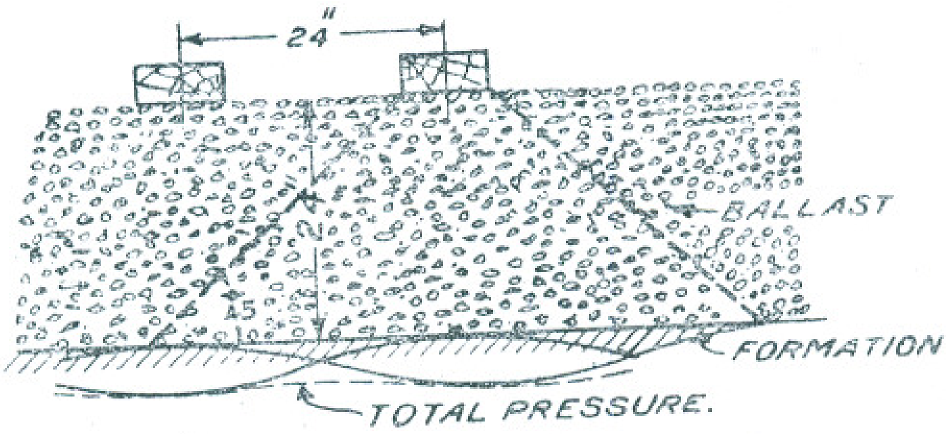


though in a freshly packed track, a greater part of the load is carried by the ballast under the rail seat and the pressure intensity decreases slightly towards the points A and B or C and D.



The above sketch indicates the shape of the pressure distribution, shear force and bending moment diagrams. In a broad gauge sleeper having a length of 9 ft., it may so happen that, under certain conditions of packing, the deflections at the ends A and D are much more than the deflections at the middle with the result that the track is very liable to take a bearing in the middle of the sleeper and becomes centre-bound. This trouble can be avoided by suitably packing the sleeper and by leaving a certain length, BC, unpacked.

3. Dispersion of sleeper load through ballast. It may safely be assumed that the pressure from the underside of a sleeper spreads on each side from the edge of the sleeper at an angle of 45°. The pressure intensity in this zone is maximum vertically under the sleeper and decreases to zero at the end of the zone of the spread. The greater the depth of the ballast, the greater is the amount of spread. It is clear that the pressure at the formation will be almost uniform if the depth of the ballast is nearly equal to the spacing of the sleepers and then the maximum intensity of pressure is also the lowest possible as shown in the diagram :—



As the sleeper spacing is reduced, the load on a sleeper and consequently the resultant pressure under the sleeper decreases, though not in the same proportion as the spacing is reduced.

In order to secure uniform distribution of pressure, across the track, it is desirable to have as stiff and rigid a sleeper as is possible. This increased rigidity can be obtained by increasing the depth of the sleeper.

4. Sleeper spacing and strength of track. The effect of sleeper spacing on the value of ' u ', the track modulus, was also investigated by the Bridge Sub-Committee on Track Stresses in 1925. Their experiments combined with later researches showed that the track modulus varied inversely as the sleeper spacing. They also indicated that any alterations of the width of the sleeper which is practicable, has a negligible influence on the value of ' u '. Further, within certain limits the stresses in the rail are not greatly affected by altering the sleeper spacing. As a matter of fact' the rail stresses are proportional to the fourth root of ' S ', the intermediate sleeper spacing. Taking a 31·5" spacing of intermediate sleepers with N+ 3 sleepers per rail as a basis, there would be an increase of 3·5 per cent in rail stresses by opening out the spacing to 36" (N+ 1 sleepers per rail) and a reduction of 4 per cent by closing in to 27" (N+5 sleepers per rail).

The maximum sleeper reaction is proportional to $S^{\frac{3}{4}}$. Here again if we take S = 31·5" (N +3 sleepering) as a basis for comparison, there is an increase in the value of the sleeper reaction of 11·5 per cent when S = 36" (N + 1) and reduction of about 11 per cent with N + 5 sleepering. These results do not hold good if wide sleeper spacing is combined with a high value of ' u ', a condition not met with in an Indian track.

Opinions vary greatly as to the correct sleeper spacing. For example, A. B. Railway (now a part of B and A Railway) found N + 1 sleepers adequate for 10 ton axles although the schedule of Dimensions recommends N +2 sleepers. For the same axle load the B. N. W. R. (now a part of Oudh and Tirhut Railway) found N + 3 sleepers per rail necessary. Similarly, the N. W. R. have been running 21·5 ton axle goods trains and 19·5 axle passenger trains on N + 1 sleepering. The E. I. Railway consider N + 3 sleepers necessary even for their 17·5 ton axles although the number recommended officially by the Railway Board is N + 1 for such axle loads. This goes to show that the official recommendation has not taken cognisance of certain important factors such as the nature of the formation, depth of ballast, amount of rainfall, etc. Further, research is, therefore, necessary to design the track on a rational basis.

5. Theoretical relationship between sleeper spacing and axle load.

It can be shown that

$$P = K \frac{I^{\frac{1}{4}}}{S^{\frac{3}{4}}}$$

where I is the moment of inertia of the rail, S is the intermediate sleeper spacing and P is the wheel load.

On the basis of the above relationship, the recommendations made by the Railway Board in items 11 R & 13 R of Chapter I R of the Schedule of Dimensions B. G. (1939 Edition) appear to be incorrect. Thus if as recommended therein, it is assumed that a 75 lb R rail can safely carry a 17 ton axle load with N+1 sleepers per rail, the safe axle loads recommended for heavier rails with more closely spaced sleepers err on the side of unsafety as indicated below :—

Rail Section.	Moment of Inertia I.	No. of sleepers per 36 ft. rail.	S inches.	Safe axle load P, $P = K \frac{I^{\frac{1}{4}}}{S^{\frac{3}{4}}}$	Safe axle load according to the schedule of dimensions.
90 R	38·45	N+3	31·5	20·8 tons	22·5 tons
115 R	62·41	N+5	27	26·4 ,,	28·0 ,,

6. Sleeper spacing in relation to the rail joint. It is a well-known fact that the useful life of the rail is considerably cut short due to the rails getting hogged as a result of bad maintenance or of a poor design of the rail joint. Hogging of the rails or low joints are due partly to the defective design and material of the fishplate and partly to the defective design and location of the rail support close to the joints.

An ideal rail joint must allow for expansion and contraction of the rails, while offering support to the rail ends sufficient to permit a deflection in the joint as nearly equal as possible to that of the solid unbroken rail.

Undoubtedly, during recent years the rail joint conditions have greatly improved. This is due to the following causes :—

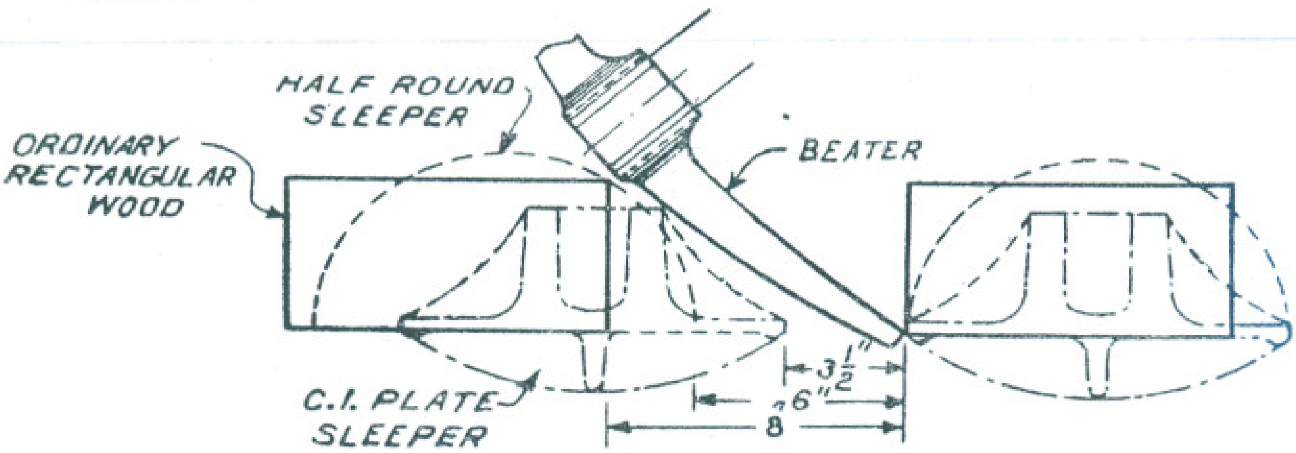
(*a*) Improvement in the design of fishplates by disposing of the metal in the most effective manner.

(*b*) The location of the bearing areas of fishplates to ensure better application of load.

(*c*) The reduction to a minimum of all dangerous stress concentrations.

Experience shows that besides improvement in the design of the fishplate and of the sleeper itself, the rail joint can be considerably strengthened by bringing the joint sleeper as close as possible to the rail joint and by bringing the shoulder sleeper reasonably close to the joint sleeper. Although it is possible by this means to arrange that the maximum joint deflection shall be equal to or less than the solid rail deflection, yet lack of stiffness of the ordinary fishplated joint cannot be entirely compensated by a local increase in the supporting power of the track.

