# WOOD TIE-FASTENER PERFORMANCE SPECIFICATION

## AN ENGINEERED WOOD CROSSTIE SYSTEM PROJECT

SPONSORED BY

## THE RAILWAY TIE ASSOCIATION


115 Commerce Drive
Suite C
Fayetteville, GA 30214
(770) 460-5553
Fax (770) 460-5573

WOOD TIE-FASTENER
PERFORMANCE SPECIFICATIONS
FOR
RAILWAY TIE ASSOCIATION*

PAGE




*Project performed for RTA under contract by:
Dr. Allan Zarembski
Zeta - Tech Associates
1060 Kings Highway North
P.O. Box 8407
Cherry Hill, NJ 08002

## EXECUTIVE SUMMARY

This report develops a detailed performance specification for a heavy duty fastener/tie system in a severe railroad environment. This performance specification is intended to serve as a guide for the design, manufacture, and use of such a heavy duty fastener(s) and its components on timber cross-ties. These specifications are performance specifications and consequently address the ability of the fastener and of the tie/fastener system to perform their respective functions within the context of the defined loading and operating environment, in this case, the severe mainline railroad operating environment. By their nature, they are intended to provide significant leeway for the designer, to develop one or more suitable systems that meet the defined performance requirements, without unduly hampering the actual design itself.

This specification defines a set of minimum performance requirements for a system (either fastener only or fully integrated tie/fastener system). It is expected that fasteners that are designed to this specification will provide satisfactory performance in track under currently approved (Association of American Railroads) maximum wheel loadings for the defined minimum service life. Therefore, it must be noted that the tie/fastener system is designed to function as part of the overall track structure and that consequently, the other portions of the track structure must also meet the performance standards for the defined operating condition.

These performance specifications are divided into two broad categories, track strength and track performance. The performance specifications are based on a fastener life of 1,000 Million Gross Tons of traffic, and present the quantified performance values for both a "new" fastening system and an "old" fastening system, i.e., one which has reached its "life". Failure is defined to be the point in time or tonnage when the performance specifications ("old") can no longer be met.

Track strength relates directly to the ability of the of the fastener/tie system to adequately and effectively perform its functions under the defined traffic and environmental loading conditions. This is the "strength" or load carrying capacity of the system, and includes the full range of loadings; longitudinal, lateral (both gage widening and lateral track) and vertical. For each of these four strength areas a defined set of allowable deflections, under load, are presented.

The second area, track performance refers to those factors (often non-quantifiable) that relate to the ability of the system to accommodate itself to railroad practices and operations. These includes system life requirements, electric insulation requirements, maintenance considerations, derailment and damage performance.

# I. INTRODUCTION

Conventional wood tie and cut spike fastener systems have been in use in North American railroads since the earliest days of the railroad industry. However, within the last decade, the nature of the railroad operating environment has changed, with an increasing emphasis on long heavy trains with high axle loading. This change in turn has put a severe burden on the ability of the traditional wood tie - cut spike system to perform its critical functions, particularly on the most severely loaded track locations, such as high curvature, heavy grade territory. In particular, the ability of the tie/fastener system to hold gauge and to maintain the track longitudinally, has been called into question, especially on those severe locations where rail has to be frequently changed. In some cases, this traditional wood tie/cut spike system has proven to be inadequate.

In light of this, the very nature of the wood tie - cut spike fastener system has been examined from the point of view as to whether this system, or its individual components are appropriate for these heavy duty load environments. In examining the failure mechanisms associated with these severe track locations, it appears that the failures tend to be more closely associated with the fastening system, i.e., the cut spikes, than with the wood tie itself. In fact, the basic properties of the wood tie, such as its natural resiliency and electrical isolation, appear to be quite desirable in the heavy duty loading environment. This in turn suggests that the basic wood tie could function in even the most severe environment, provided that an appropriate fastener, or even more effectively, an appropriate tie/fastener system is utilized.

Therefore, it appears that, a suitable "heavy duty" fastener or tie/fastener system is required in order to achieve proper track system performance in the more severe loading environments of the railways. This fastener/tie system must be such that it could perform all of the critical fastener functions, to include holding gauge and maintaining longitudinal restraint of the rail with respect to the tie, in the most strenuous environments of heavy trains, high axle loads, sharp curvature and severe grade.

The purpose of this report is to develop a detailed performance specification for this heavy duty fastener/tie system in the severe railroad environment. This performance specification is intended to serve as a guide for the design, manufacture, and use of such a heavy duty fastener(s) and its components on timber cross-ties. These specifications are <u>performance specifications</u> and consequently address the ability of the fastener and of the tie/fastener system to perform their respective functions with the context of the defined loading and operating environment, in this case, the severe mainline railroad operating environment. By their nature, they are intended to provide significant leeway for the designer, to develop one or more suitable systems that meet the performance requirements defined here-in, without unduly hampering the actual design itself.

By its nature, such a specification defines <u>minimum</u> performance requirements for such a system (either fastener only or fully integrated tie/fastener system). It is expected that fasteners that are designed to this specification will provide satisfactory performance in track under currently approved (Association of American Railroads) maximum wheel loadings for the defined minimum service life. Therefore, it must be noted that the tie/fastener system is designed to function as part of the overall track structure and that consequently, the other portions of the track structure must also meet the performance standards for the defined operating condition. As a minimum, the remainder of the track structure must meet the track performance requirements (and associated design parameters) recommended by the American Railways Engineering Association (1).

It should be further emphasized here, that while the performance specifications are directed towards a fastening system for use on a timber cross-tie, this specification can be more broadly interpreted to cover an integrated wood tie/fastener system, where the fastener performance requirements are met by a suitably designed (or engineered) tie/fastener system. The specific decision as to whether an independent fastener system or an integrated tie/fastener system is most suitable is left to the designer. The sole purpose of this specification is to provide a general set of performance specifications that must be met under the defined operating environment.

These performance specifications are divided into two broad categories: track strength and track performance.

Track strength relates directly to the ability of the fastener/tie system to adequately and effectively perform its functions under the defined traffic and environmental loading conditions. This is the "strength" or load carrying capacity of the system, and includes the full range of loadings; longitudinal, lateral (both gage widening and lateral track) and vertical.

The second area, track performance refers to those factors (often non-quantifiable) that relate to the ability of the system to accommodate itself to railroad practices and operations. These include system life requirements, maintenance considerations, and other operating considerations.

This report develops and defines these performance specifications, in both of these defined areas, together with the engineering basis for these requirements. A specific "Technical Specification" is included as Appendix I of this report.

## II. TRACK ENVIRONMENT AND LOADINGS

The specifications developed in this report are based on the current allowable Association of American Railroad interchange standards (2) which restrict the maximum vehicle weight (loaded) to 263,000 lbs in free interchange service. This translates to a static wheel load of 33,000 lbs, which will serve as a basis for the loading environment used in the determination of the fastener performance requirements.

Based on this maximum limit and noting that these specifications are directed to the most severe operating environments of sharp curves and severe grades, the following parameters define the loading environment on which these performance specifications are based.

The track loading environment can be divided into three parts, corresponding to the three major loading directions; vertical load, lateral load and longitudinal loads. These loadings are illustrated in Figure 1.

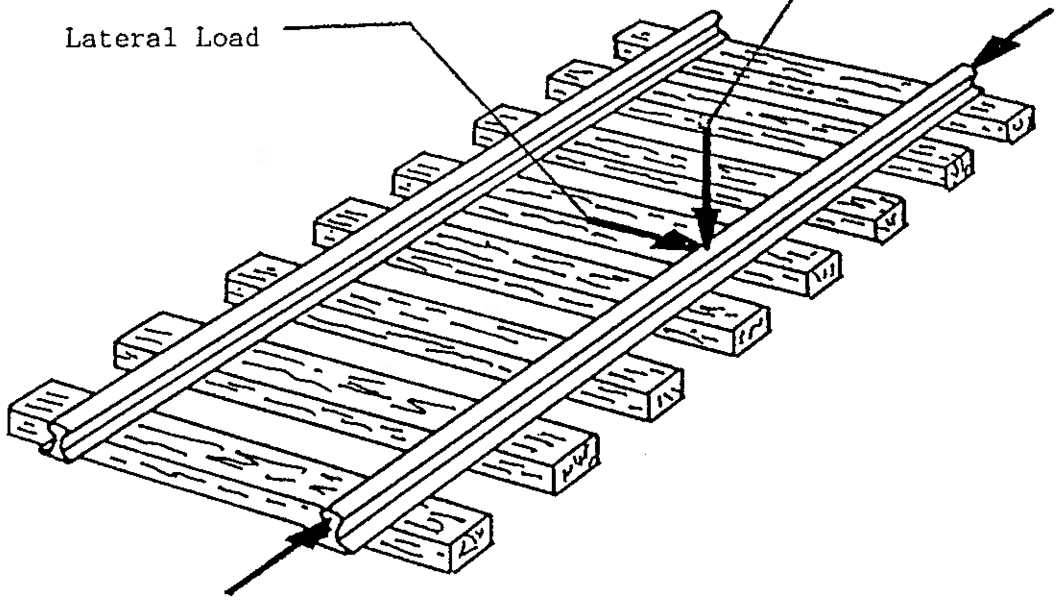
### Vertical Wheel Load

The vertical load applied to the track is applied, at the top of the railhead of both rails, normal to the plane formed by the two railheads. This is illustrated in Figure 1. The vertical load experienced by the track structure is in fact a combination of the static wheel loading due to the actual (stationary) weight of the car, together with dynamic effects associated with vehicle speed, impacts, and curvature/elevation.

The actual vertical loading experienced by the track (and therefore by the fastener/tie system) is a combination of the loadings of each of the various car and locomotive types, and is therefore in actuality, a distribution or spectrum of loadings (Figure 2, Reference 3). However, for the purpose of developing performance specifications, it is appropriate to simply define the maximum expected wheel loads. This can be done by using the maximum measured dynamic loading or by using the nominal static loading and developing equations or factors to take into account the various dynamic effects. In this report, both approaches will be used.

As noted above, the maximum static wheel load permitted in free interchange (2) is the 33,000 lb. wheel load. This wheel load is generally restricted to 36 inch diameter wheels.

In order to account for the dynamic effects associated with speed the AREA speed effect formula (1) is defined, where:




LOAD INPUTS TO RAIL

Figure 1

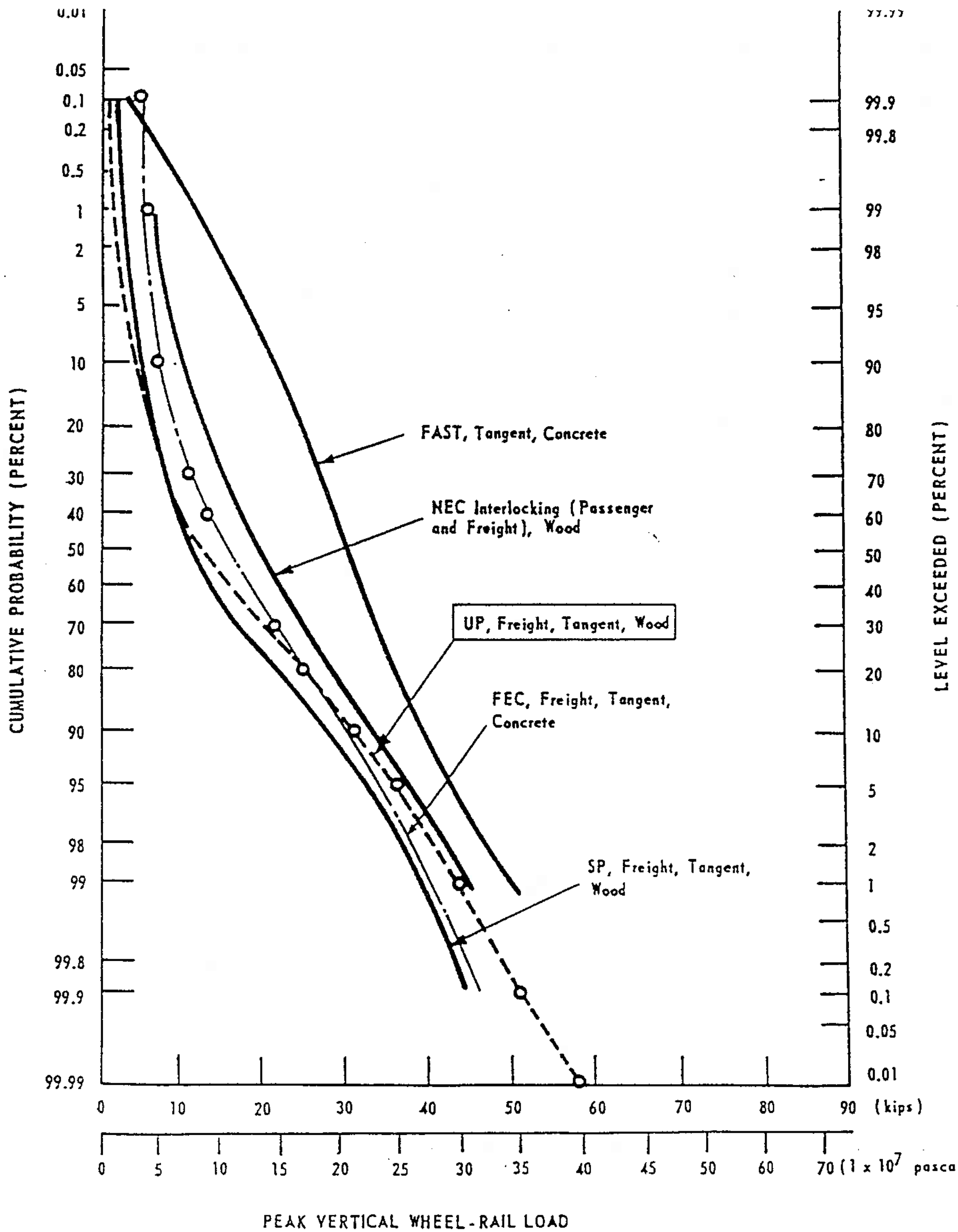



Figure 2

Level exceeded is the percentage of the loads (wheels) that exceed the peak vertical wheel-rail load (x axis).

