

PRESTRESSED REINFORCED CONCRETE RAILWAY TIES
FOR INDIAN RAILWAYS

by

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SURENDRA KESHAV MANGALMURTI¹

SYNOPSIS

The dearth of good and cheap timber and the prohibitive cost of steel and cast iron ties necessitate the search for a substitute railway tie. Presently, prestressed reinforced concrete, with its numerous advantages over the ordinary concrete, promises a suitable material for this purpose. The vibrated concrete, the air-entrained concrete, and the comparatively recent advancements in prestressed concrete and the prestressing techniques, have given an impetus to the concrete tie business.

The discussion presents an analysis of the loads acting on the tie, the selection of a proposed section and the stress analysis for it. The discussion includes a review of other current ties and the prestressed ties in use and under investigation. The loading used here is the broad gauge main line loading. The actual design of a tie, which can finally be adopted for track will have to be evolved after various tests and after installing these in a portion of existing track and testing the performance. For Indian conditions, the prestressed ties appear to be the ideal crossties, considering their long life and economy.

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INTRODUCTION

A railway track consists of rails, crossties, rail fastenings, and ballast resting on the foundation. The crosstie is a very important constituent of a railroad track.

India has been served by railways for more than a hundred years. The first section of a railway line constructed in India was that of 21 miles between Bombay and Thana. The maiden trip was made on April 16, 1853. Then the railways were owned by private companies. Presently all the railways in India, including those which were owned by some of the former Princely States, are now State-owned railways. (1)

The Indian railway system with a route mileage of 35,395, is the second largest individual network in the world and the biggest national undertaking in the country. More than 4.4 million persons and 0.4 million tons of goods were carried, on an average, by the railways daily in 1960-61. The capital-at-charge of the railways, at the end of 1960-61, stood at \$3,195 million and the gross earnings at \$960 million. They employed 1,166,482 persons and paid \$430 million in wages and salaries. (2)

Railway extensions are going on in full swing. Railways are the most important means of transport in India for passengers as well as goods traffic, and play a major role in the developing of the economy of India.

Compared with a highway, a railway is subjected to very heavy concentrated loads in the form of a heavy locomotive, and a chain of

heavily loaded vehicles moving at a great speed. The track, therefore, must be very strong from the foundation to the top and must be continually maintained in efficient condition. The quality of track virtually determines the limits on the loads to be carried and the speed at which the train should travel.

The cross-tie plays an important part in the performance and economy of a railway track. The Ministry of Railways, Government of India, has appointed a director to examine the proposal for the use of reinforced concrete ties and to prepare a project report for their mass production. This project is being considered as the wooden ties are in short supply and last only for about fifteen years, whereas the concrete ties have a life of 40 to 50 years. (3)

THE RAILWAY TRACK

A track consists of rails, ties, rail-fastenings, and ballast resting on the formation or roadbed.

Formation is either made of earthwork, on which are laid ballast (stone metal), cross-ties, and rails with their fastenings as shown in Figure 1. The formation supplies a firm foundation to the track and serves to distribute the load on a larger area so as to bring the stresses caused within the limits of bearing power of the soil below.

Ballast in tracks is in the form of a layer of broken stone, or other suitable material, under and around the ties, for distributing the load from the ties to the formation. Ballast provides a suitable foundation for the ties and also holds the ties in their

correct position, preventing the displacement due to the longitudinal or the lateral thrusts. The lateral stability of a track depends on the ballast. (4, 5)

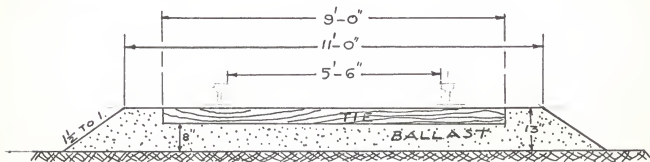


Figure 1. Section of a single B.G. track.

Figure 1 vividly brings out the details of a broad gauge single track, which emphasizes that the cross-tie is verily the life-breath of a track.

TIES

Ties came into existence in the form of stone slabs or longitudinal timber baulks laid under the rails. These were soon discarded as they made running rough and noisy. Longitudinal ties were extremely costly and also additional cross-timber was necessary to hold the two longitudinal ties in position. The cross-ties which were first introduced in 1835, are now universally used. (4)

Rails in a railway track need support and the greater the support, the lower are the stresses induced in the rails. The parallel pair of rails forming the track have to be maintained at the correct gauge, and this is done by the ties.

The position or alignment, surface, level and gauge of the railway track are constantly disturbed by the passage of vehicles and the track has to be constantly adjusted. A tie has to be so designed as to counteract these tendencies. The tie should have sufficient rail bearing area to prevent the rail from crushing it at the rail seat or cutting the rail seat along either edges at the rail foot, causing tilting. The tie should have sufficient strength and rigidity, so that it could be economically spaced.

The ties should be durable, i.e., they should be physically stable, chemically inert, weather resistant and not vulnerable to the fungi or termites attack.

Preferably the ties should be such that no special insulation is necessary.

Crossties have been made out of wood, steel, cast-iron, and recently of concrete and prestressed concrete.

The wooden tie has been used successfully throughout the world for very many years. G. M. Magee (6) has stated that the wooden crosstie is in many respects ideal for the service it performs and it is extremely difficult to develop a design of concrete tie which will equal the prevalent wooden tie in first cost and service performance. The standard Indian section for a broad gauge tie is 10 in by 5 in. (7) This tie is 9 feet long as shown in Figure 2.