The question at once arises as to how close the joint and shoulder sleepers can and should be brought. On this point there is no uniformity of practice or unanimity of opinion. The minimum distance between sleepers depends upon the method of packing and upon the type and the shape of sleeper in use. For wood sleepers which are to be packed by a beater, the minimum sleeper spacing appears to be about 8″ and for cast iron sleepers about 3½″. For the former, however, 11″ is recommended as the minimum for satisfactory packing and for the latter 7″. In bar packed pot sleepers, a minimum clear space of 3″ has been found adequate. The effect of the shape of the sleeper on the minimum permissible clear space is illustrated by the following diagram :—



This diagram explains why a cast iron plate sleeper requires less clear space for packing than a wood sleeper.

It was found many years ago that the clear space between joint sleepers of 9″ on broad gauge and of 6″ on metre gauge was not sufficiently small to avoid the low joint trouble. In India, the N. W. Railway was the first to try to space the wood sleepers at 12″ centres and cast iron sleepers at 14 or 15 inch on the broad gauge giving in each case a clear space of only 2″. Although it was feared that adequate packing of the sleepers will be impossible and that the one sided packing will cause the sleeper to tilt, yet experience over several years has shown the experiment to be quite successful. Now other Indian Railways have reduced the joint sleeper spacing with beneficial results ; the notable among them are the B. N., E. I. and S. I. Railways.

There is, however, great divergence of views regarding the minimum clear space required for efficient packing of various types of sleepers on different railways. Some Railways are definitely against the 2″ gap at joints as according to them it is absolutely essential to pack the joint sleepers from both sides which is impossible with a clear space of 2″. On the other hand, the N. W. Railway, where on the entire length the joint sleepers are laid to this spacing, has found it quite satisfactory.

Engineers who believed that it would be difficult to maintain properly 10″ wide wood sleepers with a clear space of 2″ at the joint began to think of designing special joint sleepers. For several years these special joint sleepers proved unsatisfactory. The reason was that such a sleeper probably rocked under traffic and loosened the packing. Also the additional stiffness, which such an arrangement necessarily gave, destroyed the uniformity of the wave motion in the rail under an advancing wheel load. The first defect has been eliminated from the latest design of the duplex sleeper but the second defect cannot be removed. It is for this reason that several railways prefer two wood sleepers closely spaced at joints to a duplex sleeper even when the intermediate sleepers are of cast iron or of steel. On the other hand, some Engineers dislike this arrangement because of the lack of uniformity of the track modulus under the joint and intermediate sleepers.

7. Sleeper spacing and impact. Experiments by the Steel Corrosion Committee mentioned in their third Report indicated that the leading joint sleeper (also called the landing sleeper) is subject to a greater impact than the trailing joint sleeper (one at the rear end of the rail with respect to the direction of traffic). This point was also brought out in the experiments on rail joint impact of bridges.

Researches by Messrs Gelson & Blackwood indicated further that the impact effect is increased if the sleeper spacing is increased or when the rail section is comparatively lighter. Thus the impact effect can be reduced if a larger number per rail of lighter sleepers is used instead of a smaller number of heavier sleepers.

8. Effect of sleeper dimensions on its load bearing capacity. The length of the sleeper has an important effect on its load bearing capacity but this is not independent of its depth and width *i.e.*, stiffness. An increase in length would mean an increase in the bearing area provided that the sleeper is packed right up to its end on the outside and for an equal distance on the inside of the rail. In the case of weak ballast, an increase in the effective bearing area is of great help. A longer sleeper also increases to a certain extent the area of the formation which carries the superimposed load. This lengthening, however, cannot be carried out indefinitely without taking into account the strength of the wood, as otherwise, the sleeper will break at or near the rail seat. It is for this reason that more soft wood sleepers break in the track than sal sleepers. Again, the effectiveness of the increase in length is not directly proportional to the actual increase, as in a well packed track, the greater part of the load on the sleeper is carried by the ballast under the sleeper at the rail seat, and the load carried by the parts away from the rail seat gradually decreases. However after the passage of some trains over a newly packed track, the ballast under the rail seat begins to get displaced or crushed causing a permanent depression of the ballast. The load is then transferred more and more to the ends of the sleeper as the depression of the ballast increases causing heavy bending stresses in the sleeper. Under no load the sleeper rests horizontally supported at the ends with a gap between the packing and the underside of the sleeper in the middle. During the passage of a train at high speed, this gap is closed suddenly causing the pumping out of the water in wet weather or blowing out of fine particles of sand in dry weather. Investigation has shown that under such conditions the intensity of the blows delivered by the sleeper to the ballast bed under fast moving trains varies approximately as the square of the amplitude of the wave motion, *i.e.*, as the vertical distance the sleeper moves. The repetition of such blows might even cause the sleeper to break in case the track is not repacked in time.

It would appear from the above that we cannot increase with safety the length of a sleeper without increasing its depth ; also that the depth should vary with the strength of the timber used instead of being the same for soft and hard wood sleepers. There is a tendency now in America to use longer sleepers. Sleepers as long as 9 ft. are being used for the standard gauge with good results, though the normal length in that country is 8 ft. They, however, use very much deeper sleepers (6″ or 7″ deep) and very much larger number per mile (2,900 to 3,500) with 12 inches or more of ballast. Each individual sleeper, therefore, carries a much smaller load than it does in this country.

At the end of the nineteenth century there was a controversy among Railway Engineers in India as to the best length of a Railway sleeper for the broad gauge. For many years the standard length had been 10 ft. Then experimental and theoretical investigations were carried out which showed that 8′- 6″ was, the correct length for a 10″ × 5″ sleeper. The standard length of the B. G. sleeper was, therefore, reduced to 9 ft.

It is worthwhile to note that the proportions between the length of the sleeper and the different gauges are as follows :—

Gauge G	Sleeper length L	Ratio $\frac{L}{G}$
5′ – 6″	9′ – 0″	1·64
4′ – 8½″	8′ – 6″	1·80
3′ – 3⅜″	6′ – 0″	1·83
2′ – 6″	5′ – 0″	2·00
2′ – 0″	4′ – 0″	2·00

It would appear from the above that if the ratios $\frac{L}{G}$ are suitable for the standard and the lighter gauges, the length of the broad gauge sleepers could be increased, but this, as explained above, cannot be done without increasing the depth of the broad gauge sleeper, as otherwise the danger of centre-binding of the track and of sleeper breakages will increase considerably.

The stiffness of a sleeper considered as a beam varies directly as the cube of its depth while its strength is proportional to the square of its depth. The stiffness and the strength both vary directly as its width. The bending moments and deflections in a sleeper are proportional to the load it has to carry. From this it follows that a $9'' \times 6''$ sleeper is 56 per cent stiffer and 30 per cent stronger than a $10'' \times 5''$ sleeper.

In deciding upon the width of a sleeper it is necessary to bear in mind the following considerations :—

(*a*) The minimum permissible bearing area on the ballast. Allowance has to be made for loss of width due to the rounding of a wooden sleeper when packing.

(*b*) The size of the bearing plate to be used and the minimum edge distance at which a spike can be driven.

9. Effect of the width of rail bearing upon sleeper stability. It was previously believed that the greater the width of the rail bearing on the sleeper, the better the rail support and consequently stronger the track. This has, however, proved to be a fallacy. According to modern ideas, the narrower rail seat (about 4″ to 6″ wide instead of the 10″ width of a B. G. sleeper) is much superior, as the tendency of the sleeper to rock owing to the deflection of the rail under the load is considerably reduced and therefore, the packing is much less disturbed. This explains why the old LK sleepers had a bearing width of 7″, while the latest C.S.T. ·9 sleeper has a 4″ bearing only.

In the case of wood sleepers used without bearing plates, the minimum width of rail bearing may be calculated from the safe crushing load of the wood. The safe crushing load for some species is as follows :—

Sal	605 lb.	per sq. inch
Teak	485 lb.	,, ,, ,,
Deodar	295 lb.	,, ,, ,,

10. Sleeper design as affecting the lateral strength of track. Ever since the Bihta accident, the lateral strength of the track has become an important consideration. Researches made in India after this accident show that on badly aligned curves, flange forces of 12 to 13 tons can be recorded, though on a straight track these forces do not exceed 7 tons under both dry and monsoon conditions.

As a result of these researches, it was found that the design of the sleeper and the rail fastenings had an important effect on the lateral strength of the track. Thus, a track laid with C.S.T. 9 or steel trough sleepers was found to be the best in this respect ; track with D and O plates came next and the wood sleeper road with dog spikes as rail fastenings had the least lateral strength. In Germany, this defect of the wooden road was appreciated long ago, and was entirely eliminated by the use of coach screws along with screw plugs in sleeper holes in place of dog spikes, by employment of large bearing plates and by adoption of separate fastenings between the bearing plate and the rail. Track similar to this exists in India on the N. W. Railway. The rails are secured to large cast iron plates by keys, the bearing plates being held down to the sleeper by round spikes. The lateral strength of this type of track has not yet been measured.