Cumulative probability is the percentage of loads (wheels) that are less than the peak vertical load. (x axis).

Dynamic load = Static load * (1 + 33V/100D)

where V= speed in mph
D= wheel diameter in inches

Thus for a 100 Ton car (33,000 lbs wheel load) operating at 55 mph, this produces a dynamic wheel load of 49,500 lbs.

In addition to this speed effect there can also be a dynamic impact effect, usually associated with anomalies or defects on either the wheel or the rail surface. These impact effects are specifically associated with wheel imperfections such as wheel flats, out-of-round wheels, etc. and rail defects such as corrugations, engine burns, battered joints, battered welds, etc. Severe defects, which are usually those that exceed AAR interchange standards (for wheels) or which are greater than .050 inches (over an 18" wavelength for rail) for rail defects have been found to result in dynamic impact factors or multipliers (4) of between 2 and 3 (or even higher in the case of extreme defects). This type of impact effect will result in a dynamic impact load of 66,000 to 99,000 lbs per wheel. However, the duration of these impact forces are extremely short, often as low as 5 to 15 milliseconds.

Still another effect on vertical wheel loading is the effect of underbalance or overbalance on curves. This is specifically the loading effect associated with a vehicle operating either below or above the design balance speed for a curve (i.e., the speed for which the curve is superelevated). This effect is directly associated with the difference between the actual and design speeds and can be as high as a 50 % augment (factor of 1.5)

An alternate approach to the definition of the vertical wheel loading, is the selection of a value based from data measurements taken in the field. Such a set of load measurements is presented in Figure 2 (3), which shows the distribution of loading for various types of track and traffic conditions. Specifically noting the Freight traffic on tangent wood tie track curve, the data shows that the dynamic wheel load value of 48,000 lbs. has a cumulative probability of 99.8% (i.e., 99.8% of all measured wheel loads were below this value) and the dynamic wheel load of 58,000 lbs has a cumulative probability of 99.99%.

Vertical Fastener Load

Noting that the track can be represented as a continuously supported structure, where the support is the ballast and subgrade (5,6), and using the beam-on-elastic foundation theory to represent the track structure, as illustrated in Figure 3a, the load distribution between the rail and the supporting ties can be determined. This is illustrated in Figure 3b, where it can be seen that the deflection wave under one wheel in fact encompasses several ties, so that even a single wheel is supported by a number of ties.

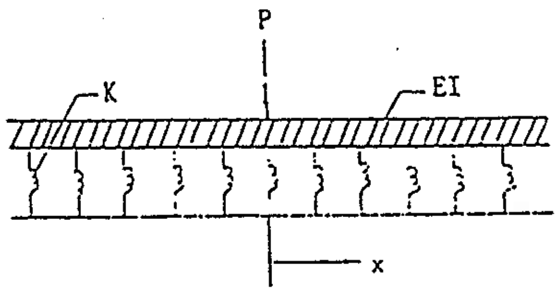



Figure 3A Beam on Elastic Foundation

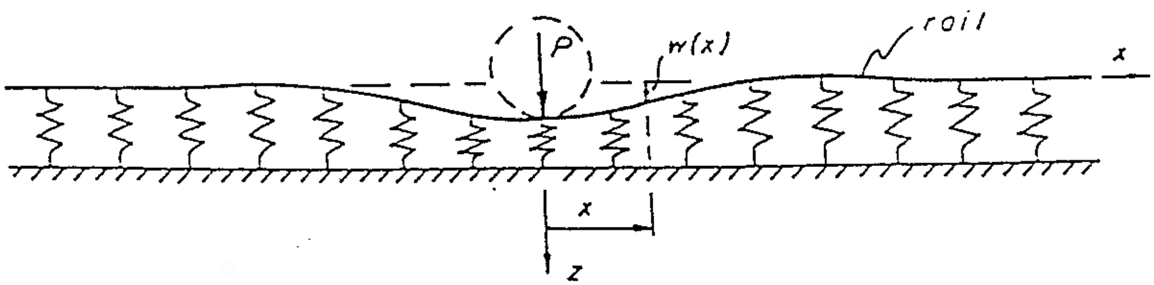



*Fig.* 3B

In order to determine what proportion of the wheel load is carried by the tie directly under the wheel, the beam-on-elastic foundation theory is used to determine the percentage of wheel load supported by that tie (7). The results are presented in Table 1, which shows this percentage as a function of track support condition or track modules and speed. As can be seen from Table 1, the individual tie (and thus fastener) receives 20 to 45% of vertical wheel load.

This corresponds to a fastener vertical load of 21,500 lbs. (dynamic).

Lateral Wheel Load

The lateral wheel load is the load applied in the lateral plane, as illustrated in Figure 1. This load can be applied either at the gage face of the railhead or at the top of the railhead, depending on the actual loading mechanism. The lateral loading is related to the manner in which the vehicle (and particularly the vehicle truck) negotiates a curve, and as such, there is a strong correlation between increasing lateral load and increasing curvature.

In order to define the lateral loading effectively, it is generally more reliable to utilize field measurement data then to attempt to model the vehicle/track interaction behavior, which is a complex behavior mechanism. It should be further noted that test data shows that the lateral loading of a locomotive is the largest lateral loading generated, and as such it will form the basis of the loadings used in this specification.

Using locomotive field test data for two and three axle locomotives (8,9,10,11), Figures 4, 5, and 6 present the distribution of lateral wheel/rail loads. Noting the difference between steady state loads (Figure 4 and 5) and total lateral dynamic loads (steady state plus transient loads, Figure 6) it can be seen that the steady state loading for two axle truck locomotives can reach 12,000 lbs, and for three axle locomotives, 16,000 lbs, for very sharp curvatures. However, the maximum dynamic lateral loads (total) can reach values as high as 35,000 lbs for commonly used three axle truck road locomotives, such as the SDP40F.

Lateral Fastener Load

In order to calculate the portion of the total load applied to an individual fastener, it is necessary to determine both the load transferred to the tie and the load transferred to the fastener.

Table 1

-DISTRIBUTION OF WHEEL LOAD TO INDIVIDUAL TIE*

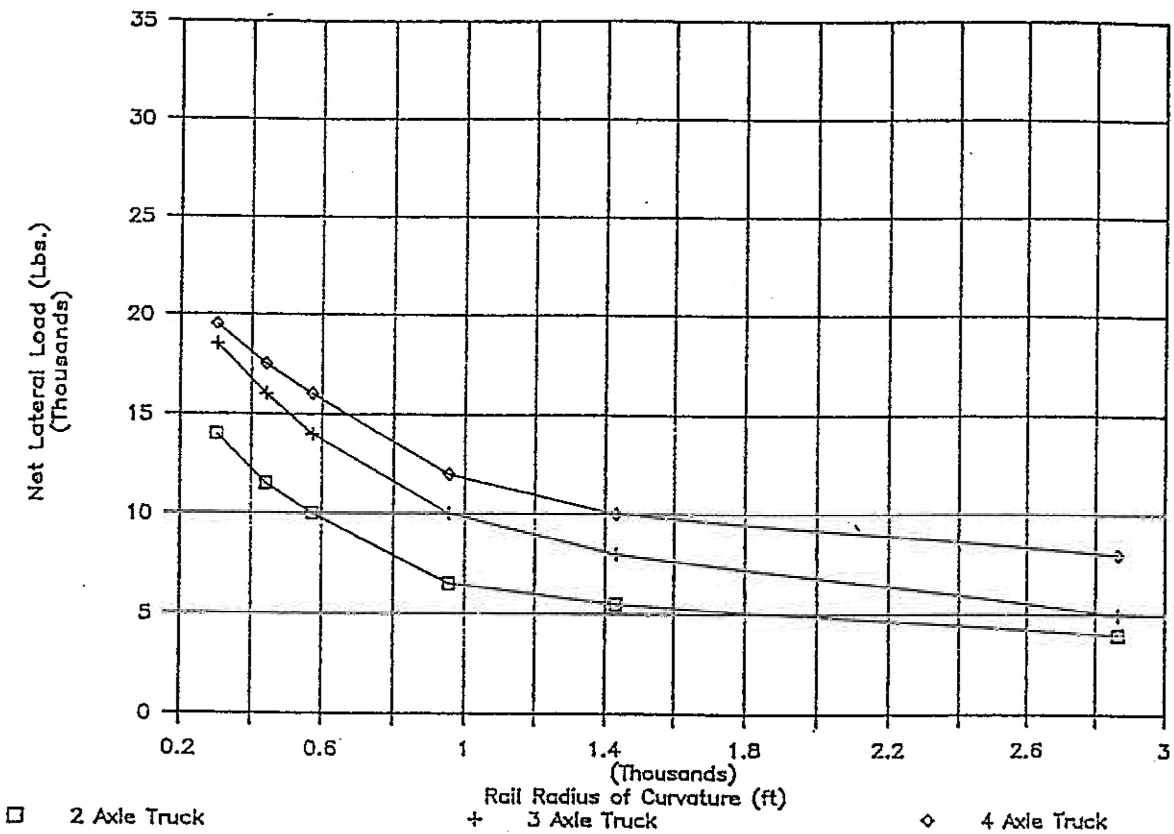
115RE , I=65.6 , S=19.5 , D=36"

| | +AW6 | SPEED 10 | 20 | 30 | 40 | 50 | 60 |
|---|---|---|---|---|---|---|---|
| TRACK MODULUS | 250 | 21.3 | 23.1 | 24.9 | 26.7 | 28.5 | 30.2 |
| | 500 | 23.4 | 25.4 | 27.4 | 29.3 | 31.3 | 33.3 |
| | 1000 | 25.5 | 27.6 | 29.8 | 31.9 | 34.0 | 36.2 |
| | 1500 | 26.7 | 28.9 | 31.2 | 33.4 | 35.7 | 37.9 |
| | 2000 | 27.6 | 29.9 | 32.2 | 34.6 | 36.9 | 39.2 |
| | 2500 | 28.4 | 30.7 | 33.1 | 35.5 | 37.9 | 40.3 |
| | 3000 | 29.0 | 31.4 | 33.9 | 36.3 | 38.7 | 41.2 |
| | 3500 | 29.6 | 32.1 | 34.5 | 37.0 | 39.5 | 42.0 |
| | 4000 | 30.1 | 32.6 | 35.2 | 37.7 | 40.2 | 42.8 |
| | 5000 | 31.1 | 33.7 | 36.3 | 38.9 | 41.5 | 44.1 |

* % of wheel load distributed to tie directly under wheel.