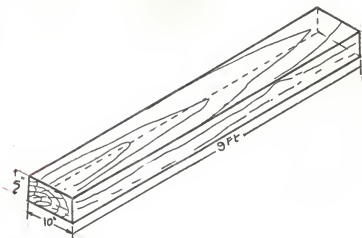


Figure 2. Isometric view of a broad gauge wooden tie.

As the number of ties required is enormous and as timber is becoming scarce, ties of other materials are being used increasingly in almost all countries and particularly in India. India uses metal ties more than any other country. Out of the thousands of miles of rails a major portion is laid on the cast iron ties. A steel tie in India takes the shape of an inverted trough, as shown in Figure 3. In the United States of America, the steel 'I' beam has become popular and rails are held to it by bolts and clips. (4)

Cast iron ties are very extensively used in India and on a small scale in South America. Cast iron ties are made in two shapes, the pot and the plate. Figure 4 shows an oval cast iron tie. Figure 5, shows the C.S.T. 9. plate type cast iron tie and the rail free duplex tie which has been used at rail joints in conjunction with the C.S.T. 9. ties.

Concrete ties

Various types of reinforced and prestressed concrete ties have been developed during the last score of years in Europe.

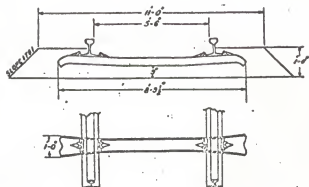


Figure 3. A steel tie.

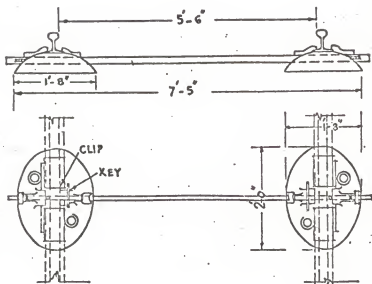


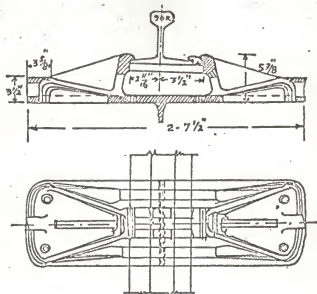
Figure 4. An oval cast iron tie.

Experiments are being carried out on these both in the U.S.A. and in India. (4, 5) Their popularity, despite initial setbacks, is increasing for various reasons. Concrete ties have a long life, the normal expectancy being 40 to 50 years, hence they can compete well with the wooden ones, their closest rivals, in price as wooden ties are expected to last only for 15 to 20 years.

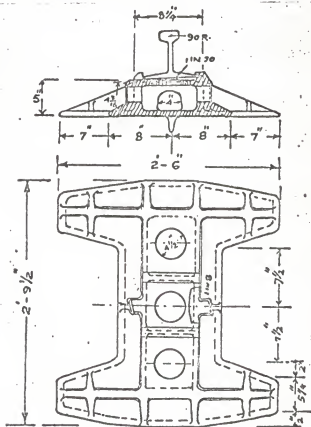
After World War I, many railroads were destroyed or needed extensive repairs. Wood for ties was scarce and very expensive. This gave an impetus to the production of concrete ties. (5) It was actually after the World War II that the concrete ties became popular.

Concrete ties are heavy. Their greater weight, which gives the rails stronger and more stable base saves on wear and maintenance, so also helps in minimizing joint maintenance by using long welded rails. (6) The added weight enables the rails to resist effectively forces caused by expansion (due to changes in temperature) which tend to buckle the track. (4)

The concrete cross-ties are made of a strong homogeneous material, which is almost impervious to water and is not affected appreciably by the chemical attack of subsoil salts and the atmospheric gases dissolved in the rain water. (4) A major atmospheric agent which tends to destroy a tie is snow and frost. This agency needs special attention in some western countries where there is always a danger of deterioration of a tie by freezing and thawing. In India, in her monsoon climate, usually no snow and



C.S.T. 9, plate type cast iron tie



Rail free duplex tie

Figure 5

frost is encountered, except in a few places like Simla, Darjeeling, Jammu-Kashmir and in Himalayan ranges.

A concrete tie can be molded easily to size and shape required by scientific investigation, to withstand the stresses induced by the fast moving and heavy traffic.

K. F. Antia (4) has stated that the weight of a concrete tie is 2.5 to 3.5 times the weight of a wooden tie, and the elastic support given by it to the rails is proportionately greater and hence, the elastic modulus, which is a measure of the rigidity of the track, is much higher for a concrete tie track than that for the wooden or metal tie track.

In Europe it is believed and to some extent proved, that during a war, tracks on concrete ties do not need replacement as quickly as tracks on wooden ties. (5) They are not damaged easily because they do not burn. A concrete tie track provides greater stability during floods.

The concrete ties suffer from a few shortcomings. They are likely to be crushed under heavy blows and vibrations. They are very heavy and cumbersome, whence their handling and placement is more difficult. Concrete ties do not have any salvage value. These ties are damaged most when the wheels are derailed.

Concrete ties are broadly divided in two types, the reinforced and the prestressed concrete types. The first type has been successfully used in France, Belgium and Netherlands, while Germany, England and the U.S.A. are using the latter type.