Track research in India showed that, while the spreading of the gauge in track laid with metal sleepers does not occur under lateral loads up to 13 tons, the maintenance of line certainly becomes a serious problem. On hard wood sleepers, gauge spreading appears to become serious after about 11 tons lateral load on a 90 lb. track, but maintenance is likely to become troublesome at somewhat smaller lateral loads than these.

Other factors which affect the lateral strength of the track were found to be the following :—

(*a*) Time the track has to consolidate after re-laying or repacking increases the lateral resistance though the type of rail or end boxing has no appreciable effect.

(*b*) The sleeper spacing and the value of grip the sleepers take in the ballast affect the lateral strength which may, with safety, be taken to vary directly as the wheel load or, what is the same thing, inversely as $S.^{\frac{3}{4}}$.

(*c*) The shape of the sleeper has an appreciable effect on the lateral strength of the track in the case of block sleepers. The greater the dimension at right angles to the track, the greater the lateral strength.

CHAPTER III.

Practical considerations affecting the design of metal sleepers.

1. Provision for gauge widening on curves in the design of metal sleepers. In the early designs of metal sleepers, the designer thought it most essential to provide some means of gauge adjustment. Provision for this was incorporated in the designs of metal sleepers for two purposes (*a*) for taking up inequalities due to the errors in manufacture, (*b*) for widening the gauge on curves. In the early designs, gauge adjustment was of two kinds. One was in the form of a step adjustment by 1/16" or 1/8" at a time by means of clips and bolts or stepped gibs and stepped cotters. Thus the four-sided gib of the 3 S/T.S.C. (Fig. 7 Plate 1) provided gauge variation in steps of 1/8 in. The second was a fine adjustment obtained by the tapered keys. The amount of gauge widening necessary on sharp curves caused a good deal of controversy in 1932 and 1933. Most of the Chief Engineers of important Railways were of the opinion that gauge widening was essential on sharp curves for reducing rail wear and curve resistance. The Railway Board decided that trials with a dynamometer car should be made on sharp curves (3° to 8°) laid in exact gauge to determine the effect on the tractive effort as compared with those laid with a slack gauge. The experiments on the G. I. P. Railway showed that the allowance for slack gauge on curves could be reduced. In fact, it appeared that for wagons with 11 ft. 6 in. wheel base and for curves up to 4 degrees, the exact gauge was better than a slack gauge. Similar trials made on the N. W. Railway with wagons of longer wheel bases produced inconclusive results. The Railway Board, however, decided that, in normal metal sleepers, no special provision need be made for widening of the gauge. Nevertheless different Railways provide a slack gauge on sharp curves to the extent obtained by keys and cotters.

2. Chief features affecting the design of cast iron sleepers. The chief features affecting the design of cast iron plate sleepers will now be discussed :—

(*a*) *Weight of the plate.* It is very generally believed that the greater the weight that resists the wave motion of the track, the greater is the stability of the track. This weight may be achieved by increasing the weight of the plate as in the N. W. Railway plate sleeper (Fig. 1, Plate 1), in which the plate is 25 lb. heavier than most other plate sleepers ; or it may be obtained by covering the plate with ballast as is done with most types of sleepers by boxing the track up to the top of the tie bar. The N. W. R. plate sleepers are, however, boxed up level with the top of the plate. In the Fowler's box sleeper, the box was filled with ballast, sand or concrete with the same object. The pot sleeper and the C.S.T. 9 (Fig 2) sleepers with the pot or pockets filled with sand, ballast, etc., have an added grip for the same reason. A good many experienced Chief Engineers of different Railways have deprecated the tendency in later designs of sleepers towards greater lightness of the plate. In fact, they suggested that with heavier rails, the weight of the plate should be correspondingly increased. It is, however, doubtful that loose ballast on the top of the plates should have any material effect in stabilizing the packing. The disadvantages of boxing up to the top of the tie bar far outweigh the advantages. It is claimed that this method of boxing protects the plates against damage in case of derailments besides securing greater stability against lateral and longitudinal displacements. Against this, the ballast mixed with dust and rubbish which comes in contact with the tie bars, cotters and gibs, promotes their corrosion. The inspection of the condition of such fittings becomes almost impossible. Further, a larger quantity of ballast is required for this purpose. In addition to these drawbacks this method of boxing necessitates the removal and putting back of all the overlying ballast when the track is to be repacked. This reduces the number of sleepers that can be repacked by a gang in one day and thus increases the cost of maintenance. For these reasons, it was once claimed for the N. W. Railway plate sleeper which, as already stated, are boxed level with the top of the ballast that they were much cheaper to maintain than other types. In the 2nd report of the Pope Committee the comparative costs of 'overhauling' and 'through packing' for different types of sleepers were given as follows :—

	Type of sleeper				
	Wood	Steel trough	C. I. N. W. R.	C. I. 3 S/TSC	KK Plate
(*i*) Overhauling	1·33	1·11	1·00	1·11	1·11
(*ii*) Through packing	1·33	1·20	1·00	1·33	1·33

Note.—Through packing does not include the removal of ballast for screening. Overhauling includes this and also shoulder dressing.

It was, therefore, admitted that the depth the plate is required to be sunk into the ballast had had a very material effect on the cost of maintenance. The Central Standards Office when designing the C.S.T. 9 sleeper preferred the bowl shape as they hoped that the ballast above the top of the plate would in the new design be replaced by the ballast in the pockets and that the new sleeper could be laid level with the top of the ballast. Their hopes were, however, not realised. The G. I. P. Railway reported in 1927 that they had found it desirable to box up their C.S.T. 9 track to the top of the tie bar to keep it in alignment. This point was also emphasised in their later reports. On the E. I. R. also, these sleepers were originally put in with practically no boxing but subsequently they found that boxing could not be eliminated.

There is, however, another aspect of the matter which needs attention. The N. W. Railway plate sleeper complete with its fittings weighs 46 lb. more than the C.S.T. 9 plate sleeper and 33 lb. heavier than a KK plate sleeper. The cost of a mile of track laid with 2,200 N. W. R. plate sleepers is, therefore, Rs.2,600 more than that of a similar track with

KK plate sleepers assuming that the cost of the sleeper is Rs.80 per ton. At 4 per cent interest, this works out to Rs.8-5-0 more per mensem, *i.e.*, half the pay of a gangman. Thus if 2 men per mile are allowed for maintenance, the increased capital cost of the track is equivalent to 25 per cent extra cost of maintenance. Most of the saving in maintenance claimed for the N. W. R. type of sleeper is thus wiped out by the higher capital cost.

The disposal of the metal in the sleeper is also important. To illustrate, the N. W. R. plate weighing 120 lb. fails under the tup test while the C-S.T. 9 plate with a weight of 95 lb. is the strongest C. I. plate. This is due to the defective design of the N. W. R. plate sleeper as, under load, the heavy keel acts as a tension member while the plate is under compression. The maximum compressive stress is about half the maximum tensile stress. Thus the design is defective as cast iron is capable of taking about 4 times more stress in compression than in tension.

(*b*) *Shape of the sleeper.* The shape of a C. I. sleeper has a considerable influence on its power to hold ballast. Thus it is widely believed that the plate sleeper does not retain the packing quite as well as an inverted pot or a trough sleeper. It was at one time suggested by one Railway that all plate sleepers should have a 1½ in. deep rim round the plate. The underlying idea in selecting a bowl shape for the C.S.T. 9 and for the original design of the Duplex plate was that the bowl would serve as a key to resist movement in any direction. The increased resistance to movement is said to be due to the increased weight of the plate but not due to any increase in the frictional resistance. For once the packing in the bowl is consolidated into a solid mass, the effect is exactly the same as if the bowl were filled with concrete. The only resistance to movement (except that provided by the keel, lug, tie bar, etc.) would be the friction between the bottom surface of the concrete and the ballast. The E. I. Railway evidently subscribe to this view as they have filled up some of their C. S. T. 9 and old type Duplex plate sleepers with cement concrete. The G. I. P. Railway, however, contend that the above reasoning applies to pot sleepers but not to the C. S. T. 9 sleepers where the depth of the bowl is not so great that the ballast in the pocket will cake up.

The effect of the shape of the sleeper on the lateral strength of the track has already been discussed in Chapter II.

(*c*) *Bearing area of a sleeper.* The question of the minimum bearing area of sleepers of all gauges was considered by the Track Sub Committee in 1926. They contended that the Fowler box sleeper, then in use, had been found satisfactory for the track loads then running. It had a bearing area of only 3·75 sq. ft. They, however, favoured an increase in the bearing area for the proposed heavier loads. The bearing area of the standard wood sleeper was taken as equal to 5 sq. ft. by assuming that 18 in. on either side of the rail provided the effective bearing area.

They, therefore, recommended that new C. I. sleepers for 90 lb. rails should also have a bearing area of 5 sq. ft. For this reason all sleepers designed subsequently till 1936 had invariably this bearing area.

The depression under load of an individual sleeper, Yo, is given by the formula :—

$$Yo = P\sqrt[4]{\frac{1}{64\ EIu^3}}$$

where P = wheel load
u = track modulus
I = moment of inertia of the rail.