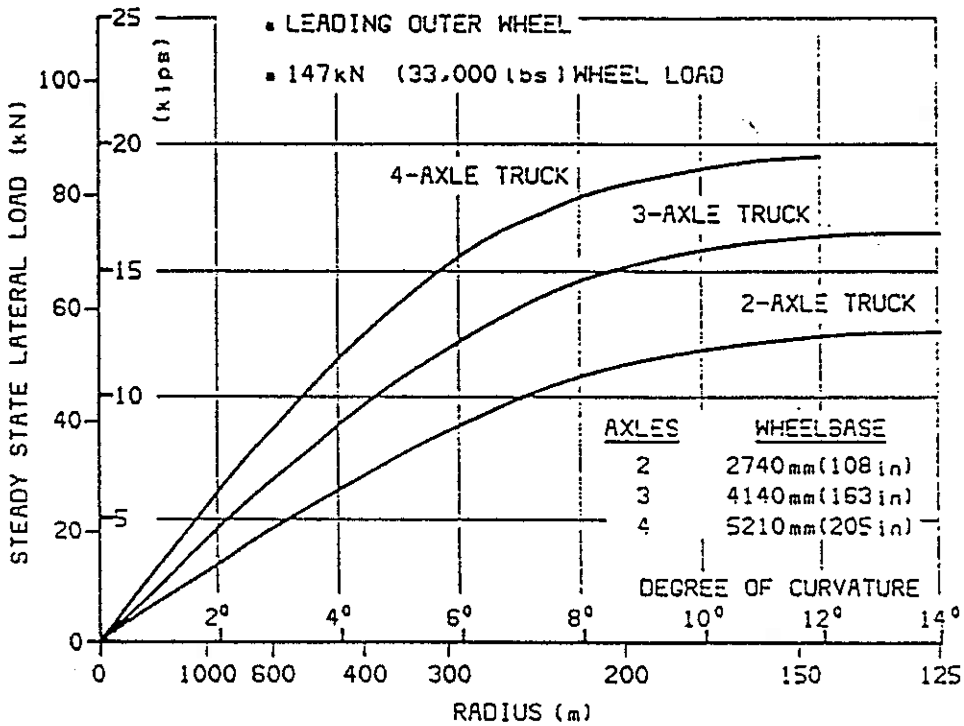
Track Modulus (LB/in/in)
Speed (MPH)

Fig 4A Experimental Results for the Net Lateral Load Between the Leading Outer Wheel and Rail




| Track Curve | | 2-Axle Truck | 3-Axle Truck | 4-Axle Truck |
|---|---|---|---|---|
| 2 | 2865.0 | 4,000 | 5,000 | 8,000 |
| 4 | 1432.5 | 5,500 | 8,000 | 10,000 |
| 6 | 955.0 | 6,500 | 10,000 | 12,000 |
| 10 | 573.0 | 10,000 | 14,000 | 16,000 |
| 13 | 440.8 | 11,500 | 16,000 | 17,500 |
| 19 | 301.6 | 14,000 | 18,500 | 19,500 |

FIG. 4B Table of Wheel-Rail Loads for EMD 2, 3 and 4-Axle Trucks Due to Curve Negotiation



LEADING OUTER WHEEL
147kN (33,000 lbs) WHEEL LOAD
4-AXLE TRUCK
3-AXLE TRUCK
2-AXLE TRUCK
AXLES
WHEELBASE
2 2740mm(108in)
3 4140mm(163in)
4 5210mm(205in)
DEGREE OF CURVATURE
STEADY STATE LATERAL LOAD (kN)
(kips)
RADIUS (m)


Figure 5

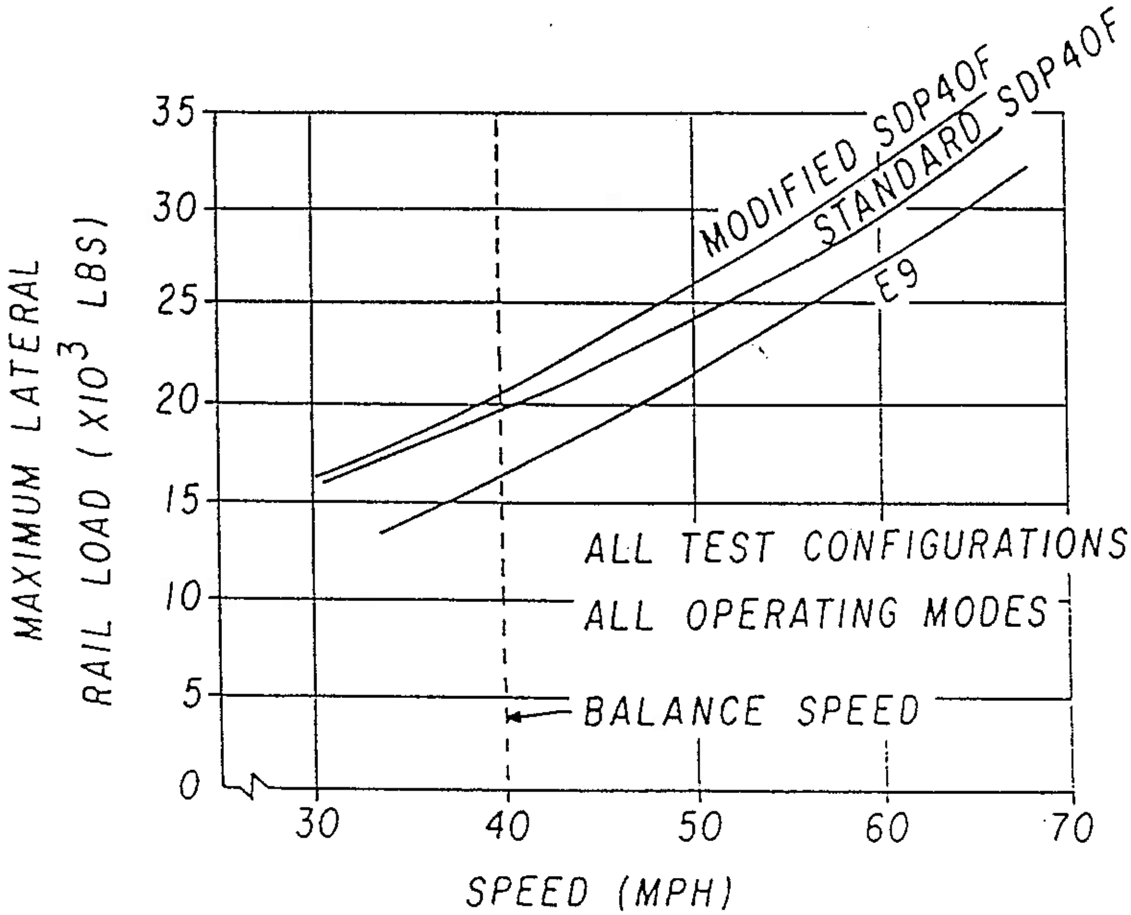



FIG. 6 MAXIMUM LATERAL RAIL LOADS- CURVE SITE

The actual transfer mechanism consists of several parts. The first part is the distribution of the load, through the railhead to the tie directly under the load (in a manner analogous to that for the vertical load distribution). This can be done through a beam analysis using the lateral section strength of the rail to determine the load distribution. The single tie distribution can vary from between 25% and 50% of the total load, depending on rail size, fastener type (and torsional resistance), tie stiffness, etc.

The second part of the load transfer, deals with the transfer of load,through the fastener itself, noting that a portion of the load is taken up by the frictional resistance of the base of the rail and the fastener railseat and the remainder is resisted by the fastener itself. (This will be discussed in further detail in Section III.2, Gage Strength). In this transfer (12), the net lateral fastener load is equal to the net lateral load at the tie (note above) minus the vertical load multiplied by the "effective" coefficient of friction between rail and fastener rail seat (12). In this case the fastener receives between 20% and 45% of the lateral tie load.

Combining these two effects result in a net lateral fastener load (maximum) of 15,000 lbs.

L/V Ratio

The L/V ratio is the ratio of the Vertical wheel/rail force and the Lateral wheel rail force. This ratio is an indication of the overturning force on the rail/fastener system (see Section III.2) as well as the tendency for the wheel to climb the rail. The former case is defined by the overturning limit of $L/V > .6$ while the later case is defined by the "Nadal" limit for wheel climb, $L/V > .8$, which is illustrated in Figure 7 (13). Noting this value and the field measured L/V ratios presented in Figure 8, it can be seen that the range of L/V of interest here is :

$$.6 < L/V < .8$$

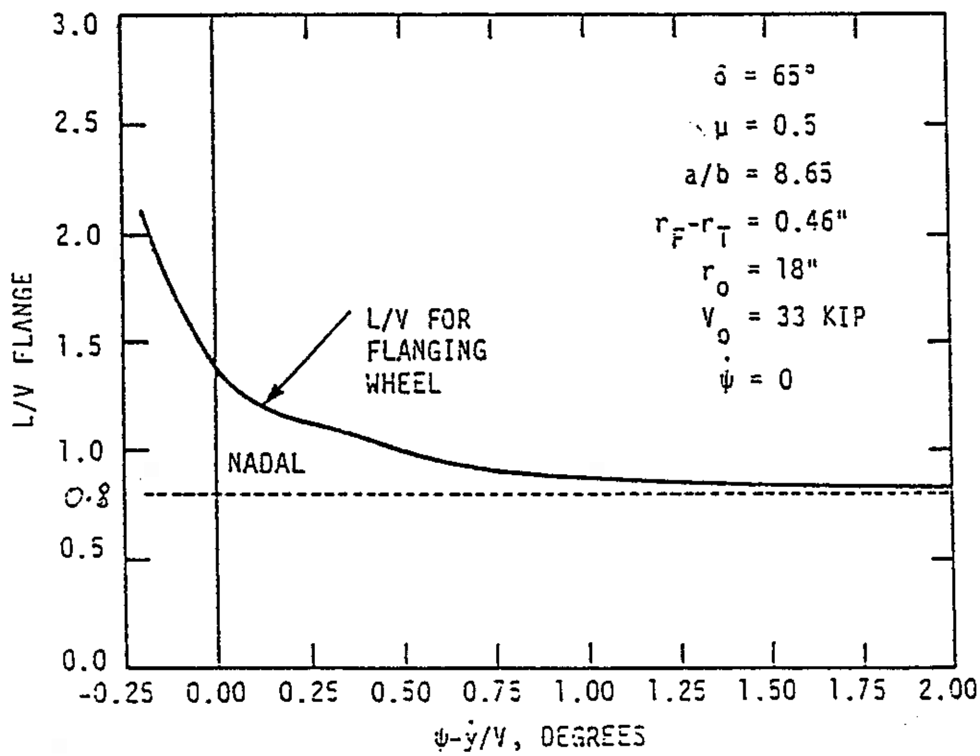
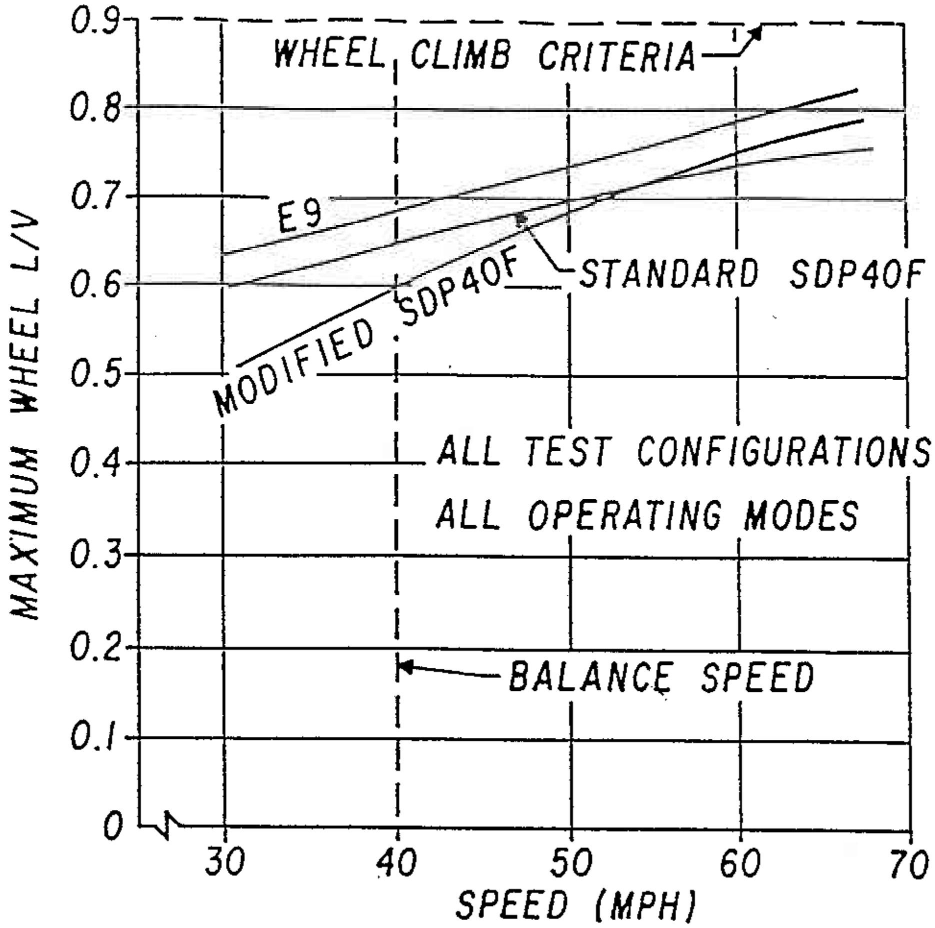
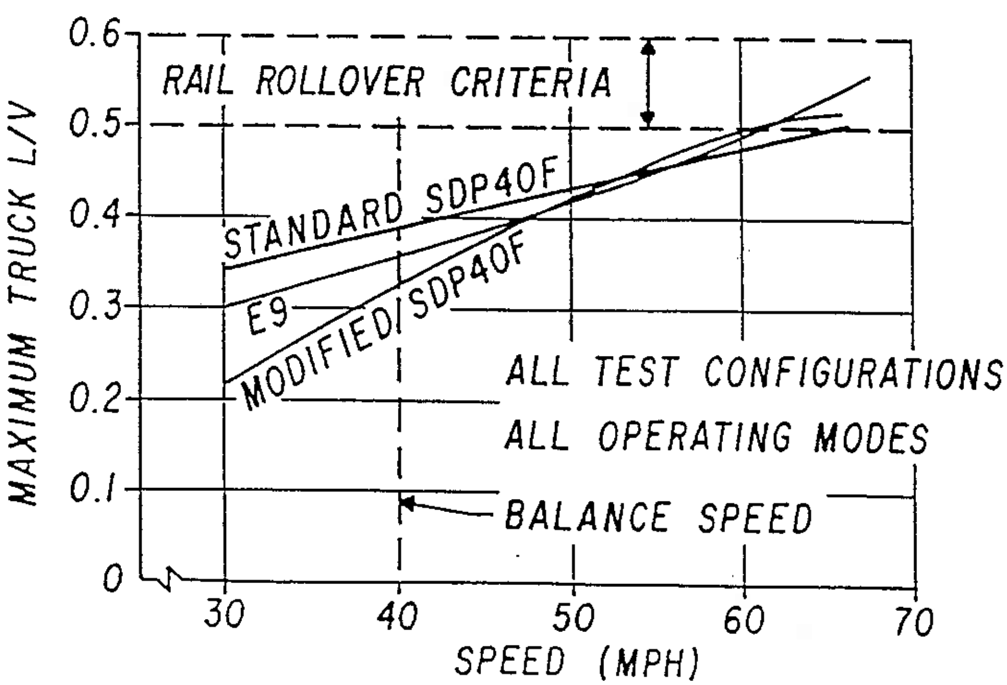



Figure 7

WHEEL/RAIL FORCES FOR FLANGING WHEEL




(A) MAXIMUM WHEEL L/V




(B) MAXIMUM TRUCK L/V

FIG. 8 MAXIMUM L/V RATIOS - CURVE SITE

Longitudinal Track Loadings

Longitudinal forces in the track structure (Figure 1) are induced through two distinct mechanisms; mechanical (train action) and environmental (thermal effects).