There are two kinds of reinforced concrete ties. The through type and the composite block and tie type. The through type is seldom used as, when this tie is stressed, cracks on the tension side are inevitable, which tend to enlarge with repeated impact loading of fast trains and ultimately lead to disintegration of concrete and failure of tie occurs. (4) The composite or block and tie type of crosstie is not subjected to the same degree of tensile stress and has given excellent results in various countries. (4) France, for many years, has been the leader in the development of concrete railroad ties. The first successful units, the Vagneaux ties, were two concrete blocks joined with an "I"-shaped tie bar of mild steel. (5) More than a million of these were made between 1922 and 1934, and many are still in use in France and North Africa. (5) The R.S. tie, named after Roger Sonneville, was then developed, which is made of two concrete blocks each approximately twelve inches by nine inches in section and 29 inches long, linked by an inverted Y-shaped, high-carbon steel bar, as shown in Figure 6.

Belgium also found reinforced concrete ties practical and economical. They have developed the Franki-Bagon tie, which consists of two reinforced end blocks carrying the tie plates and rails, a reinforced concrete cross member and the end blocks. These flexible slabs have a compressive strength of approximately 20,000 p.s.i. and a low modulus of elasticity of about 400,000 p.s.i.

(5)

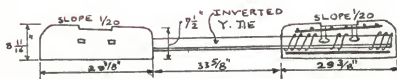


Figure 6. A composite tie, as used in France.

In Netherlands, the Patent Van den Heuvel ties are being used. These are based on the French R.S. tie. The Patent Van den Heuvel has two concrete blocks connected with three steel reinforcing bars.

(5)

As concrete is weak in tension, reinforced concrete ties begin to develop cracks even at ordinary working stresses the tensile stress in steel is only 18,000 p.s.i. It is true that these cracks are minute, and according to some are not harmful. A 0.01 inch gap at least is necessary before the reinforcement will be corroded by moisture changes, while the cracks developed at working stresses are very small. (7) R. S. V. Barber (8) has stated about the formation of minute cracks, that it is harmful in cases of ties as the heavy and repeated loads will cause these cracks to widen and finally to destroy the bond between the steel reinforcement and the concrete, and this action of damage is accelerated by the action of rain and frost. However, it is possible to avoid the cracks altogether and thus secure sound concrete in the tensile zone by prestressing.

When the concrete tie is manufactured the steel reinforcement is first subjected to a high tensile stress, and this stress is afterward utilized to induce in the concrete compressive stresses which will be directly opposite to the tensile stresses produced by the external forces imposed on the tie. (9)

Prestressing a tie not only renders it crack-free, but also reduces the amount of concrete and steel to be used. High grade cement and high tensile steel can be used economically as the full utilization of their higher strengths is made by the prestressing

process. If the beam ties were made with mild steel reinforcement, 65 lb. of steel would be required for a four inch by ten inch tie, while for a prestressed tie only 25 to 30 lb. of steel is required, which is indeed a big saving. It should also be noted that in case of prestressed concrete, the steel and the concrete react under load conditions instantaneously together, and a true homogeneous and elastic material is obtained. (9)

The vibrated concrete, the air-entrained concrete, and the comparatively recent advancements in prestressed concrete and its prestressing techniques, have given an impetus to the prestressed concrete tie business.

The prestressed ties are of stiff beam type. These are made in one piece, moreover they look like the wooden ties. These have been used in Germany, Great Britain and now are being tried in the United States. (10) Though the economy of Germany and Great Britain needs prestressed ties, in the United States wooden ones being cheaper, the prestressed ones have not been used in the actual track. In the United States, exhaustive research is being done under the auspices of the Association of American Railroads. (11) Also the actual installation on Western Pacific has revealed many favorable features. These promise to include greater track stability, lower track maintenance cost, longer life and others. (12)

Many designs and patent methods of manufacture of prestressed concrete ties have been devised in Europe. These have now crystallized in the following three types:

i) Type one is based on the post-tensioning system, whereas the other two are based on the pre-tensioning system. In the first type the ties are usually cored. The cores are placed near the center of gravity of the concrete section of the tie. In most cases, the bars with the threads rolled on the bars at both ends, are covered with asphalt or like material. This prevents corrosion and bond with the concrete. At one end of the bar, a threaded anchor plate is screwed. The bars are usually placed in cores and are secured on the other side by an anchor plate without thread, a washer and a nut.

Usually the bars are placed in the molds before filling and vibrating. The diameter of the bars is from $5/8$ inch to $3/4$ inch. After the concrete has hardened sufficiently, the reinforcement is stressed by jack and the nuts tightened. To eliminate the effect of shrinkage of the cured concrete and the creep in steel, the reinforcement can be stressed again after six weeks. The holes of the anchors are grouted with mortar or asphalt.

This is known as the Karig reinforcement, the advantage in this is that the reinforcement is dependable and the control on the amount of stress is possible. This system has the disadvantage that big pieces can break out, when hit by a derailed wheel. Loss of tension in the bars results and makes the ties useless. This may be prevented to some extent by additional mild steel reinforcement, which may increase its cost. It is possible to change non-bond system into a bond system by using unprotected steel and grouting the cores after the second stressing with cement mortar.

For mainline ties, two bar reinforcement is used; for light traffic, reinforcement may consist of only one bar of $3/4$ inch to $7/8$ inch in diameter.