Now it is a well known fact that u is not appreciably affected by the bearing area of a sleeper *e. g.*, a track laid with N+3 wood sleeper has a track modulus of about 1,000, whereas a similar track with C.S.T. 9 sleepers has 'u' exceeding 1,500. The bearing area of the wood sleeper is almost equal to that of C.S.T. 9 sleeper.

Similarly, it is obvious that an increase in the bearing area decreases proportionately the bearing pressure on the ballast immediately under the sleeper but it does not materially decrease the maximum bearing pressure on the formation.

The question now arises as to why, when the track depression is not affected by the bearing area and the pressure on the formation is not materially altered by increasing it, it was found necessary to increase the bearing area of the C.S.T. 9 sleepers. A good many railways reported in 1939 that a fine layer of dust was found to collect around the L. K. and other experimental plate sleepers at the joints. This was obviously due to the hammering of the ballast and an increase in bearing area was therefore indicated. It may be argued that the bearing area of a wood sleeper should also be increased as C. I. plate sleepers were originally designed to have a bearing area equal to that of a wood sleeper. A very important point in this connection is that whereas in all block sleepers, such as C. I. or R. C. pot or plate sleepers, the whole of the available area is packed, in rigid sleepers of wood or steel there is a certain reserve area which comes into play when a train is passing. Thus under adverse conditions, the bearing area extending from the centres of the rails to the ends of the wood sleeper, and also for the same distance inside the centre of each rail may become effective. This works out to about 5·5 sq. ft. The bearing area of the C. S. T. 9 sleeper was therefore increased to this figure.

The following table gives the bearing area of some important sleepers : —

(*i*) *Broad gauge*—

1.	Wood sleepers	... ... 788 sq. in.
2.	D. and O. plate	... ... 792 ,, ,,
3.	N.W.R. plate	... ... 700 ,, ,,

4.	C.S.T. 1 to C.ST. 6 ...	... 720 sq. in.
5.	C.S.T. 7 and C.S.T. 8 ..	... 800 ,, ,,
6.	E.I.R. Plate ...	... 800 ,, ,,
7.	Steel trough ...	... 825 ,, ,,
8.	C. S. T. 9 ...	... 792 ,, ,,
9.	Duplex old type ...	... 1356 ,, ,,
10.	Duplex H type ...	... 1462 ,, ,,

(*ii*) *Metre gauge—*

1.	Wood sleeper (6′ × 8″ × 4″)	... 486 ,, ,,
2.	Steel trough standard	... 577 ,, ,,
3.	C. S. T. 9 ...	... 516 ,, ,,
4.	Duplex old type ...	... 882 ,, ,,
5.	Duplex H. type ...	... 916 ,, ,,

It will be noticed that in both M. G. and B. G. C.S.T. 9 sleepers, the bearing area is independent of the rail section for which the sleeper is designed. This would appear to be incorrect as, if the bearing area of a sleeper is suitable for a branch line laid with lighter rails. it cannot be adequate for a main line laid with heavier rails and with faster and heavier traffic. Since the recommended number of sleepers for M. G. track increases proportionately with the axle loads, approximately the same bearing area of sleeper is justified for M. G. track with light as well as with heavy rails. In the case of B. G. sleepers, as the variation in the number of sleepers per rail is very much smaller between the H. M. and B. L. standards of loading, the sleeper load is greater under H. M. loads than under B. L. loads. At present the weight of the C.S.T. 9 sleeper for 75 lb. rails is about the same as that of a sleeper for a 115 lb. rail. To have one size of a sleeper for all rail sections may be justifiable in the case of wood sleepers or possibly also in the case of steel sleepers but in the case of C. I. sleepers it is better to have a lighter sleeper with a reduced bearing area for 75 lb. B. G. track. By using a lighter sleeper on sections carrying a lighter standard of loading and laid with light rails, considerable economy can be effected. Again, if the number per rail of the lighter sleeper were increased, the impact effect and therefore the maintenance costs would be reduced although the first cost with the increased number of sleeper may be just the same as with the present day heavier sleepers but with a smaller number of the sleepers per rail.

(*d*) *The effect of tie bar on the lateral stability of a sleeper.* The tie bar gives practically no rigidity to the sleeper in the horizontal plane but it does add however to its rigidity in the vertical plane. The function of the tie bar is liable to be misunderstood as is shown by the following quotation from the Pacific Locomotive Committee's report :—

> " Plate and pot sleepers which are cross tied below the bottom of the rail have a tendency to deflect outward under the effect of flange pressure, when the play in the tie bar is excessive and its moment of inertia is insufficient ".

To this the Track Standards Committee aptly replied as follows :—

"It is considered that the function of a tie bar is to act as such and not to act as a beam resisting the tendency of the plate to tilt under the load. When the plates are properly packed, they should provide stability against both the lateral pressure and the tendency to tilt ".

There is, however, nothing to prevent the gangmen packing the plate at a slight inclination. As a matter of fact, the plate can be so easily tilted that it is a farce to provide a cant of 1 in 20 at the rail seat. From this point of view, C. I. sleepers are defective as not only the cant but the gauge can also be altered very easily by packing either the outside or the inside of the plate or the pot. In this respect sleepers with short tie bars are much worse. It is for this reason that in 1935, the Engineering Section was unanimously in favour of the long tie bar.

The position of the tie bar relative to the rail level or to the plate is also of great importance. The lower the tie bar, the less is the lateral strength of the track as, in the case of defective packing, a greater tilt and consequently a greater gauge widening would result under the effect o flange forces. Moreover, a tie bar below the sleeper plate is liable to corrode and to increase difficulties in maintenance. It has been found that in the case of N. W. Railway plate where the tie bar is below the plate, the tie bar seizes the plate due to corrosion. This is avoided by removing the tie bar periodically for coaltaring. During this operation the packing is liable to get disturbed and increased maintenance cost is the result. The cotters also get badly corroded and have to be frequently replaced.

3. Duplex joint plate sleeper and the rail-free principle. The idea of designing a Duplex sleeper which replaces two ordinary sleepers at the joint seems to have been borrowed from the Continent where a Duplex steel trough sleeper was in use several years ago.

The chief advantages claimed for a Duplex sleeper are the following:—

(*a*) It provides two rail seats close to the rail joint at a comparative short distance apart. The result is that for any position of a wheel load in the neighbourhood of the joint, whether on one side or the other, the weight is thrown to the centre of the plate which is of an appreciably greater area and supporting power than one plate of an ordinary sleeper.

(*b*) Under the conditions mentioned above, reliance has not to be placed on the strength and satisfactory fitting of the fishplate to effect a distribution of the load from one rail to the other. On the other hand, when two ordinary sleepers are provided at a rail joint and if the fishplates are worn or slack, the whole of the wheel load is liable to be carried on one ordinary sleeper and hence there is a greater load on that sleeper than it is designed to carry.

The designs of the Duplex sleepers so far used in India incorporate the rail-free principle, *i. e.* the rail is not secured to the Duplex sleeper by any keys. (*vide* Fig. 5).

The rail-free principle was introduced to avoid any lifting or disturbance of the plate in the track under the elastic movements of the rail under traffic. The idea was probably borrowed from the D. and O. plate, the great success of which in achieving a smooth running of the track is attributed to the fact that the rail can lift up independently of the jaws without disturbing the packing of the sleeper. Similarly, a chaired road with wooden keys after a few years service allows enough play for the rail to move independently of the sleeper. Pot sleepers for the DH or BH rails with wooden keys behave in the same way. There is, however, one essential difference which seems to have been overlooked. The chief advantage of the D. and O. plate road lies in its freedom from the vertical movement of the rail along its entire length. Therefore, by providing a rail-free sleeper at a joint with ordinary sleepers elsewhere, it is not possible to simulate the conditions of the D. and O. track or of the chaired track with wooden keys. All sleepers would have to be of the keyless type for achieving this object.

The chief advantages claimed for the rail-free principle are:—

(*a*) The sleeper remains undisturbed in the ballast and is not rocked by the deflection of the rail.

(*b*) A visual indication of the slackness of the packing is given. As the plate remains undisturbed the movement of the rail in relation to it is clearly visible.

Against the above advantages, the following drawbacks have been reported by different railways. They are mainly attributable to the rail-free feature of the design:—

(*a*) There is a distinct tendency of hammering on the landing rail due possibly to the rigidity of a well packed rail-free support. Different railways report considerable wear of the rail seat due probably to the constant pounding of the rail seat by the rail.

(*b*) The alignment appears to kink inwards towards the centre of the track at the inner rail of curves on account of there being no stop or jaw on the inner side of the plate at its centre.

(*c*) The sleeper requires very careful maintenance and is more difficult to pack than two closely spaced ordinary sleepers near the joint. The sleeper cannot be lifted with the rail for packing; the bars of the men lifting the sleeper get in the way of men packing it. The same difficulty is found when the track has to be straightened.

(*d*) As the rail is not keyed to the sleeper, the danger due to sabotage is greatly increased.

To get over these defects inherent in the rail-free feature of the design, the E. I. Railway carried out a trial with a small number of rail-fixed Duplex sleepers and found that there was no appreciable difference between the two types of Duplex sleepers so far as the running was concerned whereas most of the defects mentioned above disappeared. The author, therefore, recommends that the rail-free principle should be discarded.