Mechanically induced longitudinal forces are directly related to longitudinal train handling and operations. These include train acceleration, specifically at the traction wheels of the engines, and train deceleration or braking, either in the locomotive wheels only (dynamic braking) or at all the wheels in the consist (train air braking). Noting Reference 14, maximum mechanical forces of up to 60,000 lbs per rail have been recorded, however, more typically these forces are in the range of 20,000 lbs per rail.

Thermally induced longitudinal rail forces are caused by the changes in ambient (and thus rail) temperatures and the difference between the instance temperature and the force free or laying temperature of the rail. These forces, which can be either compressive or tensile in nature can reach significant levels, as is illustrated in Figure 9 (15). These forces are the primary cause of movement at the ends of rail strings or at gaps in the rail, such as due to joints (desirable) or pull-apart (undesirable). In curved track these longitudinal forces also contribute to the moving in or out of the curves. As can be seen in Figure 9, a 100 degree temperature change in 132 RE rail can generate a longitudinal rail force of 250,000 lbs.

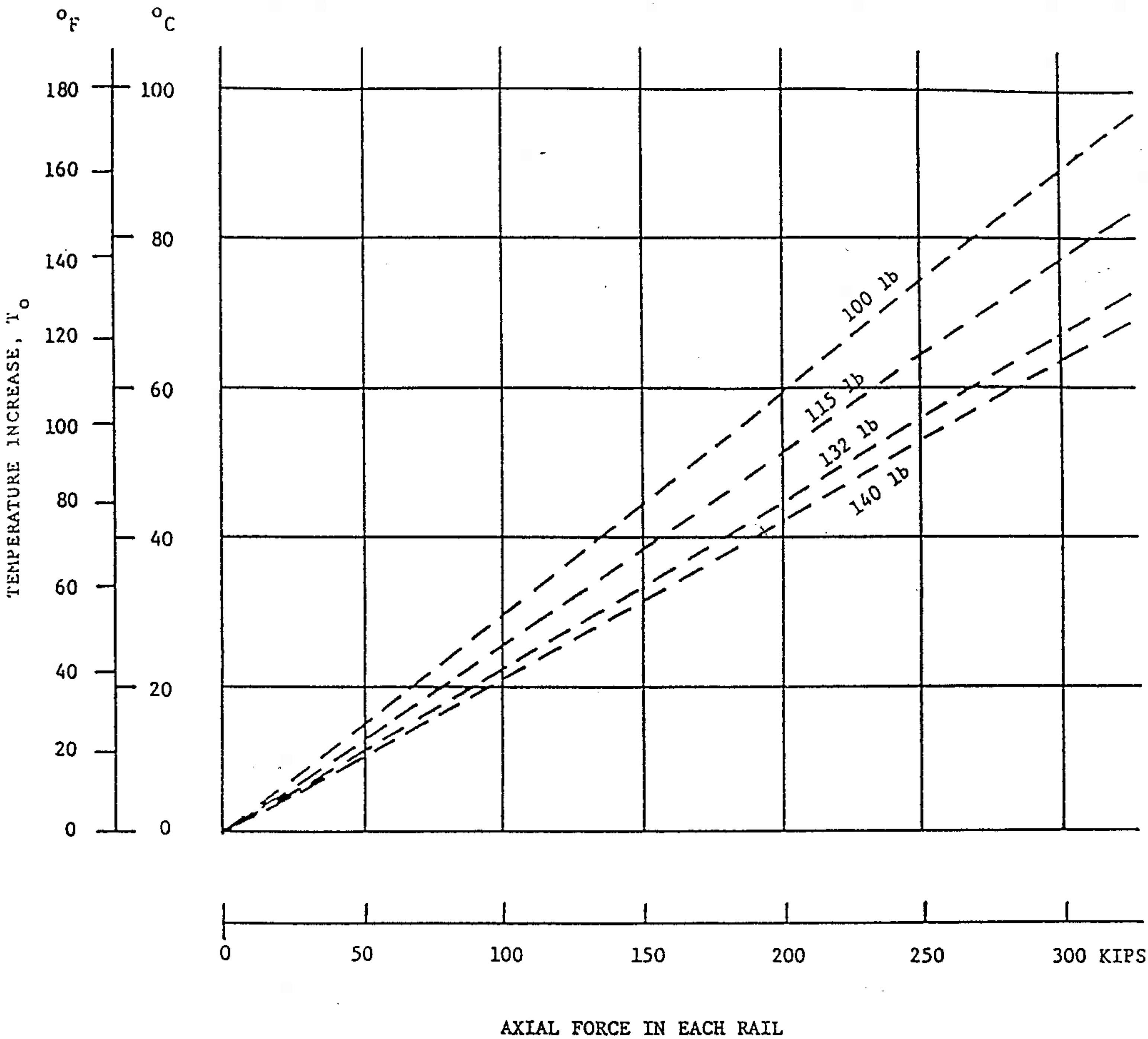



FIGURE 9

RAIL TEMPERATURE INCREASE VS. AXIAL FORCE IN RAIL

## III. TRACK STRENGTH

As noted in the Introduction, Track Strength refers to the ability of the of the fastener/tie system to effectively perform its functions under the defined traffic and environmental loading conditions. This is the "strength" or load carrying capacity of the system, i.e., its ability to carry the vehicle and environmental loadings without "excessive" deflection or deformation. These strength requirements form the basis of the performance specification.

There are four basic areas of track strength performance, corresponding to the three principal loading directions presented in Figure 1. These are:

a. Longitudinal Strength
The resistance of the fastener/tie system to longitudinal loading, both mechanical and environmental (thermal).

b. Lateral Strength;
The resistance of the fastener/tie system to lateral loadings. This in turn is composed of two distinct mechanisms:

b.1 Gage Widening Resistance
The resistance of the fastener/tie system to static or dynamic gage widening.

b.2 Lateral Shift Resistance
The resistance of the fastener/tie system to the lateral deformation of the track structure (alignment or buckling).

c. Vertical Strength
The resistance of the fastener/tie system to vertical loadings.

For each of these four track strength areas a performance requirement, defined as an ability of the tie/fastener system to resist external loading, must be specified. In this performance specification, this is specified as a maximum allowable deflection for a given level of loading.

Noting the behavior of track structural systems under long term traffic loadings, it is observed that the "strength" of the system will degrade after time and/or traffic. In order to take this behavior into account in defining these performance specifications, it is necessary to take one of two approaches. One approach, the traditional railroad component approach, is to define a single set of performance values that the system must always exceed. In this case, the strength of the system, when new, is usually significantly higher than that after long service. However, this value is never specified.

A second approach is to define both a "new" strength value and an "old" strength value, reflecting the requirements in both states. This is a somewhat more restrictive approach than the single value approach, however, in terms of providing guidance to a fastener designer, it provides additional information. In light of this fact, this second approach, the "new"/"old" value approach will be the one utilized in these specifications.

Therefore, in these track strength specifications, each performance requirement must have two sets of values, a "new" value, its strength when it is new, and an "old" value" which is its strength after being in traffic. This value is based on the life of the fastener/tie system.

For mainline track a minimum life of 500 to 700 MGT is defined, corresponding to the life of rail in tangent track under heavy axle load conditions. For 33,000 lb. wheel loads, this translates into 15,000,000 to 21,000,000 loading cycles, where each cycle represents a single passing axle.

Since this specification is defined to be a severe environment specification, it is expected that the annual tonnage levels will be quite high and that the minimum life, in tonnage, will occur, before any life limit (in years) is reached. However,for the sake of completeness, a supplemental "life" value of 20 years, is also defined. In this definition, minimum life is attained when either of the two parameters, cumulative tonnage or years in service, is first reached.

In addition to the above defined "new" and "old" values, a third value, which can be called "repeated applications" value, can also be defined. This value represents the strength of the fastener system after multiple removal/applications of the fasteners. Specifically this requires that the fastener be capable of surviving repeated removal/application cycles of the rail hold down portion (not necessarily the connection between the fastener and the tie) during the above defined "life", without excessive loss of strength. Thus it must meet this "repeated applications value" (which can be set equal to the "old" strength value) after a defined number of application cycles. This number is set here-in to be 6 removal/application cycles. (Note, for mainline curves, this could be 4 to 8 cycles during the life of the tie.) In this specification, unless specifically stated otherwise, the "repeated applications" value is to be set equal to the "old" value.

Therefore, in light of the above considerations, the life values will be defined as follows: At the conclusion of 15 Million cycles or 500 MGT, the "old" strength values specified in this section must be at a level equal to 90% of the "new" strength levels defined for all strength categories, unless otherwise stated. In addition it must maintain these defined levels of performance after removal and reinsertion 6 times. The "repeated applications" strength values must be equal to 90% of the "new" strength levels (i.e., equal to the "old" levels) defined for all strength categories, unless stated otherwise.

The fastening system and its individual components must be resistant to corrosion and decay (due to radiation, moisture, temperature variations and corrosive chemicals, as can be encountered in a range of track conditions found in North America). The life of these components, and specifically the strength of the fastener/tie system must meet the defined component life specifications based on strength levels and tonnage history. In no case should the component life be less than that of the other parts of the track structure, subject to the same environment.

The following defined track strength parameters shall be obtained for a full range of component tolerances, as defined by the manufacturer. Therefore, these values must be obtained, not only for the nominal tolerance range but for the full range of maximum and minimum tolerances, on each component, when that component is incorporated as part on a complete fastener assembly.

## III.1 LONGITUDINAL STRENGTH

Longitudinal fastener strength is the ability of the fastener system to provide longitudinal restraint to the rail and prevent rail movement or creepage under all loading conditions. As noted in Section II, longitudinal loading can be due to train action, such as train or engine braking and/or acceleration, and to environmental action, specifically the variation in temperature, both rail and ambient. In the case of the latter loading, large rail compressive and tensile forces result from temperature changes (both daily and seasonally) with a defined range of -30 to +150 degrees Fahrenheit. Figure 9 presented the relationship between temperature change and rail longitudinal forces.

In the case of longitudinal forces, the function of the fastener is to provide longitudinal restraint to prevent any movement of the rail with respect to the tie. Under mechanical loadings, this is simply the case of each fastener picking up a portion of the load, up to its maximum capacity, until the entire longitudinal load is restrained. In the case of thermal loadings, the distribution of longitudinal force is presented in Figure 10. This distribution consists of two distinct loading zones, the two end zones or "breathing" zones in which

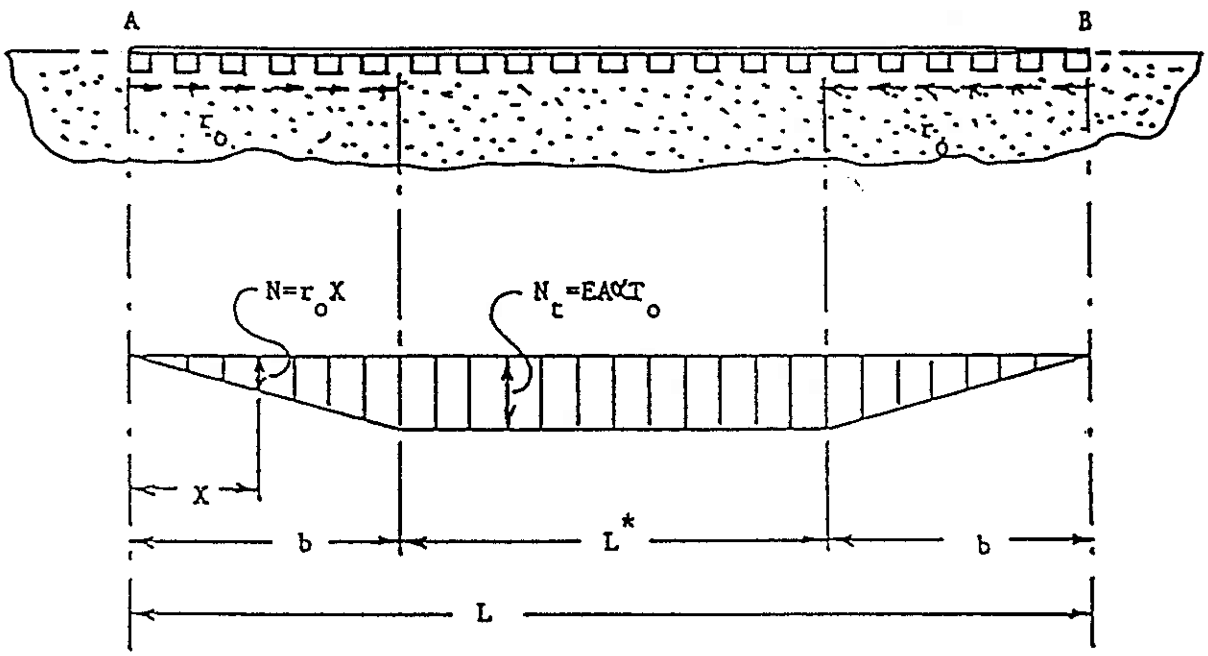



FIGURE 10

AXIAL FORCE DISTRIBUTION IN A TRACK OF LENGTH L longitudinal movement of the rail takes place and the center "constrained" zone in which no longitudinal movement occurs. (15) Therefore, the fastener longitudinal restraint is most critical in these end or "breathing" zones. These zones are at the ends of the Continuously Welded Rail (CWR) strings or at each side of a rail gap, such as occurs during a rail pull-apart or break. Good longitudinal restraint strength is required to minimize the size of these gaps.