Also a special German system of making the B 53 tie (and also the B 55 tie) consists of anchoring the rod reinforcement at both ends with mechanically upset heads in two anchor plates which have become bonded in the concrete. The rods are tensioned against the molds and released right after steam curing. (5) The rods are coated with a 0.04 inch thick layer of asphalt to prevent bond.

(ii) In the second type, the reinforcement is of $1/2$ inch to $5/8$ inch diameter bars of ribbed spring steel, usually four in number. The bars are anchored to the mold and stressed, then the concrete is poured and vibrated. Usually the concrete is no-slump concrete. When the concrete attains a compressive strength of at least 6500 p.s.i. the anchors are released and the molds taken off.

As before, there could occur loss in pre-stress due to creep and shrinkage, so the initial stress should be 16 to 18 percent more than the calculated stress to account for these losses.

The advantages in this type are, stressing is simple, no second stressing is necessary and as there exists bond no great damage is done when hit by a wheel. Also when damaged, undamaged parts are still under compression as the concrete is bonded to the ribbed steel and is not isolated from the tie. After an accident such tie can still be used for some time.

A disadvantage is that there is no control over the ultimate stress in the bars.

(iii) In the third type, the only difference from type (ii) is that the strands of wires of $1/8$ inch or so, replace the bar reinforcement. (a) The reinforcement in the first type could be replaced by two groups of four wires placed just below and above the neutral axis. (b) The arrangement for the second type could also be by four groups of four wires.

This method is useful for the long bench process for tie manufacture. This is used at Dow-Mac Limited, Tallington factory, England.

There is also a unique system which is sometimes adopted, but is not very much in vogue. In this the wire reinforcement is bent into loops over cast-iron anchor blocks. One anchor is fastened to the mold, the other is connected with a jack and after stressing is also anchored to the mold. The molds and anchors are released after the concrete has hardened sufficiently. The anchor block stays in the concrete. With this system the wires are anchored and bonded to the concrete.

A curved prestressed reinforcement can also be used. This system is not often used, and when used is used only with the one or two bar reinforcement.

A Russian system for prestressing concrete ties is a peculiar one. The tie is cast as a block with grooves on all four sides. After the tie is cured it is placed in a winding machine, the Michailow stressing machine, acting on the same principle as the machines used for the construction of prestressed concrete pipes.

The wire is wound around the tie. After winding the steel is covered for protection against corrosion.

Rail-to-Tie Connection

The rail-to-tie connection is a very important aspect of performance and stability of track and the life of ties. A resilient fixture between the rail and the concrete tie is required if deterioration of the concrete through pounding is to be avoided. Moreover, as concrete ties are very suitable for use with long welded rails, the fixtures should have adequate grip on the rail to restrain the locked up temperature stresses and prevent creep. The long welded rails have sometimes to be freed for stress relieving purposes, the fixture should provide a ready means of freeing and retightening rails without subsequent diminishing of the grip.

Figure 7 shows a channel type fastener, which proved better than the wedge nut fastener in the actual installation test. (13)

The rail-to-tie connections have to be insulated and the hard rubber insulation bushings which were experimented upon got crushed or torn in the experimental tracks of the Atlantic coastline and the seaboard Air Lines installations. (13) A new type Delrin plastic bushings, which laboratory tests have shown to have considerably greater strength could be recommended until further research.

In India, timber being very costly, metal ties have been used for a very long time. The iron deposits of India have not yet been fully tapped and iron and steel are very costly in India, whereas cement is the cheapest construction material used for structural

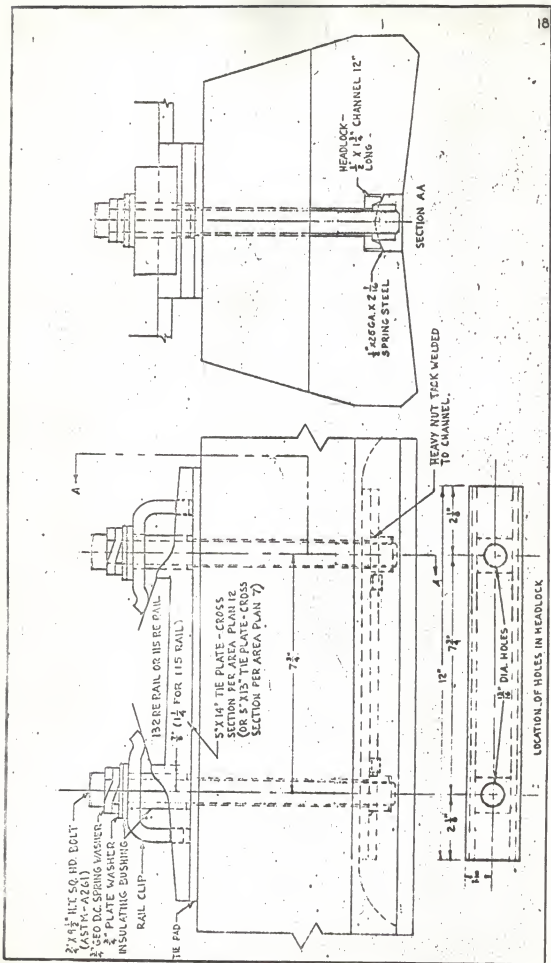


Figure 7. A channel type fastener for the prestressed tie.

work. Many new cement factories are being set up, so also high tensile wiredrawing plants are being set up. Labor is also very cheap in India. All these factors indicate that the prestressed ties may prove to be the most suitable choice in India. The Ministry of Railways, Government of India, has already taken steps to investigate the feasibility of using concrete ties for railway tracks. The prestressed concrete ones are superior to ordinary reinforced concrete ties. If a prestressed concrete tie is to be selected a design of such a tie shall have to be made for current Indian standard loading. Such a design is attempted here after the track analysis is made based on the elastic theory.