4. **Discussion of the chief features affecting the design of a steel trough sleeper**. The following features will now be discussed :—

(*a*) Waisted shape *versus* parallel sides.

(*b*) Strength of the sleeper and its relation to its shape.

(*c*) Provision of baffles or lips to prevent centre binding of sleepers.

(*d*) Four key *versus* two key attachment.

(*a*) *Waisted shape versus parallel sides.* It is difficult to state any definite views concerning the advantage of a waisted shape of the standard trough sleeper (Fig. 4) over a sleeper such as the Henry Williams Saddle plate sleeper (Fig. 3) with parallel sides. It, however, appears reasonable to infer that the waisted centre prevents the movement of packing from the rail seat to the centre, which causes centre binding of the sleeper. Further, it may be considered that the wedge shape and deeper centre of the standard sleeper is better than a trough with parallel sides but it can scarcely be said that the wedge shape is essential. Once the dies have been prepared, the costs of both types of sleeper are almost equal. The Railway Board preferred the waisted shape as they believed that it assisted in retaining the ballast under the rail seat and that if parallel sides were adopted, some additional means would be required to achieve this.

(*b*) *Strength of the sleeper and its relation to its shape.* Calculations in Appendix B show that the standard trough sleeper has its strength and stiffness somewhere midway between those of a sal and a chir sleeper of the standard $10'' \times 5''$ size. Mr. Strick, formerly a Bridge Engineer of the M. and S. Railway, designed in 1935 a new steel trough sleeper called the Zodiac sleeper. This used the same rolled plate as the standard design shown in Fig. 4 but was deeper and stiffer at the rail seat. A deeper section will undoubtedly achieve greater flexural strength but the resulting disadvantages will far outweigh this advantage. The sides of the sleeper will then become more nearly vertical. This would make packing of the sleeper far more difficult. Further the vertical and deeper sides will prevent the full and efficient consolidation of the packing for a very long time. The Railway Board rejected Mr. Strick's design as they were not convinced that there was any real necessity for any additional strength or stiffness over the existing standard design.

The existing sleeper section of the standard design is mostly criticised on the ground that the neutral axis divides the depth of the sleeper at the rail seat not in the middle which is the condition for maximum strength but in the ratio of about $1 : 2\frac{1}{2}$. This makes the sleeper very strong in compression but comparatively weak in tension. This, however, may be considered as an advantage as it provides a great reserve of strength against crushing of the rail seat which obviously has to carry heavy local stresses besides the flextural stresses.

(*c*) *Provision of baffles to prevent centre binding of trough sleepers.* The Track Sub-Committee were the first to recommend that a rectangular portion of the top table of the sleeper at about 15″ on either side of the centre of the sleeper should be pressed down to form a lip or baffle to prevent the tendency of the packing to move towards the centre and produce centre binding of the sleeper. The Engineering Section of the Indian Railway Conference Association also suggested the provision of a baffle but this was not agreed to by the Railway Board on the ground that the sleeper would be appreciably weakened at the section and besides, with a waisted centre, a baffle had not been found to be necessary. The author, however, recommends that baffles 4″ wide and $3\frac{1}{2}''$ deep would considerably improve matters without unduly weakening the sleeper and there will be no additional cost. Further much strength is not required at the section at about 15″ from the centre as the sleeper there acts more as a tie than as a beam.

(*d*) *Four key versus two key attachment.* Even since the early days, each rail in the track has been secured to the steel trough sleeper by two keys thus using four keys per sleeper. A pair of keys is required at each rail for adjustment of gauge and to take up inequalities of manufacture, there being no other arrangement for it.

The subject of easy removability, malicious or otherwise, of keys has long been considered by the Railway Engineers. There is thus an element of potential danger in a steel sleeper track with 4 keys per sleeper. Another objection formerly raised against the four-key attachment was the likelihood of the keyman hitting the wrong key to tighten the keys and thereby upsetting the gauge. Practical experience has, however, shown that this fear was unfounded.

To prevent sabotage, the Engineering Section recommended to the Railway Board some years ago that the outside key in a steel trough sleeper should not be easy to remove. To fulfil this requirement, the Central Standards Office designed a non-removable key (Fig. 6). This key is used on the outside of the steel sleeper track and cannot be removed till the inner keys of all the sleepers in the rail length have been removed and the rail moved inward towards the centre. It will be noticed that this key can be obtained by a variation in the mode of cutting from the same rolled bars as are used for the ordinary two-way keys. The use of this key, therefore, does not entail any extra expense. In spite of this, the key has not become popular, which shows that the danger of sabotage is not considered to be real.

From the above, it would appear that the 4 key attachment has become a permanent and indispensable feature of the steel trough sleeper.

CHAPTER IV.

Practical considerations affecting the utility of wood sleepers.

1. Special requisites of a wood sleeper. In addition to the essentials of an ideal sleeper given in Chapter I, a wood sleeper should be capable of seasoning without excessive splitting, be amenable to treatment and should have sufficient compressive strength to resist rail pressure and adequate hardness to withstand rail abrasion.

2. Average life of a wood sleeper.

(*a*) Life figures in India.

(*i*) N. W. Railway's view. This railway is the biggest user of soft wood sleepers.

	In 1937	In 1943
Treated deodar	21	18
,, chir	19	16
,, fir and kail	14	...
Untreated sleepers soft wood	...	12

(*ii*) View of C. W. Scott, Timber Advisory Officer, Railway Board

Untreated sal	12 to 16 years
Treated pine deodar	20 to 22 years
Treated fir and spruce	14 to 18 years
Half round teak sleepers	16 years
Rectangular ,, ,,	26 to 30 years.

(*b*) Life figures in other countries.*

(*i*) America—Treated sleepers—over 25 years. Life figures on several railways are now as high as 35 years.

(*ii*) England

(1) Treated Scots pine and Baltic Redwood—25 years.

(2) Treated fir—8 to 12 years.

(*iii*) Germany—Treated oak and beach—25 years.

(*iv*) France—Treated oak and beach—20 to 30 years

3. Causes of low life figures of the wood sleepers in India. From the preceding section it is obvious that life figures of the wood sleepers in India are about the lowest as compared with those of other important countries. This appears to be due to a combination of some of the following causes :—

*These figures are mainly based on the information given in Railway Board's Technical Paper No. 306.

(*a*) *Inadequate section of soft wood sleepers.* Although it is shown in Appendix A that a 10″×5″ rectangular section is safe for the heaviest axle load imposed by an O. S. wagon even when a soft wood sleeper is used, yet it must not be forgotten that these calculations are based on an assumption that the sleeper load is uniformly spread over the whole bearing area, and the sleeper has a full depth of 5″. This is true when the sleeper is new and when the packing is on the whole in a good condition, but there are numerous occasions when such conditions do not obtain. In a run-down track the load gets transferred more towards the ends of the bearing area. The bending moments, the impact effect and consequently the stresses are considerably increased. It will be noticed that except in England (where the higher life figures are due to the use of heavy C. I. chairs with B. H. or D. H. rails) other important countries like America and Germany use deeper sleepers.

(*b*) *Inadequate treatment of soft wood sleepers.* The average consumption of the creosote oil mixture in the Dhilwan Depot—the only Depot in India where sleepers are impregnated—is from 3 to 5 lb. per c.ft. while the corresponding figures of absorption for America are about 6 to 8 lb. per c.ft. of wood. The author recommends the adoption of the American practice. Even though this proposal tends to increase the first cost, yet the improvement in the life figures will be out of all proportion to the additional initial cost.

(*c*) *Inadequate protection against mechanical wear and spike killing of wood.* One of the factors which affects adversely the life of a sleeper is the mechanical wear which takes place in the region of the rail seat. This is due to the use of relatively flexible bearing plates in the case of soft wood sleepers, and to the absence of the bearing plates in the case of sal sleepers. It may be argued that the safe crushing strengths (compressibility perpendicular to the grain) of sal and deodar are 505 lb. and 295 lb per sq. inches respectively, and that the bearing area af about 50 sq. inches of rail on the sleeper can, therefore, safely carry 6·6 tons, whereas it has been shown in Appendix 'A' that the maximum load carried by a sleeper under each rail does not exceed 6·5. tons. It is true that the bearing plates on the basis of this argument are not necessary even for the soft wood sleepers, but it is the mechanical destruction of the wood fibres by the abrasive or sawing action of the rail foot which is to be prevented. A bearing plate by providing a greater area over which this rubbing takes place considerably reduces this mechanical wear. Another advantage in using a bearing plate is that the cant of 1 in 20 for the rail can be provided for in the design of the plate, and the necessity of adzing the sleeper to provide this cant, whereby its effective depth is reduced, is obviated.

It is a well known fact that sleeper renewals are quite often proposed and carried out because dogspikes have lost their grip and become loose. Experienced engineers, however, try to remove this defect by driving wooden plugs and respiking or alternatively by treating spike holes with Cresswell or Fridera A Compounds. Such remedies are however mere palliatives and dogspikes get loose again.