Noting this, the minimum longitudinal restraint value is the restraint necessary to prevent an excessive rail end opening or "gap" at any discontinuity in the CWR. In addition, the fastener restraint is intended to prevent any excessive rail movement (longitudinal), between the rail and the cross-tie. This is particularly important in a critical "failure" situation, such as in the event of a pull-apart or rail break where the break or gap must be controlled to avoid an excessive gap in the rail.

Table 2 presents a set of calculated rail end openings or "gaps" as a function of the fastener longitudinal restraint (14). Based on a 132 lb. rail and 19.5 inch tie spacing for a 75 degree temperature change (such as would be encountered in a large portion of continental US) the required minimum restraint per rail seat is:

1814 lbs/rail seat for a gap of 1"

or

2720 lbs/rail seat for a gap of 3/4".

This defines a range for the minimum longitudinal restraint.

In order to properly qualify the range of restraint it is necessary to also specify a maximum longitudinal restraint value. In order to do this, it is necessary to note that the longitudinal restraint of the rail/tie fastener system should not be significantly greater than the resistance of the tie in the ballast. This latter value is the plowing resistance of the cross-tie in the ballast, as presented in Table 3 (16). There is no need for the longitudinal fastener strength to be significantly greater than the tie/ballast strength since any excessive fastener strength could never be used, once the tie moves with respect to the ballast.

By designing the fastener/rail restraint to be greater than the resistance of the tie in the ballast, the tie/ballast interface becomes the weak link in the track structure, not the fastener/tie interface (as has often been the case in the past, when the rail "runs" due to the inability of the fastener to hold the rail).

Based on this tie/ballast resistance data (Table 3), a resistance of 4900 lbs per tie or 2450 lbs per rail seat is an effective maximum limit for the longitudinal restraint of the fastener. This corresponds to a value of 1500 lbs/ft per rail seat.

TABLE 2

FASTENER LONGITUDINAL RESTRAINT FOR PULL A PART

| RAIL BREAK "GAP" (INCHES) | RESTRAINED LENGTH OF TRACK ON EACH SIDE OF GAP (FT) | TIE SPACING (INCHES) | LONGITUDINAL RESTRAINT PER FASTENER (LBS) |
|---|---|---|---|
| 0.5 | 86 | 19.5 | 3627 |
| 0.75 | 129 | 19.5 | 2720 |
| 1.0 | 172 | 19.5 | 1814 |
| 1.5 | 258 | 19.5 | 1360 |
| 2.0 | 344 | 19.5 | 907 |

RAIL WEIGHT = 132 RE

MAXIMUM TEMPERATURE CHANGE = 75° F

TABLE 3

LONGITUDINAL RESISTANCE OF WOOD TIES IN BALLAST

LONGITUDINAL RESISTANCE* (LBS PER TIE)

| | UNCONSOLIDATED ** | | | CONSOLIDATED ** | |
|---|---|---|---|---|---|
| MGT | TANGENT | CURVE | | TANGENT | CURVE |
| 0 | 2588 | 2763 | | 3049 | 2712 |
| .5 to 1 | 3030 | 3476 | | 3279 | 3279 |
| 1 to 2 | 3194 | 3814 | | 3530 | 3296 |
| Maximum Individual Case | | | 4900 | | |
| Average (all cases | | | 3180 | | |

* Defined to be longitudinal force necessary to displace tie .08 inches (Reference 5)

** Average of test data from Boston & Maine, Southern, St. Louis-South Western, and Missouri Pacific Railroads

It should be noted that AREA (1) specifies 2400 lbs. fastener restraint for concrete tie fasteners on 24 inch spacing. This corresponds to 1950 lbs. on 19.5 inch spacing or 1200 lbs/ft per rail seat.

Based on this, a longitudinal restraint of 1500 lbs/ft. per rail seat is defined. This is the "new" value. In addition, the fastener must maintain a longitudinal restraint value 1200 lbs/ft. per rail seat even after 15 Million cycles and through 4 multiple removal/insertion cycles. This is the "old" value.

Note: values are in lbs. per track foot, to allow for variation in tie spacing.

Finally, it must be noted that these are static values, without any dynamic excitation of the track structure. The dynamic longitudinal restraint should be no less than 75% of the static longitudinal restraint values.

## III.2 LATERAL GAGE STRENGTH

As noted earlier, longitudinal gage strength refers to the ability of the fastener /tie system to limit the amount of gage widening, both static and dynamic. This is an important parameter, since a key fastener function is to maintain track gage under loading, i.e., to prevent dynamic gage widening. Gage widening is defined to be any increase in the standard gage of the track structure (usually 4' 8 1/2", sometimes higher on curves), measured at the gage point, 5/8" below the top of the railhead (17).

Gage widening is associated with three distinct mechanisms (17) as follows:

A. Rail wear; abrasive wear on the railhead, particularly the gage face of the high rail. While primarily outside the scope of the fastener system, it is affected by fastener stiffness.
B. Rail translation; rigid body movement of the rail, without any rotation, i.e., lateral movement of the base of the rail.
C. Rail rotation; rotation of the rail about its longitudinal axis, i.e., overturning. This mode is illustrated in Figure 11.

Fastener strength is defined in terms of deflection under loading, as noted in Section II, with defined lateral and vertical wheel/rail or equivalent tie/fastener loadings. For the values presented here-in, a lateral fastener loading of 15,000 lbs. will be defined under a simultaneous fastener vertical load of 21,500 lbs. This corresponds to an L/V ratio of however, it is below the wheel climb limit.

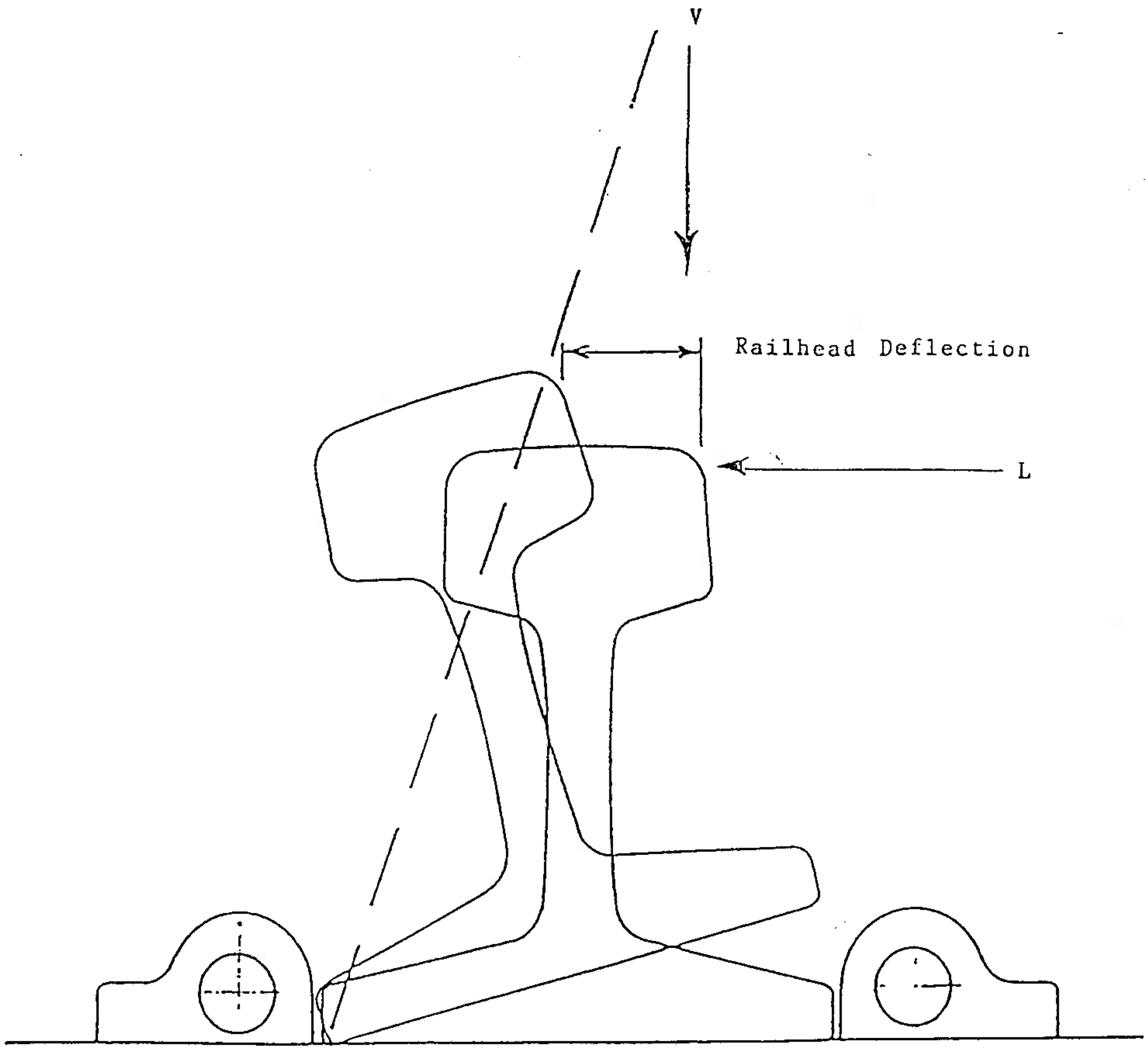



FIGURE 11
RAIL ROTATION UNDER LATERAL AND VERTICAL LOADING

The following deflections, and consequently performance standards, are based on this defined load level.

Rail Wear.

In general rail wear is effected by the fastener system only in that a change in the fastener rotational resistance (torsional strength or overturning strength) will affect the dynamic wheel/rail lateral interactions and thus the gage face wear. Limited test data (18) suggests that fasteners that are very stiff, torsionally, will result in a greater amount of gage face wear than those that are somewhat softer (see Figure 12). However, on the other extreme, fasteners that are too soft torsionally, and which have large variations in dynamic gage with vehicle dynamic loading, will also result in excessive and non-uniform gage face wear (14).

In order to minimize this effect, the following range of torsional stiffness about the longitudinal axis (see Figure 13 for the definition of this rotation) is:

Range of torsional stiffness = 1500 to 4000 in-Kips/radian.

Where the stiffness is defined as the Overturning Moment (the Force in thousands of lbs or Kips times the moment arm in inches) divided by the rotation of the rail about the longitudinal axis (in radians). This is illustrated in Figure 13.

Table 4 presents a sample of rotational stiffness values for wood tie fastener systems (19).

Rail Translation.