ANALYSIS OF LOADING ON A TIE

To design a tie, the stresses to which it shall be subjected are to be studied. A crosstie is an integral part of a track and so the loads acting on a track and how the track reacts to it is an important thing.

Considerable research has been carried out in the U.S.A., in India by the Central Standards Office of Railway Board, in Great Britain and in Germany on the stresses which a railway track has to withstand with the movement of heavy loads at high speeds passing over it and to distribute the load satisfactorily to the formation beneath.

Up to 1922, the stresses in a railway track were determined on the assumption that the rails formed a series of girders supported

rigidly by the crossties. This assumption being found inadequate, in the year 1922, the elastic theory was accepted for the stress calculations.

Results of extensive tests in India and in the States have proved this to be a satisfactory theory. (4) It is assumed in this theory that, the rails forming continuous beam are carried over ties which are considered as elastic and not rigid supports according to this theory, the four constituents of the track, viz., 1) the rails with their fastenings, 2) crossties, 3) ballast, and 4) the sub-grade below the formation, behave as perfectly elastic members of the track, which under the forces acting on them are strained, but as soon as the load is removed, the strains are completely recovered.

(1) This may not be quite correct when applied to ballast only, which by its very nature is loose, and is likely to be displaced slightly every time by the vibration and impact of the moving load, and part of it even to be crushed.

The variables in determining track stresses are so numerous that no precise results can be achieved, but a close assessment of these, through calculations not only forms a basis for correlating results of tests, but also provides a reliable estimate of stresses likely to be produced in a track with different types of vehicles.

Theoretically, it is considered that any depression in the track is supposed to be set right with the least possible delay, assuming that the wheels are uniformly loaded, the path of the wheels will be horizontal and the track will be depressed on the approach of the wheel and recover after the wheel has passed.

K. F. Antia (4) has stated that if a track is considered a uniformly loaded structure supported on wheels (this can be visualized by imagining the track and the load turned upside down), the track will be bent between the supports, namely between the wheels, and due to continuity, the track forms a sinusoidal curve.

From the track depression curve it is seen clearly that the effect of an adjoining wheel is to reduce the bending moment but to increase the "track" depression.

Track Modulus--The rigidity of the track support is termed the elastic modulus of track or track modulus. (4)

Track modulus is the weight in pounds per inch length of rail required to produce a deformation or depression of 1 inch in the track. (4)

The modulus of track μ varies with the gauge, the type and spacing of ties, nature of ballast, etc. It can, however, be easily obtained by measuring the deflection of each tie under the rail loaded with a locomotive of known weight. As stress is the product of modulus and strain, the load per tie equals modulus μ x deflection δ x ties spacing. For broad gauge (5' - 6") track modulus is between 1000 to 1200 p.s.i. Track stress equations are as follows: (4)

The equation for bending moment M_p under wheel load P is

$$M_p = P \sqrt{\frac{EI}{64 \mu}}$$

which reduces to

$$M_p = 0.318 P. x.$$

where

E = modulus of elasticity of rail

$$= 30 \times 10^6 \text{ lb. sq. in.}$$

I = moment of inertia of rail

μ = track modulus.

The distance x from load P to the point of zero bending moment is

$$x = 82 \sqrt{\frac{I}{\mu}}$$

and taken as 33.5 inches by the Indian Railway Board.

The depression of the track Y_p under wheel load P is

$$Y_p = \frac{0.39 P}{\pi(x)}$$

The maximum load on a sleeper under one rail, i.e., the rail seat load, is the product of track depression, track modulus μ , and tie spacing S .

$$\text{i.e. } Y_p \cdot \mu \cdot S.$$

and the maximum rail seat load P_t with the wheel load P just over the tie is

$$P_t = \frac{0.39 P \cdot S}{x}$$

P , the equivalent load, is obtained by making use of B. G. (M. L.) Loading (vide Appendix A) and the master diagram for bending moment and depression (vide Appendix B).

$$S = \text{Sleeper spacing} = \left(\frac{n \times 3}{n + 3} \right) \text{ ft} = \frac{14 \times 3}{14 + 3} = \frac{42}{17} = 2'-6'' \text{ c to c.}$$

To calculate the equivalent load P

(I) 1st wheel load W_1 on the sleeper.

Effect of W_1 on P from the diagram is found to be unity for both curves,

$$P = 11.5 \times 1 = 11.5.$$

(II) 2nd wheel load W_2

This affects P.

The distance of this wheel from $W_1 = 72\frac{1}{2}"$.

Starting at distance $72\frac{1}{2}$ inches and following the diagonal line down to horizontal through $x_1 = 33.5"$ then proceeding vertically up in the master diagram,

$$\left(\frac{m}{m_0}\right) \text{ curve} = -0.21$$

and

$$\left(\frac{y}{y_0}\right) \text{ curve} = +0.15$$

A reduction of $(0.21 \times \text{wheel load } W_2) = 0.21 \times 11.25 \text{ Tons}$ is obtained in the wheel load of W_1 .