It is most desirable from the point of view of safety, economy in maintenance and longer life of sleepers to adopt a fastening which gives a positive hold on the sleeper and not merely the frictional hold of a dogspike. A force of about 2,000 lb. is required to pull out a dogspike from a new soft wood sleeper and of about 3,500 lb. from a new hard wood sleeper. In course of time, due to the wave motion of the rail under traffic, the dogspike tends to rise by about one-eighth of an inch. It is then driven down by the keyman. This process frequently repeated destroys its grip. The loose grip of the dogspike causes the bearing plates to rattle which defect, besides making for a noisy road, accentuates the mechanical wear of the rail seat. In Great Britain, where a substantial cast iron chair with a felt pad between it and the sleeper is bolted to the sleeper, there can be practically no mechanical destruction of the rail seat. This explains why in spite of the treatment of sleeper being no better than it is in India, the life figures obtained there are higher than in this country.

The dogspike has been eliminated in the presented German State Railways' K Type track by substituting the coach screw for the dogspike, while the hole in the sleeper is provided with a screw plug. The use of C. I. anchor plates with round spikes on the N. W. Railway has also overcome to a great extent the trouble due to the loosening of dogspikes. For the same purpose, the G. I. P. Railway use fang bolts for securing their chairs to the sleepers in a D. H. or B. H. track. The experience of the coach screw in India was very unsatisfactory as the thread corroded rapidly and the thread in the wood sleeper also wore away. The coach screw then acted rather as a poor dogspike. Unless, therefore, the coach screws are galvanised before use and used with screw plugs as in Germany they are not likely to prove successful.

The only solution, therefore, appears to be to use bolts with the nuts at the top. The additional cost will be found to be fully justified on account of the longer life of sleepers and the reduced maintenance of track.

(*d*) *Defective system of sleeper renewals.* A referendum taken in 1926 disclosed that most of the major railways in India, such as the N. W. R., E.I.R., E. B. R., N. S. R., and the Jodhpur Railway carried out 'through' or 'programme' renewals of sleepers while other railways generally renewed their sleepers at random as and when each sleeper became unserviceable. The former method is very uneconomical as it stands in the way of the full life of a sleeper being obtained and is a potent cause of the wood sleeper falling in disrepute.

When spot or random renewals are carried out, the whole track remains at a uniform sleeper condition in so far as it always contains a certain small percentage of unserviceable sleepers. On the other hand with through renewals, a renewed length of track will, for some time, be below the standard of the adjoining settled track. After the sleepers have done about half their average life, the condition of the track generally begins to deteriorate till during the last few years of the life of the sleepers, the running is poor and maintenance more difficult. Every maintenance official from the ganger to the Engineer is then keen to have the sleepers renewed early. The tendency, therefore, is to inflate the percentage of unserviceable sleepers in the track and to propose renewals. In this the Engineer is helped by the fact that it is difficult to define exactly what an unserviceable sleeper is, different Engineers having different standards for it. Although proposals for the renewals are carefully scrutinized by the Chief Engineer, yet the author is aware of cases where the sleepers were renewed long before they had reached the end of their useful life.

Further, the serviceable sleepers released from the track in through renewals lose more than half of their residual life because of the punishment they receive in transit from one place to another where they are re-used. Also in the removal of the dogspikes and respiking subsequently at the new site, the wood fibres are damaged and the spike grip is considerably lost.

Mr. Salberg showed in an article published in the Quarterly Technical Bulletin that the cost of maintenance of the track is reduced by about 18 per cent if spot renewals replace the programme renewals.

At the second meeting of the Engineering Section of the I. R. C. A., the following conclusion was arrived at :—

> "Different methods of renewals are appropriate to different varieties of permanent way. There is a far greater variation in quality in wooden sleeper than in metal sleepers and while casual renewals may be necessary for the maintenance of a wooden road, programme renewals would be adopted for maintenance of uniform durability (as in the case of metal sleepers)."

The N. W. Railway introduced some years ago on certain sections the system of spot renewals as an experiment but it appears that for one reason or the other, they have now abolished this system. It may be mentioned that in America, which has achieved the highest life figure for its wood sleepers, spot renewals are almost exclusively adopted.

4. Recommendations for improving the economic order of the wood sleepers. For raising the economic order of the wood sleepers, it is necessary to devise ways and means for increasing their life and for reducing their initial cost. In the preceding section, different ways of increasing the life of sleepers have been described.

Suggestions for reducing the first cost of wood sleepers are the following :—

(a) *Relaxation of the existing sleeper specifications.* The sleeper specifications in this country are more strict than in many other countries both with regard to the use of a boxed heart and to the sapwood content. Even hardwood sleepers like sal are not accepted with a boxed heart.

In American practice, the average sleeper is merely a pole of small diameter hewn or sawn on all four sides to a 9″×7″ or a 9″×6″ section with heart in the centre. It is for this reason that wood sleepers in America cost much less than those in India where the labour is comparatively much cheaper. The price of a sleeper depends mainly on the cost of the labour involved in felling, shaping, sawing and carriage charges.

In Germany, sleepers with boxed heart are freely used. A wane of 2″ is also permitted at each corner.

If boxed heart is permitted in hardwood sleepers, deeper sections can be used without any increase in the initial cost. The useful life of the sleepers will, however, be considerably increased thereby.

The result of restriction of sapwood content is that only trees of large girth have been used in the past for making sleepers. Such trees are now in short supply and price of the sleepers must naturally increase. Unlike the soft wood which may have a thickness of 4″ of sapwood, the thickness of the sapwood ring in a sal log of 12″ diameter is about 1″. An untrimmed half round sleeper obtained from such a log can only have about 30 per cent of sapwood. Sleepers from larger logs slabbed at the top and trimmed on the side would have even a smaller percentage. It will, of course, be necessary to treat such sleepers before use but cost of such treatment will be small as the sapwood in sal absorbs the preservative readily though the heartwood is almost impervious to it. This is due to the ducts in the heartwood being clogged with resins and internal cell growths. The present restrictive specifications regarding sapwood content in sal, teak and deodar involve a considerable waste of timber which factor alone puts up the cost considerably.

(*b*) *Use of other species of wood hitherto not used.* Except in the forests of Himalayas, which abound in conifers, practically all the indigenous timbers are hardwoods but so far only a very few species, such as sal and teak, have mainly been used for sleepers. Hardwoods like laurel, yon (Anogeissus accuminate), hollong, irul, ping should provide first class sleepers.

(*c*) *Use of half round sleepers of sal, teak and chir, etc.* The chief reasons in favour of encouraging the use of half rounds are the following :—

(*i*) The reduced bearing width of a half round reduces the rocking of the sleeper on its packing. The large base width increases its stability.

(*ii*) The increased base width reduces the pressure per sq. ft. on the ballast below, hence failure of the ballast is prevented. Cheaper grades of ballast can, therefore, be safely used.

(*iii*) The shape of the sleeper enables small spacing to be adopted without creating any difficulty for packing. (See Section 6 Chapter II).

(*iv*) By using half rounds the cost of sawing is considerably reduced. The number of sleepers that will become available by permitting the use of half rounds will increase by 25 per cent to 50 per cent.

(*v*) Timber which cannot provide square sawn sleepers can be utilised for providing half rounds.

(*d*) *Standardisation of two to three different standard sections of sleepers for any particular gauge.* This step will have two chief advantages :—

(*i*) It will enable the Railways to select sleepers to meet the different conditions of track, the varying sources of supply and the quality of timbers.

To illustrate, wider and deeper sleepers can be used at the rail joints, in points and crossings and where the road bed is weak. For weaker varieties of soft wood, a deeper timber, although more expensive in the first cost will, in the long run, be more economical because of its longer life. To use the same section of sleeper for species of wood which vary so widely in strength as for example, sal and fir, is not scientific.

(*ii*) This step will provide a great facility to the timber merchant as it will enable him to cut from a log, sleepers of different standard sections when he cannot obtain sleepers of one standard section. There will, therefore, be less wastage of timber and sleeper prices will tend to fall.

(*e*) *Accelerated seasoning and expedition and care in handling sleepers.* The chief points in this connection are the following :—

(*i*) Steps should be taken that sleepers should be brought to the plains within as short a time as possible after cutting the logs into sleepers. This will prevent degrade in wood and infection from fungi and rot.

(*ii*) The possibility of introducing accelerated seasoning by the use of drying kilns having steam heat should be explored. At present sleepers are air-seasoned for some six months by stacking them on the one-by-nine system in covered sheds. By accelerated seasoning, the danger of degrade in wood will be mitigated and the long delay between the reception of sleepers in the depot and their treatment will be avoided. This will reduce the interest on the capital locked up.

(*iii*) More care should be taken in handling sleepers during loading and unloading from trucks so as to avoid injury to them.

(*iv*) More clamps should be used at the ends of sleepers to prevent end splitting. Ratee patent and Stuart patent clamps are quite suitable for this purpose.

CHAPTER V.

Economic considerations.

1. The annual cost of a sleeper. In deciding upon the best type of a sleeper, prejudice should play no part. The relative merits of any two sleepers should be determined purely from economic considerations based on their initial prices and on their probable lives in the track under identical conditions of service. For this purpose, it is necessary to find a common criterion for all and the most convenient form of this is to determine the "Annual cost of a sleeper."