Rail translation is the lateral movement of the rail section, without rotation, i.e., the lateral movement of the rail base. For fastener/tie systems in "good" condition", this is not a significant value, as illustrated in Figure 14 (20,21) which shows that rail translation is significantly smaller than the corresponding rotation in good track. However, as the track begins to deteriorate, this mechanism becomes quite significant, with values of over .025 inches per rail seat having been measured under relatively small loadings (14). Noting this behavior, the following performance specifications are defined:

A. Under above loading rail base deflection should be, for new condition, less than 0.060 inches per rail seat.

B. For old condition less than .10 inches per rail seat.

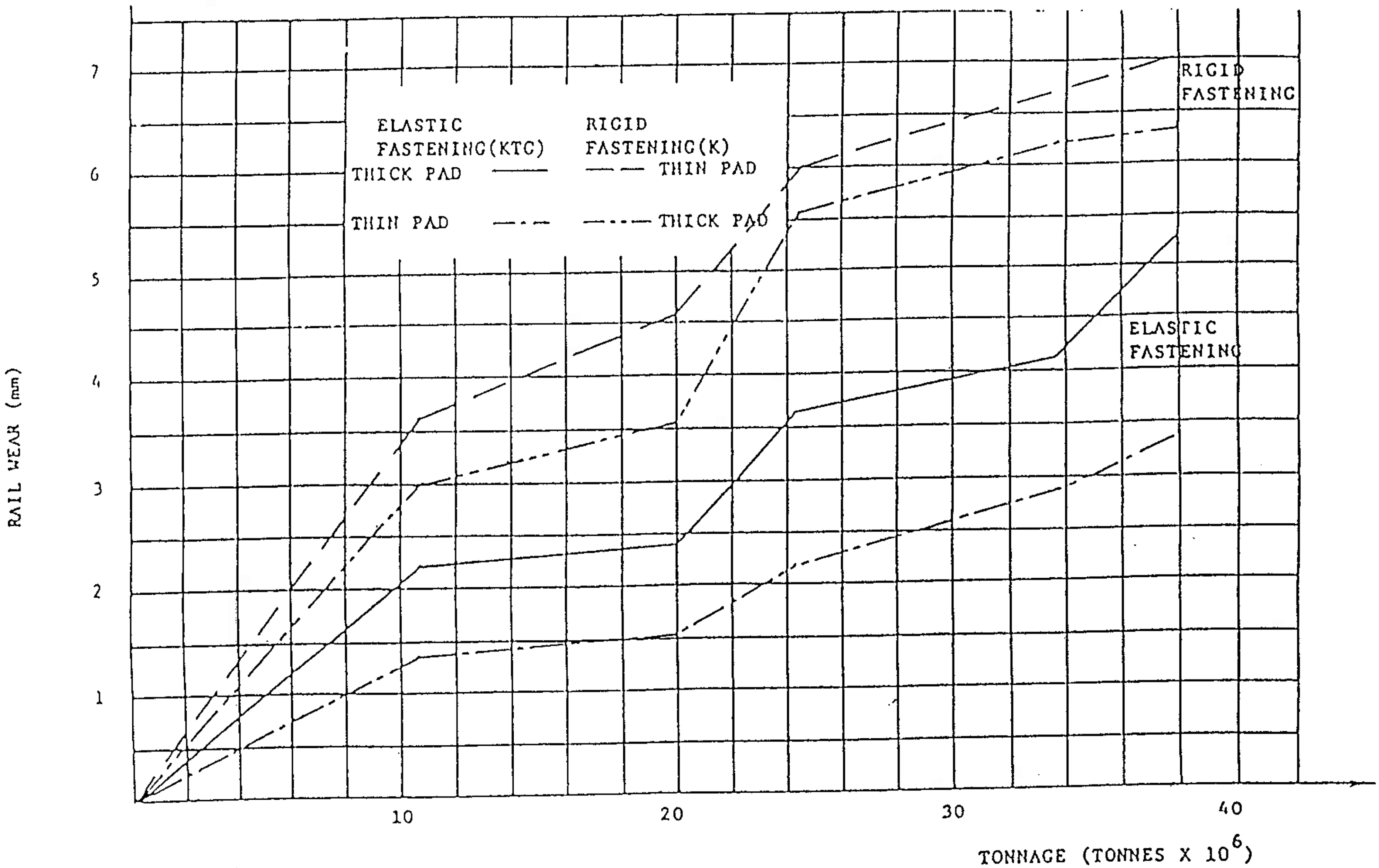
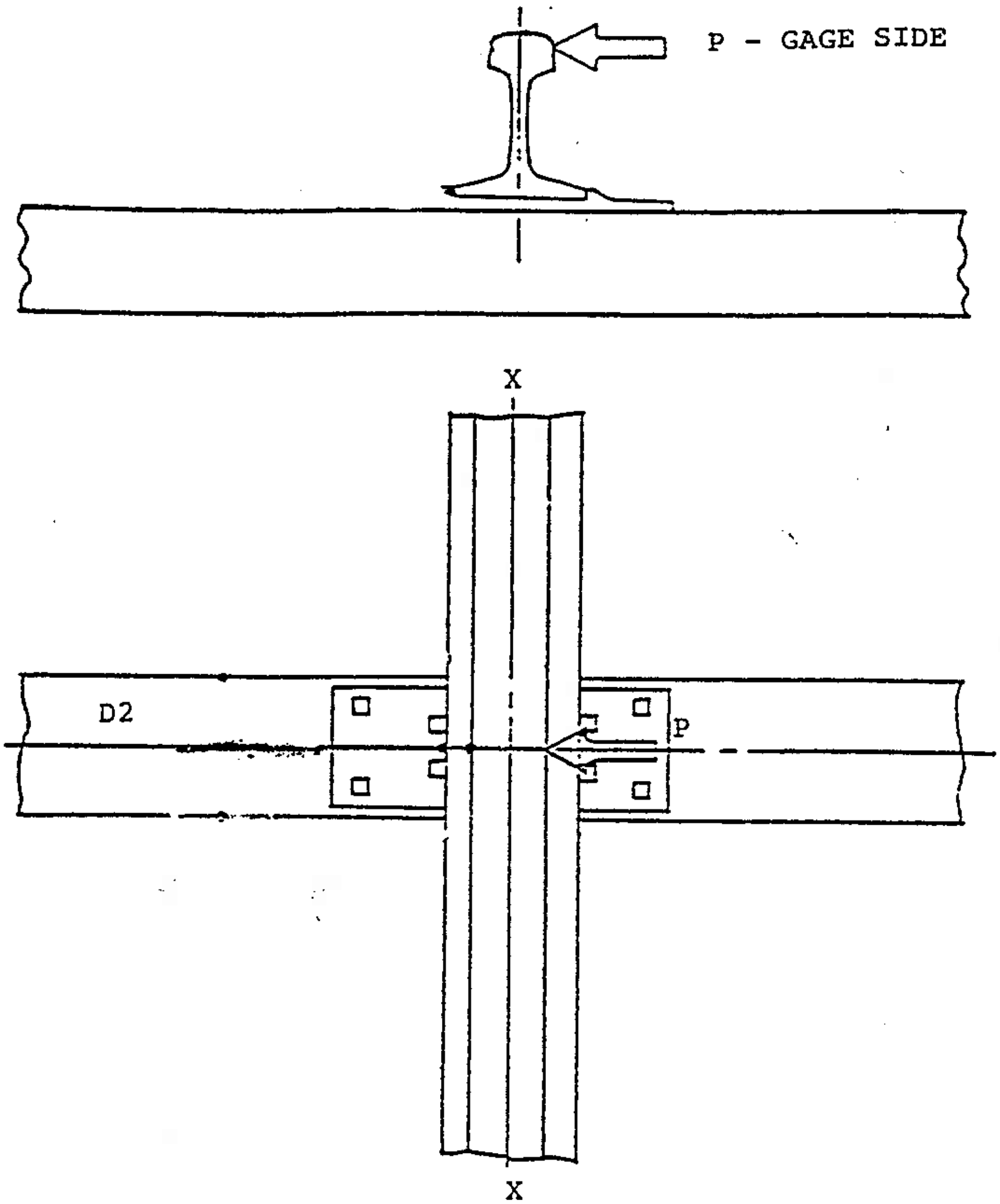



FIGURE 12

RAIL WEAR FOR RIGID VS ELASTIC FASTENINGS




Stiffness = $\frac{\text{Moment}}{\text{Rotation about Axis}}$

Where moment = Pxh in in-kips
and Rotation is in radians

Figure 13 Fastener Stiffness
About Longitudinal Axis

TABLE 4

FASTENER ROTATIONAL RESISTANCE TEST RESULTS FOR 115 RE RAIL SECTION ON WOOD TIES

| TYPE OF FASTENER | ROTATIONAL STIFFNESS 10**6(LB.-IN/RADIAN) VERTICAL AXIS | LATERAL AXIS | LONGITUDINAL AXIS |
|---|---|---|---|
| 2 CUT SPIKES | 0.92* | 1.68 | 1.49 |
| 4 CUT SPIKES | 3.32* | 1.64 | 3.09 |
| PANDROL | 3.52* | 0.73 | 1.66 |
| SCREW SPIKE | 1.27 | 1.89 | 2.60 |
| COMPRESSION CLIP | 2.79 | 0.94 | 1.99 |

Rail Rotation

As presented in Figure 11, rail rotation is the relative movement of the railhead with respect to the rail base. Noting the test data presented in references 20 and 21, it can be seen that this mechanism generally account for the largest amount of railhead movement, particularly in track in relatively good condition . This is clearly illustrated in Figure 14, which shows test data for gage widening resistance.

Rail rotation is a behavior that occurs only under combined lateral and vertical loading, when the vector sum of the two loadings falls outside the base of the rail (see Figure 11). When this occurs, the rail is potentially unstable and the fastener system begins to resist the overturning movement of the railhead. This condition occurs when the ratio of the lateral and vertical forces, the L/V ratio, exceeds 0.6, the exact value being dependent on the geometry of the rail section (17).

Rail rotation is given in lateral movement of the railhead (in inches) with respect to the rail base. (Note, for total dynamic gage widening (under load), rail rotation (inches) must be added to the rail translation.)

Once again referring to the above defined loadings, for new fastener/tie systems, railhead deflection with respect to the rail base, should be less than .25 inches per rail seat. For "old" systems, it should be less than .4 inches per rail seat.

DYNAMIC GAGE WIDENING

In order to effectively define the performance of the entire track structure, it is necessary to define the total gage widening under load, i.e., the dynamic gage widening. This is the total gage widening of both rails under loadings. Note, for total dynamic gage widening (under load), rail rotation (inches) must be added to the rail translation (in inches) for both rails.

As defined here-in, the dynamic gage widening values do not include rail wear. They are based on a new railhead only.

Once again noting the above levels of loading, the total dynamic gage widening, new, should be less than 0.4 inches. Likewise, the old value i.e., after the defined "life", should be less than 0.75 inches.

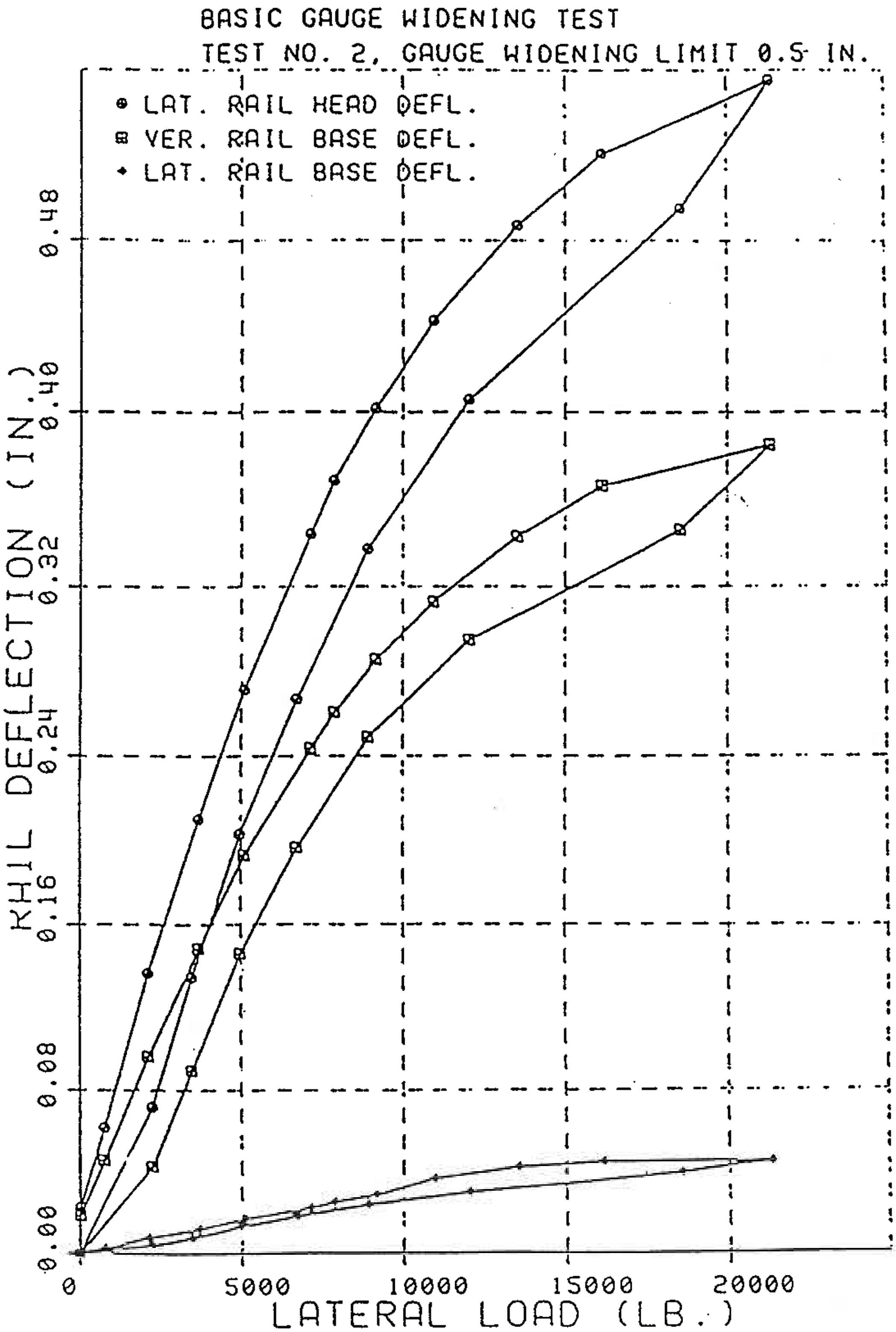



FIGURE 14 GRAPH SHOWING VARIOUS RAIL DEFLECTIONS VS LATERAL LOADS, FOR ZERO VERTICAL LOAD.