But due to effect of W_2 the depression or intensity of pressure is increased by $(0.15 \times \text{wheel load of } W_2) = 0.15 \times 11.25 \text{ Tons}$.

(III) Consider effect of W_3 which is at $72\frac{1}{2}" + 67\frac{1}{4}" = 139\frac{1}{4}"$ from our sleeper.

Master diagram is read as before and the following values obtained:

$$\left(\frac{m}{m_0}\right) \text{ value} = -0.013$$

$$\left(\frac{y}{y_0}\right) \text{ value} = -0.05$$

(IV) Consider effect of W_4 which is at 207.0" from W_1 , i.e., tie position.

$$\left(\frac{m}{m_0}\right) \text{ value} = +0.000$$

$$\left(\frac{y}{y_0}\right) \text{ value} = -0.005$$

beyond this the effect of any wheel corresponds to zero change in $\left(\frac{m}{m_0}\right)$ and $\left(\frac{y}{y_0}\right)$ values.

Therefore maximum wheel load on the tie is

$$P = 1 + 0.15 - 0.21 - 0.035 - 0.55 - 0.005 \times 11.25$$

$$= 11.25 (1 - .155) = 11.25 (.845)$$

$$= 9.5 \text{ Ton .}$$

$$1 \text{ Ton} = 2240 \text{ lb.}$$

The maximum rail seat load on a tie based on track depression is given as,

$$P_t = \frac{.39 \text{ P.S.}}{x_1} = \frac{.39 \times 9.5 \times 30}{33.5} \text{ Ton}$$

$$= .39 \times 9.5 \times .825 \cdot 2240 \text{ lb.}$$

$$= 7420 \text{ lb.}$$

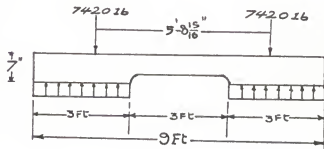


Figure 8. The Max. loads on the tie.

So also the Central Standards Office of the Railway Board of India specifies the following modifications on this obtained load:

- 1) due to speed effect.
- 2) overbalance or hammer blow on the driving wheel.
- 3) steam effects on the driving wheels.
- 4) inertia of the reciprocating parts of the engine.

These corrections are of more practical use than the theoretical treatment as these are wholly based on experiments and factors or constants obtained therefrom.

The practical aspect of replacement of old ties and renewal of track warrants that the tie length should remain the same as that for other types, viz., 9 ft. Middle third portion of the tie should be made wedge-shaped to overcome the tendency of being center bound.

The strength of the sleepers may be determined from the bending moment M_o of the overhang portion.

$$M_o = \frac{P}{b} \times \frac{c^2}{2}$$

$$\frac{P}{b} = \text{uniformly distributed rail seat load.}$$

A Proposed Section for a Prestressed Tie

Calculations must be made to develop a tie, which will not crack in everyday use under the biggest normal loads, with an eye on the fact that in prestressed ties, cracks close again and would not do any harm to the reinforcement. Here instead of trying to develop a new section for such a tie, the writer proposes to select

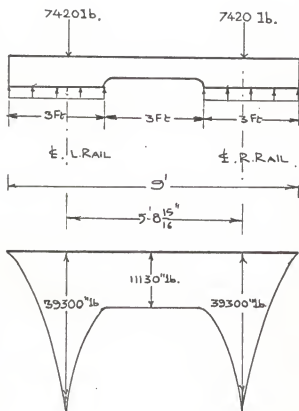


Figure 9. B. M. Diagram due to Max. loads.

a section on the basis of the existing ties and particularly based on the Design B, of the AAR, and check the stresses induced. The author proposes the same section as that for the Design B of the AAR except changing the length of the tie from 8 feet and 6 inches, to 9 feet. (11) The proposed section is shown in Figure 10. Keeping the successful installation of the ties by the Western Pacific Railroad in view, the following specifications are suggested. The concrete in the ties should have a compressive strength of 7000 psi in sixty days and a strength of 4000 psi at the time of transfer of the prestress. Type II cement, with three to five percent of entrained air and maximum aggregate size of $3/4$ in. should be used, in the concrete. The prestressing steel in each tie should consist of four $7/16$ ϕ high-tensile stress-relieved strands (7 wires), having an ultimate strength of 250,000 psi. In addition, No. 2 reinforcing steel ties should be placed at six inch centres near each end of the tie. The initial prestress should be 175,000 psi (which is at transfer). After transfer the prestress will be 140,000 psi. The reinforcement is of Type (iii), i.e., bonded wire reinforcement.

Stress Analysis of the Tie

Section A-A and section C-C in Figure 10 represent extreme conditions.

The centre of gravity of steel lies 4 inches below the top fiber for both sections.