The annual cost of a sleeper is now understood to mean the sum of the following three charges :—

(*a*) Interest charges on the first cost of a sleeper which includes besides its price the cost of its treatment (if any) and of its fastenings; freight and labour charges for transporting to and handling it at the site and the cost of laying it in the track. The rate of interest should be the rate at which money is available in the market.

(*b*) *Depreciation charges.* This represents the amount which funded annually will produce at the end of the anticipated life of the sleeper, an amount equal to the cost of the replacement of the sleeper. The cost of replacement of a sleeper is the first cost of a sleeper less its scrap value after it has been removed from the track at the end of its useful life.

(*c*) *Maintenance charges.* This equals the amount spent on the sleeper in maintaining it in the track.

Thus $A = I + D + M$,

where A = Annual cost of a sleeper.

I = Interest charges.

D = Depreciation charges.

M = Maintenance charges.

Now it is easy to prove that

$I = cr$

and $D = \dfrac{r(c-s)}{(1+r)^{n-1}}$,

When c = Total first cost of a sleeper as explained in (*a*) above.

s = Scrap value of the sleeper

r = Rate of interest per annum at which money can be borrowed.

n = Anticipated life of the sleeper, in years.

From the above it is clear that

$$A = cr + \frac{r(c-s)}{(1+r)^{n-1}} + M$$

2. Probable life of sleepers and their fittings. This is a vexed question and one in which prejudice frequently plays an important part. The following figures of life are given by the N. W. Railway :—

	Type of sleeper	*1937*	*1943*
(*a*)	C. I. Plate	45	30
(*b*)	Steel trough	37	45
(*c*)	Treated chir	19	16
(*d*)	Treated deodar	21	18
(*e*)	Tie bars and bearing plates keys and gibs	45	30
(*f*)	Dogspikes and cotters	30	30
(*g*)	Round spikes	39	30

3. Cost of sleeper renewals. On the E. I. Railway in 1937, the cost of resleepering with wood or metal sleepers was stated to be Rs.3,160 per mile with 2,200 sleepers per mile. This includes freight on sleepers and fittings from the depot, labour, and all charges incurred while resleepering. Fifty per cent of the above cost of sleepering may be assumed to remain constant, the remaining 50 per cent will be increased or reduced proportionately with the number of sleepers used per mile. Thus with 2,500 sleepers per mile, the cost of sleepering may be assumed to be equal to $\frac{3160}{2} + \frac{3160}{2} \times \frac{2500}{2200} = 3375$ Rs.

On the North Western Railway in 1937, the cost of sleeper renewals with wood and steel trough sleepers was stated to be annas eight per sleeper and for C. S. T. 9 sleepers annas nine per sleeper. These figures do not include freight charges but provide annas two per sleeper on account of traffic restriction charges.

4. The cost of maintenance of a sleeper in track. On the basis of the information supplied by the E. I. Railway in 1937, the cost of maintenance was Rs.360 per mile of track laid with 2,200 sleepers of C. S. T. 9 and Rs.333 per mile of track with a similar number of wood or steel trough sleepers. If the number of sleepers per mile is altered, it is safe to assume that 50 per cent of the above figure remains constant as representing the maintenance of joints and the remaining 50 per cent to be varied in direct proportion to the number of sleepers as illustrated in the preceding section. The annual maintenance per sleeper works out as follows :—

(*a*) Wood or steel trough sleeper 0·1514 rupee per sleeper

(*b*) C. S. T. 9 plate sleeper 0·1636 ,, ,, ,, The N. W. Railway figures for maintenance costs based on their job analysis in 1937 were the following :—

(*a*) Wood or steel trough sleeper 0·1631 rupee per sleeper

(*b*) C. S. T. 9 plate sleeper 0·1762 ,, ,, ,,

5. Analysis of the first cost of different types of sleepers. For comparison of the annual cost of different types of sleepers, the life figures given in section 2 for 1937 and the then prevailing prices will be adopted :—

(*a*) Chir wood sleeper with anchor bearing plates :—

(*i*) Sleeper (Life 19 years)

	Rs.	as.	p.
(1) Initial cost including inspection, treatment, handling, freight and renewal charges. ...	6	2	0
(2) Scrap value ...	0	8	0
Net cost of replacement ...	5	10	0

(*ii*) Anchor plate and key (Life 45 years)

	Rs.	as.	p.
(1) Cost of two anchor plates and two keys ...	2	8	0
(2) Scrap value ...	0	1	0
Net cost of replacement ...	1	8	0

(*iii*) Four round spikes (Life 39 years)

	Rs.	as.	p.
(1) First cost ...	0	8	3
(2) Scrap value ...	0	1	0
Net cost of replacement ...	0	7	3

(*b*) C. S. T. 9 sleeper (Life 45 years)

	Rs.	as.	p.
(1) Total first cost including cost of keys, cotters and renewal charges and cost of extra and finer ballast ...	11	9	0
(2) Scrap value ...	3	7	0
Net cost of replacement ...	8	2	0

Note.—For simplifying calculations, the life of cotters and key has been assumed to be 45 years.

(*c*) Steel trough sleepers (Life 37 years)

	Rs.	as.	p.
(1) Total first cost including cost of all fittings, renewal and freight charges and cost of additional and finer ballast ...	12	11	0
(2) Scrap value ...	3	6	0
Net cost of replacement ...	8	5	0

6. **Annual costs of different types of sleepers.** In the following calculations a rate of interest of five per cent per annum has been taken. The margin in favour of the C. S. T. 9 sleeper will, however, tend to increase if the rate of interest falls to a lower figure :—

(*a*) Chir wood sleeper.

		Rs.
(*i*)	Five per cent interest on first cost Rs.6-2-0 ...	·3062
(*ii*)	Depreciation on net cost of replacement of Rs.5-10-0 (Life 19 years) ...	·1840
(*iii*)	Annual maintenance ...	·1631
(*iv*)	Five per cent interest on first cost of anchor plates ...	·1250
(*v*)	Depreciation on net cost of replacement of Rs.1-8-0 ..	·0094
(*vi*)	Five per cent interest on first cost of round spikes ...	·0258
(*vii*)	Depreciation on cost of replacement (Life 39 years) ...	·0040
		·8175

(*b*) C. S. T. 9 sleeper.

(*i*)	Five per cent interest on first cost of Rs.11-9-0 ...	·5781
(*ii*)	Depreciation on cost of replacement of Rs.3-2-0 (Life 45 years) ..	·0513
(*iii*)	Annual maintenance ...	·1762
		·8056

(*c*) Steel trough sleeper.

(*i*)	Five per cent interest on first cost of Rs.12-11-0 ...	·6344
(*ii*)	Depreciation on cost of replacement of Rs.9-5-0 (Life 37 years) ...	·0894
(*iii*)	Annual maintenance ...	·1631
		·8869

Note.—A life of 19 years has been assumed for a chir sleeper with anchor plates although this figure is based on observations of chir sleepers with ordinary bearing plates and dog-spikes. There are strong reasons to believe that the sleepers laid with anchor plates and steel keys will have a longer life.

From the above figures, it is easy to conclude that on the N. W. Railway in 1937, the C. S. T. 9 sleeper was the most economical; the wood sleeper came next and the steel trough sleeper was the last on the list. If life figures given in 1943 are adopted for comparing the annual costs of sleepers, the steel trough sleepers will head the list, the wood sleeper second and the cast iron will be the last. This fact shows how vitally can the average life figures swing the balance in favour of one type of a sleeper and against another.

CHAPTER VI.

Conclusions.

About half the track mileage on Indian Railways, at present, is laid with metal sleepers, the remaining being laid with wood sleepers. The present day tendency appears to favour the metal sleeper. In India, the use of the metal sleeper has been advocated from considerations of economics and on account of the non-availability of the required number of wood sleepers of the required quality. The author is inclined to the view that both these considerations fail to do full justice to the wood sleeper.

In the first place, the forests of India can supply all the wood sleepers provided an organised effort is made to develop the use of new species of timber. The specifications should be relaxed and better life obtained by a more rational use of the sleepers as indicated in Chapter IV. The sceptics will do well to read Railway Board Technical Papers No. 253, 269, 279 and 306, which will convince them that the timber resources of Indian forests have not yet been fully developed. Unfortunately, the timber industry in India is not organised and there is no Association in India like the Wood Preservers Association of America so that the case of the wood sleepers suffers by default.

Secondly, the justification of the metal sleeper from considerations of economics is of a doubtful nature. Calculations based on assumptions of the capital cost, cost of maintenance and renewals, probable average life and rate of interest on the capital cost are used to prove this contention. Such calculations are, more often than not, of little value as the data usually assumed are based on prejudice in favour of one type of sleeper or the other, with the object of justifying a preconceived conclusion. Statistics can be made to lie.