## III.3 LATERAL TRACK STRENGTH (SHIFT/BUCKLING RESTRAINT)

As noted earlier, the lateral loading of the track structure results in two distinct mechanisms of deformation. the first, gage widening has already been discussed. the second mechanism, that will be discussed in this section, is the lateral movement of the entire track structure, i.e., the lateral shift of the track. This lateral shift can be either slow, such as occurs with a loss of alignment, particularly on curves where the lateral loadings are most severe, or it can be abrupt such as due to a sun kink or track buckle (15). Lateral resistance of the track structure is a key aspect of this deformation behavior in both cases.

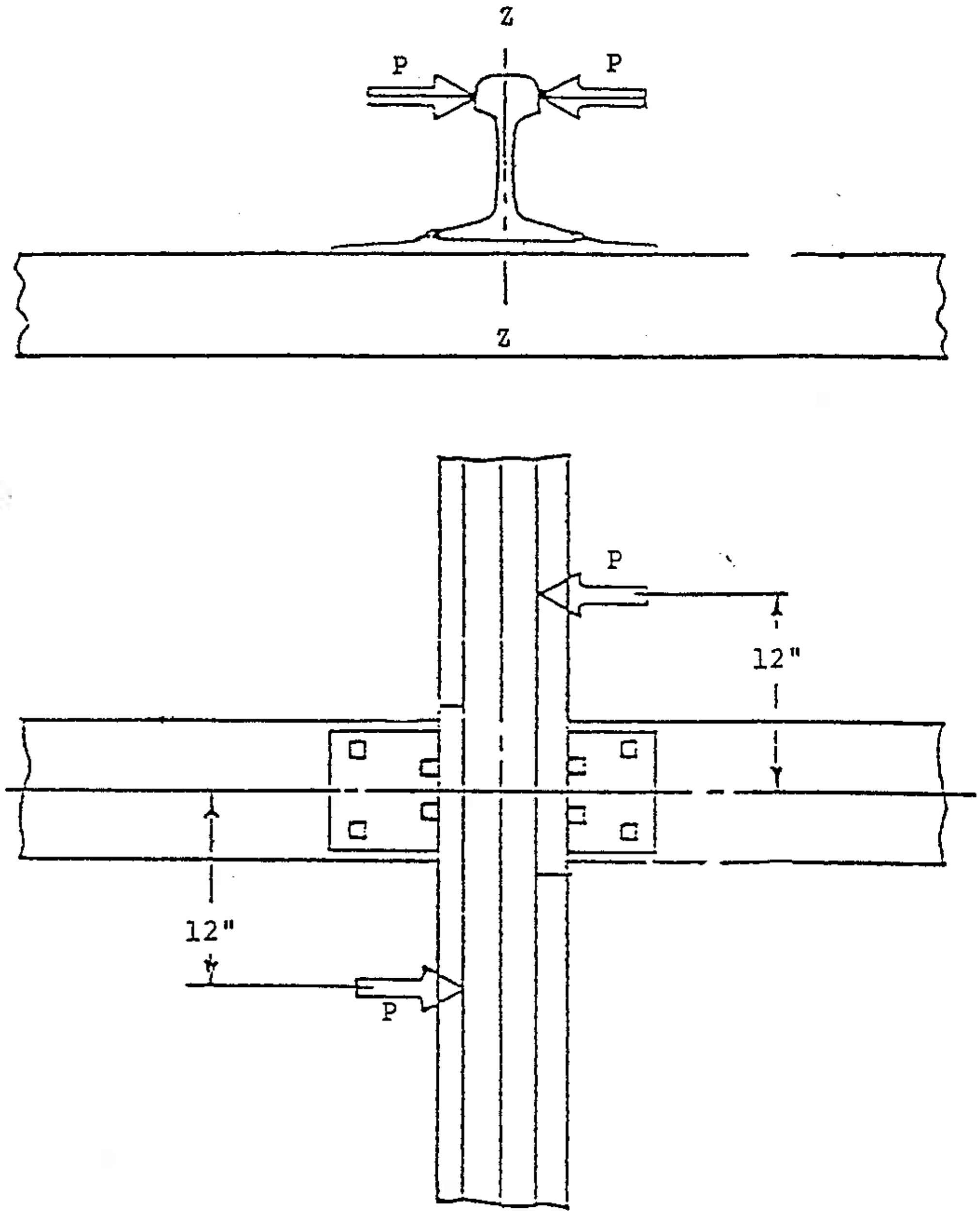
Lateral track resistance is primarily related to the tie/ballast resistance mechanisms, rather than the rail/tie mechanisms (22,23). This is true for both lateral track deformation mechanisms, lateral shift (22) and lateral track buckling (15,24). Improving the resistance of the tie in the ballast, such as by modification of the tie/ballast system (which is outside the scope of this specification), provides a significant increase in resistance to lateral shift. However, the fastener system provides a secondary effect in that it affects the frame strength of the track, and consequently its lateral resistance (25).

The in-plane torsional resistance of the fastener (i.e., the torsional resistance about the vertical axis, as illustrated in Figure 15) directly affects the frame strength of the track structure. This is the strength of the rail/tie system, with the rails acting as the longitudinal frame members and the cross-ties as the cross members. The fasteners then act as torsional springs in the plane of the track (Figure 15), which directly affect the total structural stiffness (lateral). Variation in this torsional resistance, will affect the lateral deformation of the track under load, but the effect of this stiffness, is generally an order of magnitude (factor of 10) below the effectiveness of the tie ballast interface.

Noting the definition of the torsional resistance about the vertical axis (Figure 15) and the previously defined units (in-Kips/radian, i.e., the applied moment divided by the resulting rotation), and noting the range of values for existing fasteners presented in Table 4, the following range of torsional stiffness values (about the vertical axis) are specified.

Range of in-plane torsional resistance= 3000- 5000 in-Kips/radian

The effect of this stiffness variation on the deformation of the rail-tie structure is presented in Figure 16.



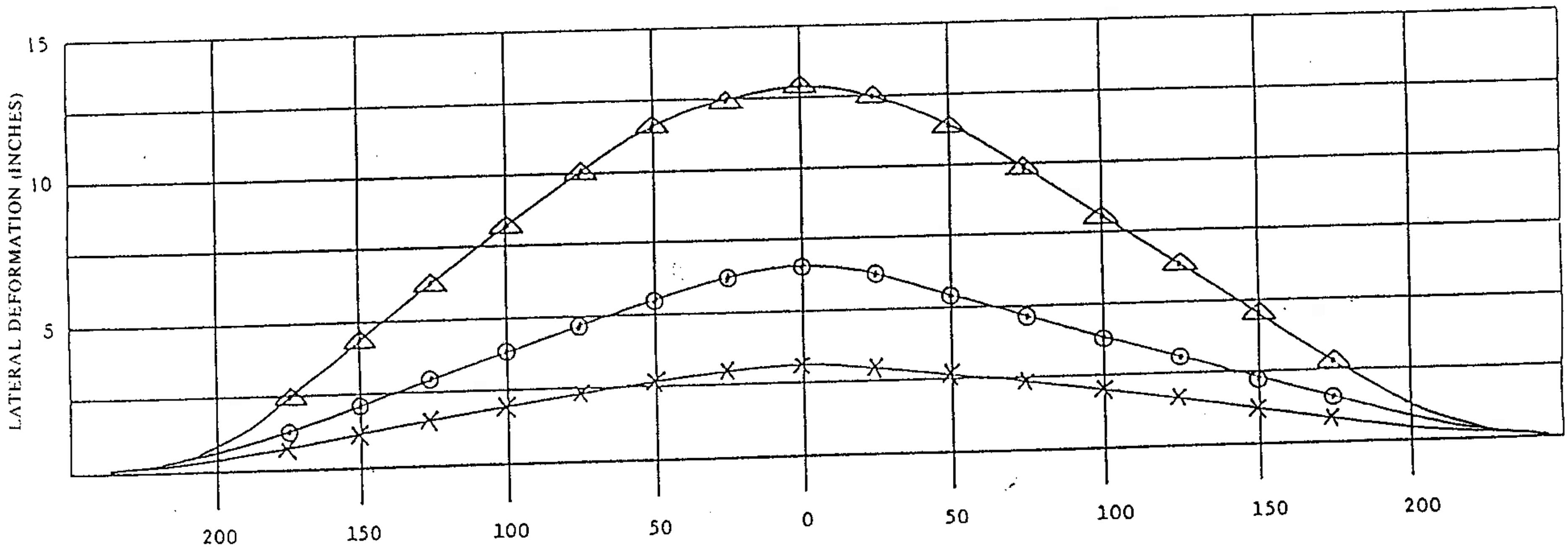

$$\text{Stiffness} = \frac{\text{Moment}}{\text{Rotation about Axis}}$$

Figure 15 Fastener Stiffness
About Vertical Axis

LATERAL DEFORMATION OF TRACK

(NO BALLAST)

EFFECT OF FASTENER STIFFNESS




LATERAL LOAD = 10,000 lbs applied at center of track (0)

X  Y = $5X10^6$ (PANDROL CLIPS)

⊙  Y = $1.5X10^6$ (NEW SPIKES)

△  Y = $1.5X10^4$ (OLD SPIKES)

FIGURE 16

An additional effect on track buckling, associated with fastener/tie systems is the longitudinal resistance of the system, as already discussed. Once again, the tie/ballast resistance is the dominant influence with the tie/fastener resistance playing a distinctly secondary role, unless the fastener longitudinal restraint is less than the tie/ballast restraint, and rail slippage occurs.

## III.4 VERTICAL STRENGTH (PERFORMANCE)

Vertical strength refers to the ability of the tie/fastener system to respond to loadings in the vertical plane. As noted earlier, Figure 2 presents a spectrum or distribution of vertical wheel rail dynamic loadings that is representative of the dynamic loading environment of the track structure. These loads are then transferred to the individual tie/fasteners in a manner previously described (Section II). As noted earlier, beam-on-elastic foundation theory has been used in the determination of the vertical behavior of the track structure (5,6,7).

### Uplift Strength

Uplift strength is the resistance of the fastener system to vertical uplift (upward) forces that can cause pullout or yielding of key fastener components. These can be due to either the vertical component of the rotational forces (see Figure 11) or to the vertical uplift forces due to the track "uplift" wave (from beam on elastic analysis), and the corresponding ability of the fastener to support the track superstructure (rails,ties, fasteners). Note: an alternate design, which allows the rail to "float", such as the cut spike system, does not require any resistance to the uplift wave, since in this case the rail is free to move vertically within the bounds provided by the fastener. However, there is no longer any longitudinal restraint provided by the fastener in this case and so an external system, such as the rail anchor, must be used for the longitudinal restraint.

The effect of track uplift, due to the track acting as a beam on elastic foundation, provides a force of approximately 600 to 850 lbs/foot of uplift (at the precession wave), depending on the track modulus. (Note this corresponds to 20% of the effective downward force) However, for wood tie track, this is more than the weight of the rails, ties, and fasteners, whose weight is of the order of 350 to 400 lbs/foot. Therefore there is a net upward force of over 200 lbs/foot,which indicates that the track superstructure, will be lifted (approximately 1/16 inch). This net vertical force is a corresponding pullout resistance.

In addition, the applied loadings previously defined can result in an individual fastener uplift force that is a function of the specific fastener design. Therefore, the fastener must be designed so as to withstand these previously defined loadings, without any additional deformation of the system.

Static Strength

The static strength of the tie/fastener system is based on the crushing strength of the wood under the applied vertical loading (see section II). This loading, when converted to a per railseat vertical force, is used to determine the minimum bearing area of the fastener system on the tie necessary to avoid crushing of the tie fibers.

Noting the crushing strength of hardwood ( specifically those used in Railroad applications) ranges from 300 to 1,000 lbs./ square inch (compression perpendicular to grain; Reference 26), the vertical fastener load of 21,500 lbs requires a minimum fastener bearing area of 75 square inches. For softwood ties, this value increases to 100 square inches of fastener bearing area.