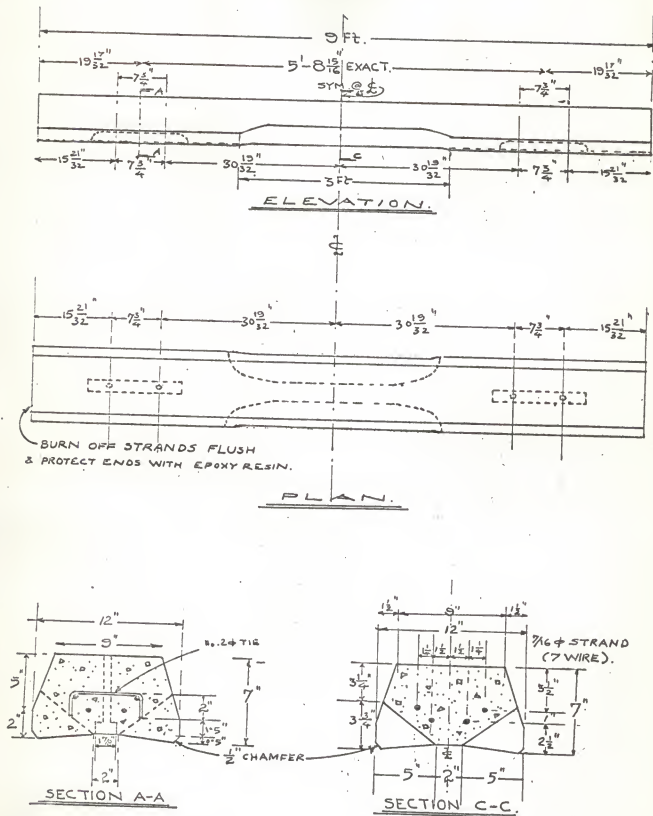


Figure 10. Prestressed concrete railway tie for broad gauge main line loading with channel type fastener.

Section A-A:

The initial prestress = 175,000 psi.

Prestress after transfer = 140,000 psi.

Maximum moment = 39,300 in. lb.

Moment of inertia of the section = 215 in.⁴

Area of steel 4 x 0.1089 = 0.436 sq. in.

Area of concrete = 76.0 sq. in.

$$\text{Fiber stress at the top} = \frac{F}{A} + \frac{F \cdot e \cdot y_t}{I}$$

F = Prestressing force after transfer = .436 x 140,000 lb.

$$= 436 \times 140 \text{ lb.}$$

$$= 61000 \text{ lb.}$$

$$ft \text{ (top)} = \frac{61000}{76} + \frac{61000 \times 0.33 \times 3.67}{215}$$

$$= -850 + 345$$

$$= -505 \text{ psi (comp.)}$$

$$\text{Fiber stress at the bottom} = -\frac{F}{A} - \frac{F \cdot e \cdot y_b}{I}$$

$$= -\frac{61000}{76} - \frac{61000 \times .33 \times 3.33}{215}$$

$$= -850 - 310$$

$$= -1160 \text{ psi (comp)}$$

The section is O.K. for no load condition.

The maximum moment imposed is 39300 in. lb. The losses are assumed as 15% of initial prestress after transfer.

The prestressing force after losses = 61000 x .85

$$= 52000 \text{ lb.}$$

$$\begin{aligned}
 \text{Fiber stress at the top} &= -\frac{F}{A} + \frac{F \cdot e \cdot y}{I} - \frac{M \cdot y}{I} \\
 &= -\frac{52,000}{76} - \frac{52000 \times .33 \times 3.67}{215} \\
 &\quad - \frac{39300 \times 3.67}{215} \\
 &= -720 + 293 - 671 \\
 &= -1098 \text{ psi (Comp)}
 \end{aligned}$$

$$\begin{aligned}
 \text{Fiber stress at the bottom} &= -\frac{F}{A} - \frac{F \cdot e \cdot y}{I} + \frac{M \cdot y}{I} \\
 &= -\frac{52,000}{76} - \frac{52,000}{215} \\
 &\quad + \frac{39300 \times 3.33}{215} \\
 &= -378 \text{ psi (Comp)}
 \end{aligned}$$

The section A-A is safe when the maximum load is imposed on it.

Section C-C:

The initial prestress = 175,000 psi.

Prestress after transfer = 140,000 psi.

Maximum moment = 11,130 in. lb.

Moment of inertia of the section = 175 in.⁴

Area of steel 4 x 0.1089 = 0.436 sq. in.

Area of concrete = 60.5 sq. in.

Stresses in section C-C when no load is on;

$$\begin{aligned}
 \text{Fiber stress at the top} &= -\frac{F}{A} + \frac{F \cdot e \cdot y}{I} \\
 &= -\frac{61000}{60.5} + \frac{61000 \times 0.94 \times 3.06}{175}
 \end{aligned}$$

$$= -1010 + 999$$

$$= -11 \text{ psi (Comp)}$$

$$\text{Fiber stress at the bottom} = -\frac{F}{A} - \frac{F.e.y.}{I}$$

$$= -\frac{61000}{60.5} - \frac{61000 \times 0.94 \times 3.44}{175}$$

$$= -1010 - 1140$$

$$= -2150 \text{ psi (Comp)}$$

With the load on and accounting for a 15% loss in the pre-stressing force

$$\text{Fiber stress at top} = -\frac{F}{A} + \frac{F.e.y.}{I} - \frac{M.y}{I}$$

$$= -\frac{52000}{60.5} + \frac{52000 \times 0.94 \times 3.06}{175}$$

$$= -\frac{11,130 \times 3.06}{175}$$

$$= -203 \text{ psi (Comp)}$$

$$\text{Fiber stress at bottom} = -\frac{F}{A} - \frac{F.e.y.}{I} + \frac{M.y}{I}$$

$$= -\frac{52000}{60.5} - \frac{52000 \times 0.94 \times 3.44}{175}$$

$$+ \frac{11,130 \times 3.44}{175}$$

$$= -1611 \text{ psi (Comp)}$$

The tie is adequate for B. G. (M. L.) loading.