To illustrate, it is usually supposed that metal sleepers have a useful life of 35 to 50 years. As a matter of fact, D. and O. plate sleeper is the only C. I. sleeper, which has been known to give a life exceeding fifty years. Recent calculations made on the N. W. Railway go to show that the C. I. plate sleeper of N. W. R. type has an average life of 18·8 years. In Chapter V, calculations based on a life figure of 45 years for the cast iron C. S. T. 9 sleeper showed that this was the best sleeper from the consideration of its annual cost but this sleeper has recently been designed and it is difficult to predict its probable life in the track. If its life were to be taken as equal to that of the C. I. plate sleeper of the

N. W. Railway type, it will not be able to compete with the wood or the steel trough sleepers.

Further in the first quarter of this century, the traffic requirements of the Indian Railways developed so rapidly that the metal sleepers then in the track became obsolete for use in the main line before they had completed even half their assumed life. They had, then, to be relegated to branch lines for secondary tracks. The design of the metal sleeper was in the experimental stage and numerous designs were got out, tried out in the track and discarded. The recent and more successful types of metal sleepers have not long been in use. These facts have been mentioned to indicate that the calculations of annual cost are based on a very slender evidence in the case of the metal sleepers.

The popularity of any particular type of sleeper seemed to have changed rapidly during the last ten or twelve years. In 1930, for example, the important Indian Railways were asked as to which sleeper they would prefer for a high speed track if the cost of sleepers of all types varied between 10 per cent. With the exception of the Nizam State Railway, all Railways voted in favour of the wood sleeper. At this time, the steel trough sleeper was the last on the list. In 1935, the Engineering Section of the Indian Railway Conference Association again discussed the running qualities combined with the economic efficiency of the various types of sleepers. All Railways were practically unanimous that steel-trough sleeper gave the best running. All except the G. I. P. Railway, which favoured the L. K. type of C. I. sleepers agreed that steel trough sleeper required the least attention. Four railways, namely the B. B. and C. I., N. S., S. I. Railways preferred the steel sleeper for economic reasons also but the E. I. and the G. I. P. Railway considered that the C. I. plate sleepers were the most economical. Unfortunately, no referendum has since been taken from the Indian Railways but the author feels confident that if the Railways had been asked to indicate their preference in 1939, before the War started, they would have almost unanimously shown their preference for the C. I. plate C. S. T. 9 sleepers and the steel trough sleeper would probably have occupied the second place.

The reason for this rapid change of opinion becomes obvious if one studies the history of the development of the different types of sleepers. The wood sleeper has come down to us almost unchanged from the time the first rail was laid in India. In the beginning good wood for sleepers was plenty in the Indian forests and without any planning the best trees were cut into sleepers till trees of large girth were almost exhausted. The average life of the wood sleeper began to decline gradually and the prices began to rise. Instead of developing the untapped sources of the Indian forests to the full extent and organising the timber industry in India, attention was diverted from the wood sleepers to the metal sleepers. During the last fifteen years much labour, ingenuity and money have been spent in evolving suitable types of steel and cast iron sleepers and luckily the efforts have borne fruit. The steel trough sleeper was the first among the metal sleepers to be developed and to achieve success. The C. S. T. 9 cast iron sleeper was evolved after many years of experimental work; it was, therefore, the last to receive recognition. What is going to be the best sleeper of the morrow? Who can tell! The author, however, believes that if some of the suggestions given in Chapter IV for improving the wood sleepers are adopted, the wood sleeper may come back to its own again.

In conclusion, the author wishes to make it clear that he recognises no general or universal superiority of any particular type of sleeper (timber, cast iron or steel) but advocates the use of a sleeper which is superior to others on account of its technical suitability to local conditions and of its financial advantage based on its probable life in the track and on its initial cost.

APPENDIX A

Calculation of stresses in a B. G. wood sleeper under load. Assume a track with 36 ft. 90 lb./R rails and N+3 sleepers per rail. The intermediate sleeper spacing, 'S', with this sleepering is 32″ on the N. W. R., 33″ on the E. I. R., and $30\frac{1}{2}$″ on the G. I. P. Assume 'S' = 32″ for purposes of this calculation. Assume $u = 1{,}000$. This is a reasonable figure for this type of track with N+3 sleepers.

Among the locos, the heaviest are the XE or XS engines but it can be shown that the standard O. S. goods wagon with an axle load of 22·5 tons now in use on the E. I. Railway is a severer load than that due to the heaviest locomotive.

With the notation adopted in the Railway Board's Technical Paper No. 245

Wheel load = 2 P $\therefore$ P = $\frac{45}{8}$ tons

$$\beta = \sqrt[4]{\frac{u}{4\,E\,I}} = \sqrt[4]{\frac{1000}{4 \times 13{,}400 \times 38{\cdot}45 \times 2{,}240}}$$
$$= {\cdot}0215$$
$$I = 38{\cdot}45 \text{ for 90 lb. R rail}$$
$$\triangle = \frac{P\,\beta}{u} = \frac{45 \times 2240 \times {\cdot}0215}{8 \times 1{,}000} = 0{\cdot}27''$$

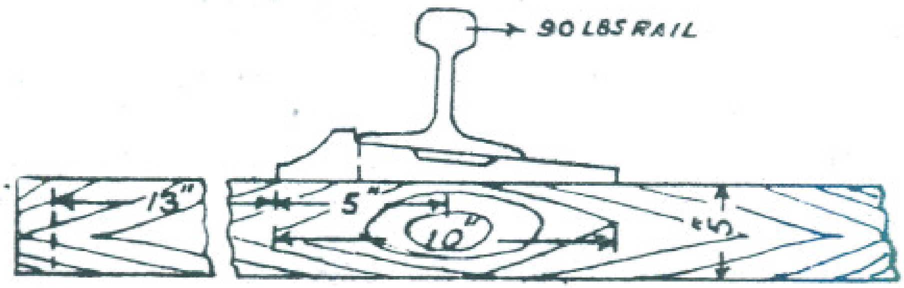
Load carried by a sleeper under each rail without impact

$$= u\,S\triangle = 1000 \times 32 \times 0{\cdot}27$$
$$= 8640 \text{ lb.}$$

Assuming that the load is distributed over 18″ on either side of the centre of the rail seat, the load per inch length of the sleeper $= \frac{8640}{36} = 240$ lb.

Max bending moment at the edge of the bearing plate

$= 240 \times 13 \times \frac{13}{2} = 20,280$ lb.



Section Modulus of the sleeper $= \frac{bd^2}{6} = \frac{10 \times 25}{6} = 41{\cdot}6$ in^3

Stress under a static load $= \frac{20280}{41{\cdot}6} = 488$ lb. psi

O. S. wagon being a goods wagon, its maximum speed V is not likely to exceed 40 m. p. h. Impact factor for O. S. wagon with tracks heavier than $88\frac{1}{2}$ lb. $= 0{\cdot}24 + 0{\cdot}007$ V (*vide* P 31 of the Track Stress Research by Gelson and Blackwood).

Impact factor $(V=40) = {\cdot}24 + {\cdot}007 \times 40 = 0{\cdot}52$

Maximum fibre stress in a sleeper after allowing for impact load $= 1{\cdot}52 \times 418 = 742$ lb. psi.

This is quite safe even for soft wood sleepers.

The safe stress figures for common species of timbers used in sleepers may be safely assumed as follows:—

Name of wood.	Extreme fibre stress lb. per sq. in. Tension.	Compression.
Sal	1990	1560
Teak	1590	1240
Pynkado	2220	1780
Chir	1000	810
Fir	1110	820
Deodar	1240	990

Sal sleepers are used without bearing plates but as their safe stress figures are very much higher than those of soft wood sleepers, they are adequately strong for the heaviest load.

APPENDIX 'B'

Calculation of the strength of the Standard B. G. Steel Trough Sleeper. Consider the standard steel trough sleeper for 90 R rail under the heaviest load due to an O. S. wagon with an axle load of $22\frac{1}{2}$ tons as was assumed in Appendix A for wood sleepers.

With N+3 steel trough sleepers *u*, the track modulus may be safely assumed to be 1500.

It can be easily shown that the load carried by a sleeper is directly proportional to the fourth root of the moduli of the track in which it is laid.

Load carried by a wood sleeper without impact.
(u=1000)=8640 lb. (vide Appendix 'A').
Wth u =1500, the corresponding load

$$=8640\times\sqrt[4]{\frac{1500}{1000}}=8640\times1\cdot107=9564\text{ lb.}$$

Including impact the load at each rail seat $=9564\times1\cdot52$
$=14538$ lb.
$=6\cdot5$ tons.

Assuming that the load is uniformly distributed over a width of 18″ on either side, of the centre of the rail (width of rail foot=5·4″), the load per inch length $=\frac{6\cdot5}{36}=\cdot18$ ton

Max^m B. M. at edge of rail $=\cdot18\times15\cdot3\times\frac{15\cdot3}{2}$
$=21$ in/ton.

Section moduli of the standard S. T. sleeper are as follows :—

$Z_c=6\cdot15\text{ in}^3$

$Z_t=2\cdot40\text{ in}^3$

Moment of inertia at the rail seat $=6\cdot05\text{ in}^4$

Stress in tension $=\frac{21}{2\cdot4}=8\cdot75$ tons psi

,, ,, compression $=\frac{21}{6\cdot15}=3\cdot4$ tons psi

As the steel used has a tensile of 28 to 33 tons, the maximum permissible stress is 9 tons psi.

It is now proposed to compare the strength and stiffness of the standard S. T. sleeper and the wood sleeper of 10″×5″.

For comparison of stiffness, the products of the moment of inertia and the moduli of elasticity of the two types of sleepers should be compared and for comparison of strengths, their moments of resistance.