CONCLUSIONS AND RECOMMENDATIONS

It is economical to use prestressed ties for Indian railways. The proposed section may be adopted for the broad gauge main line track, after laboratory and field investigations.

For mass manufacture, the long line process similar to the one developed by Dow-Mac (Products) Limited, England, may be adopted. This process has been evolved to satisfy the economic requirements for labor and to save material, introducing the principles of mass production. Specifications given in this text should be followed in the manufacture of the ties. The curing period for the ties should be between ten to fourteen days. The tension in the wires should be kept constant over this period and prestress be transferred at the end of this period. Before accepting the proposed section, the ties should be first tested in the laboratory for calibrating the stresses as calculated and those as found from laboratory tests. Experiments should also be conducted to find the distribution of bending moment along the length of the tie. The following tests should be carried out on the ties in the laboratory:

Static loading test

Repeated loading test

Repeated loading test in ballast

Tests on anchor nuts, rail fastenings, the Plates and Pads.

After conducting a series of tests, specifications should be drafted for future use.

The ties, after laboratory tests, should not be used directly in the main line tracks, but should be installed in experimental tracks on sidings or branch lines. After this test, which simulates actual track conditions, the ties could be used in the track. In field investigations following things should be studied:

Laboratory loading of tie for field data calibration

Maximum recorded strains at center of the track

Behaviour of rails, ties, and rail fastenings, etc.

As long as specifications are not available for maintenance work, frequent maintenance should be done under the guidance of a qualified inspector who should collect the information about the maintenance work done.

While laying the track, the ties should not be jerked or else they develop cracks. When ties are to be used in actual track the reinforcement should not be exposed to atmosphere and the strands should be burned off flush and the ends protected with epoxy resin.

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APPENDICES

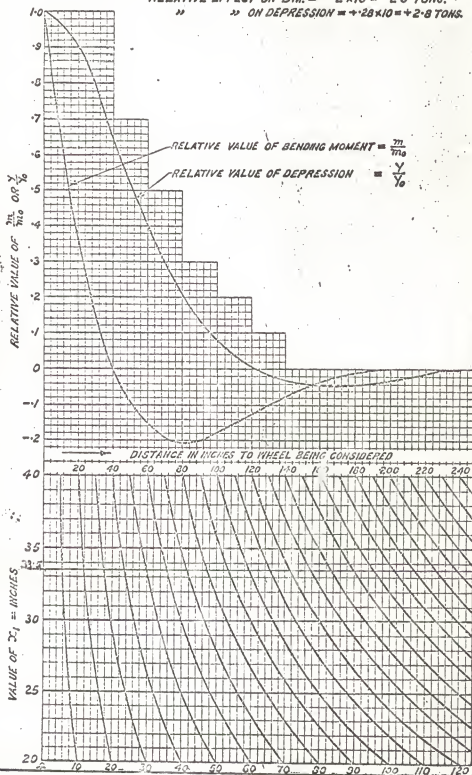
APPENDIX B

TRACK CALCULATIONS.

MASTER DIAGRAM FOR BENDING MOMENT & DEPRESSION.

EXAMPLE OF USE:-

WHAT IS THE EFFECT OF A WHEEL OF 10 TONS, DISTANT 60" IF $\alpha_1 = 33\frac{1}{2}^\circ$?
 START AT DISTANCE = 60" & RUN DOWN DIAGONAL LINE TO HORIZONTAL
 THROUGH $\alpha_1 = 33\frac{1}{2}^\circ$. THEN PROCEED VERTICALLY UP TO MASTER DIAGRAM
 AND READ OFF.

RELATIVE EFFECT ON B.M. = $-2 \times 10 = -2.0$ TONS." " ON DEPRESSION = $+28 \times 10 = +2.8$ TONS.

PRESTRESSED REINFORCED CONCRETE RAILWAY TIES
FOR INDIAN RAILWAYS

by

SURENDRA KESHAV MANGALMURTI
B.E. (CIVIL ENGG.) NAGPUR UNIVERSITY, 1961

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas .

1964

ABSTRACT

This report probes into the possibility of using prestressed ties for Indian Railways. This also includes a brief discussion of ties, in general, and the analysis of loads on ties by the elastic track theory. Extensive work has not been done on the prestressed ties and comparatively scanty reference material is available. England has officially adopted prestressed concrete ties for their tracks.

The dearth of good and cheap timber and the prohibitive cost of steel and cast iron ties necessitate the search for a substitute railway tie. Presently, prestressed reinforced concrete, with its numerous advantages over the ordinary reinforced concrete, promises a suitable material for this purpose. The vibrated concrete, the air-entrained concrete, and the comparatively recent advancements in prestressed concrete and the prestressing techniques, have given an impetus to the concrete tie business.

The discussion, also, presents an analysis of the loads acting on the tie, the selection of a proposed section for it and the stress analysis for it. The discussion includes a review of other current ties, and the prestressed ties in use and under investigation. The loading used here is the broad gauge main line loading. The actual design of a tie, which can finally be adopted for track, will have to be evolved after various tests and after installing these

in a portion of existing track and testing the performance. For Indian conditions, the prestressed ties appear to be the ideal ties considering their long life and long run economy.