Dynamic Strength

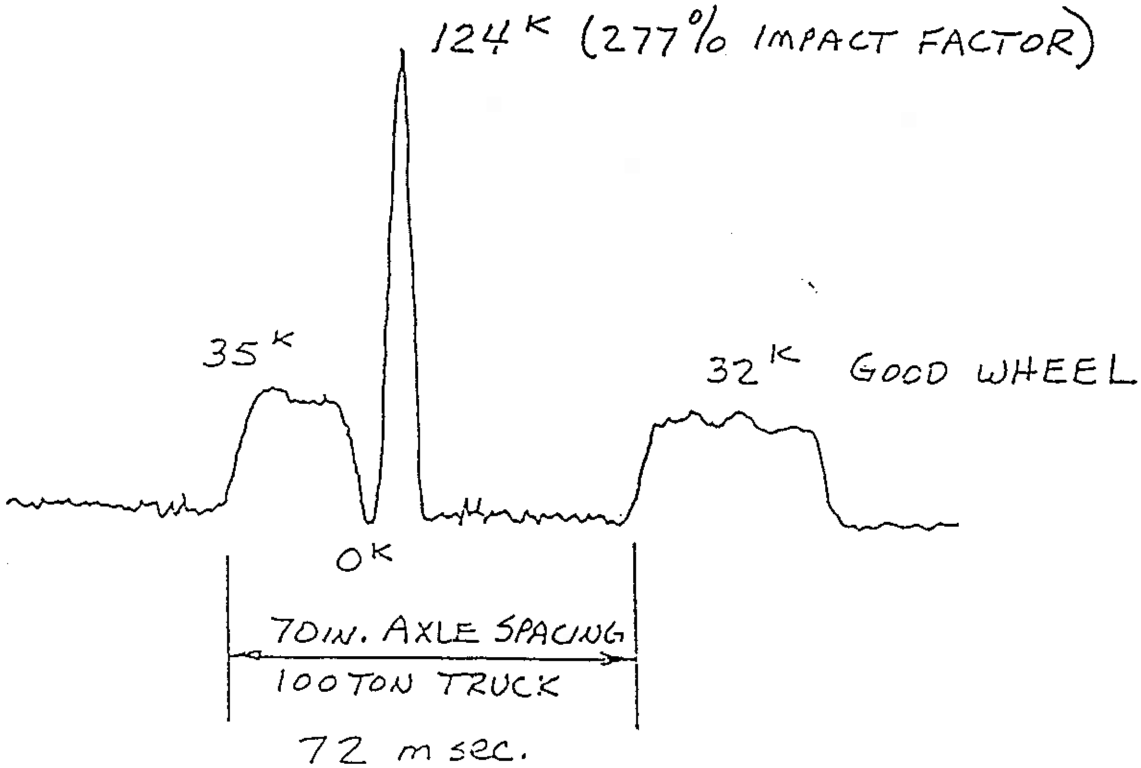
As noted earlier, dynamic fastener loads (vertical) can be as high as 21,500 lbs per rail seat. This does not take into account any dynamic impact sources, such as defects on the rail surface (corrugations, engine burns, battered welds), rail joints, or imperfections in the wheel tread, i.e., flats or out-of-round wheels. These defects can magnify the dynamic loads by factors of 2 to 3 (4), thus providing an instantaneous load (of very short duration) per rail seat of the order of 66,000 lbs, vertical. These forces must be transmitted through the tie/fastener system without failure of any tie or fastener component. An example of a particularly severe impact on stiff concrete tie track, is presented in Figure 17 (27). Note, the very short duration of the impact peak (9 milliseconds) in comparison with the total load duration of 72 milliseconds. For stiff track, such as concrete tie track, soft rubber pads are required to reduce the effect of these impact forces (4,27).

In the case of wood ties, the tie itself, acts as a resilient pad to reduce the effect of these impact forces. This is a particular feature of the wood material itself, in that it has a very high natural resiliency. The wood cross-tie acts, in fact, as if it were a 6 or 7 inch thick pad, with good dynamic attenuation capability. Thus these dynamic impact effects are immediately reduced.

In general the allowable flexural strength of the wood tie, is significantly greater than that required by the dynamic loading, because of this resiliency. Therefore, the issue of wood tie "cracking' does not enter into any design consideration (6).

However, the dynamic strength of the fastener system must be such that it can endure short duration dynamic impact loads of up to 66,000 lbs vertically, for a duration of 10 to 15 milliseconds, without component failure.

"This page intentionally left blank".




IMPACT LOADING FROM WHEEL
WITH" OUT-OF-ROUND " DEFECT

FIGURE 17

## IV. PERFORMANCE REQUIREMENTS

The previous section has presented a set of track strength performance requirements for the fastener and/or fastener/tie system. These strength characteristics are the directly quantified values which can be addressed through conventional design engineering. However, in addition to these strength requirements there are an entirely new set of requirements, some not readily quantifiable, which address the operational and maintainablility characteristics of the tie/fastener system. These are a set of "practical" characteristics (14) that relate to the ability of the fastener system to accommodate itself to railroad practices and to use by "typical" railroad personnel.

These performance characteristics can be as important as the strength characteristics because they address those issues of usage and "practicality" that lend themselves to direct use by appropriate railroad personnel.

### IV.1 LIFE

Fastener life has been defined to be the "period of time or cumulative tonnage until the fastener, or its individual components, must be replaced" (14). In actuality, fastener life is an economic criterion as well as a design criterion, since there is a tradeoff between increased cost and increased life. However, from an operational point of view, there is in fact a minimum "practical" life that should be achieved by any rail fastener, in order to avoid excessive efforts on the part of the local maintenance of way forces. It is this aspect of the operational considerations that provides a justification for a "premium" type fastener, whose first cost is higher than a conventional system, but whose overall (life-cycle) cost can be significantly lower. While it is beyond the scope of this report to address the issue of system economics, the operational considerations noted above will result in a definition of component life, to be presented here.

The general approach presented here addresses the fastener or tie/fastener system as a system, rather than as individual components. Therefore, individual fastener components should not be evaluated as to their individual strength or performance. Rather this evaluation should be performed at the tie/fastener system level. If the system meets the above defined performance levels than the components will be deemed acceptable, <u>provided no visible breakage or component failure is observed.</u>

As was previously presented, "life" is defined in terms of either cumulative tonnage (in Million Gross Tons) or in years. In the case addressed here, that of a high density, severe environment operation, it is anticipated that the cumulative tonnage life will be reached, well before the time based (year) life limit. Note; this value defines the time in which the "old" strength criterion must be addressed.

Therefore, as noted earlier (section III), the fastener systems must be capable of maintaining a defined level of performance after a minimum of 1,000 MGT or 30 Million cycles of loading (at 33,000 lbs. wheel load per cycle).

This is based on the minimum life of rail in tangent or low curvature mainline service. It is expected that the fastener should not be replaced prior to this minimum mainline rail life. (Note: on curves rail life is shorter, however the fastener life should be equal to several curve rail life cycles.)

Since this specification is defined to be a severe environment specification, it is expected that the annual tonnage levels will be quite high and that the minimum life, in tonnage, will occur, before any life limit (in years) is reached. However, for the sake of completeness, a supplemental "life" value of 20 years, is also defined. In this definition, minimum life is attained when either of the two parameters, cumulative tonnage or years in service, is first reached.

In addition to the above defined life values, an additional value, which can be called "repeated applications" value, can also be defined. This requires that the fastener be capable of surviving repeated removal/application cycles of the rail holdown portion (not necessarily the connection between the fastener and the tie) during the above defined "life", without excessive loss of strength. The number of such cycles is set here-in to be 6 removal/application cycles.

At the conclusion of 30 Million cycles or 1,000 MGT, the "old" strength values must be at a level equal to 90% of the "new" strength levels defined for all strength categories, unless indicated otherwise. The "repeated applications" value should be equal to the "old" value unless stated otherwise.

## IV.2 ELECTRICAL INSULATION

The fastener/tie system must provide adequate electrical isolation of the rail to prevent interference with signal systems and deterioration of the fastening system through electrical leakage. This is particularly important for high density trackage since it is most likely to be signaled territory. The electrical insulation properties must be such as to maintain a minimum resistance value between the two rails in a wet and dirty ballast environment.

Noting this requirement, the resistance for a wet and dirty environment for the fastener/tie system must be at least 20,000 ohms.

It should be noted here that wood is a natural insulator material. As such, the natural electrical resistance of the wood cross-tie is such that it should provide sufficient electrical insulation without the need for additional external fastener components. This should hold true except for those cases where the fastener/tie system is such that it provides a conductive medium through the ties and thus short-circuits the insulative properties of the wood ties.

## IV.3 MAINTENANCE CONSIDERATIONS

Maintenance considerations or maintainability relates to ease of use and acceptability of the fastener systems by railroad forces. These are unquantifiable factors that enter into the design and application of the fastener system.

### Ease of Use

An important consideration in the acceptability of a fastener system is the ease in which that system can be handled by field forces. This relates only to that portion of the fastener system that must be handled by field or gang forces, specifically the rail holdown portion of the fastener (i.e., the rail holdown clips, bolts, etc.) The connection between the fastener and the tie does not have to be "easy to use" if it is separate from the rail holdown system. In fact, a secure fastener holdown assembly is an advantage (it is an important part of the strength requirement as well). Thus the plate holdown system (fastener to tie connection) can be such as to require pre-assembly in plant or in a yard.

Therefore, the rail holdown portion of the fastener system should be readily installed or removed by local forces in the field. It is not necessary for the field forces to remove or install the fastener to the tie. However, it is important that the local forces be able to readily remove and install the rail hold-down portion of the system, so as to allow for various field maintenance activities.

This operation, relating to rail removal, should be capable of being performed in the field, by local forces, using convention and commonly available hand tools. If special hand tools are required, they should be kept to a minimum level (multiple "special" tools becomes a burdensome activity in transportation and availability).

Finally, the amount of physical effort required to remove the fasteners, with these hand tools, should be kept to a minimum. However the fastener system should be resistant to tampering in the field by unauthorized personnel using rocks or other crude tools.

In order to avoid confusion and improper or incorrect installation in the field, the portion of the fastening system that must be removed and reinstalled in the field should be kept as simple as possible. In addition, the fastening system components should be readily identifiable, as to their location and direction of installation so as to avoid improper installation of components and assembly of system (in the field). If the possibility for confusion exists, fastener components must be appropriately identified to avoid improper field application. This does not apply to that portion of the fastener system that would be applied in the plant and not removed or disassembled in the field.

## Potential for Mechanization

For large production applications, the industry trend is towards mechanization of all large production gangs. This is in keeping with an overall industry philosophy of increased productivity of operations.

If the fastener system, specifically the rail removal and installation feature, allows for mechanization, this would be extremely attractive from an overall "economics" point of view, since it will not interfere with the production gangs rate of work. The requirements for a manual application, within the context of a large production gang, could result in the loss of overall gang productivity, and a correspondingly higher installation cost.

Therefore, the fastener system should directly lend itself towards mechanized application. This should specifically permit the development and use of production fastener inserters/removers within the overall context of a railroad production gang.

## Field Adjustment Requirements

In the railroad environment, there is very limited capability for "follow" up adjustment of systems. Such a follow up entails high manpower costs associated with specialized maintenance gangs or local force activities. In order to eliminate or minimize these follow up costs, the fastener/tie system should not require any period adjustment, such as bolt tightening, retorquing, clip retensioning, etc., after the initial installation and adjustment. The system should be installed and should maintain its performance at the above defined performance levels without any additional attention on the part of the maintenance forces.

Ease of Inspection

In order to facilitate field inspection of the track structure in general and of the fastener system in particular, the fastener system should allow for ease of visual inspection of all key parts by local inspections. This should include the ability to observe all components for breakage and/or movement from "proper" position.

Environmental Effect

The fastening system must retain its ability to perform (as defined previously under track strength) for the entire range of environmental conditions encountered in the railway to include rain, ice, snow, heat and cold.

IV.4 DERAILMENT AND DAMAGE

While it is impossible to expect that any track system should be able to survive a derailment, in which the full brunt of the derailment force is concentrated on the fastener, it is possible to design a system so as to minimize the "potential" for derailment or other damage, such as damage due to other mechanized maintenance operations. Such design features can include a "low" profile, i.e., a profile significantly below the bottom of the railhead, and an orientation such that the fastener, even when "hit" by a wheel or piece of maintenance equipment, will not completely fail. The ability to maintain a minimum level of performance under such adverse circumstances is extremely desirable.

Derailment Performance

Noting the above, the fastener system should have a high "survivability" rate in the event of a derailment and should maintain a minimum "emergency" level of performance even when subject to extreme conditions, i.e., derailment conditions. This level is defined to be 40% of the previously defined performance characteristics. Note however, that this is not an absolute requirement, but rather a desirable condition that would strongly depend on the specific mechanism and conditions of the derailment.

In conjunction with this, the fastener system should allow for the replacement only of those parts of the system damaged during the derailment, while retaining "undamaged" components as much as possible. In this case, it may not be necessary to replace all of the fastener components, but only those that have truly "failed".

The fastener should avoid any damage to other track components, in the event of a derailment, such as "nicking" of the rail.

Vulnerability to Field Damage

In conjunction with the above derailment criterion, the fastener system should not be vulnerable to damage in the field due to the operation of conventional maintenance equipment. Particularly, "low" profile maintenance equipment, such as brooms and ballast spreaders, should not cause damage to the fastener system nor should they result in displacement or removal of the rail hold down fasteners themselves.

As noted earlier, fastener systems must be capable of maintaining a defined level of performance after 1,000 MGT or 30 Million cycles of loading (at 33,000 lbs. wheel load per cycle).

At the conclusion of 30 Million cycles or 1,000 MGT, the above strength values must be at a level equal to 90% of the strength levels defined above or at the "old" parameter strength value for all strength categories.

## V. References


1. American Railway Engineering Association, "Manual for Railway Engineering", 1986.

2. Association of American Railroads, " Field Manual of the AAR Interchange Rules, Rule 91.

3. Zarembski, A. M. and Abbott, R. A., " Fatigue Analysis of Rail Subject to Traffic and Temperature Loading", Association of American Railroads Report R-315, July 1978.

4. Ahlbeck, D. R., "An Investigation of Impact Loads Due to Wheel Flats and Rail Joints", American Society of Mechanical Engineers, 80-WA/RT-1, November, 1980.

5. Talbot, A. N., et al, "Report on the Special Committee on Stresses in Railroad Track", Bulletin of the American Railway Engineering Association Bulletins 205,224, 253, 275, 319,358 and 418, 1918-1940, Reprinted as <u>Stresses in Railroad Track - The Talbot Reports</u>, AREA, 1980.

6. Hay, W. W., <u>Railroad Engineering, Second Addition</u>, John Wiley and Sons, 1982.

7. Hetenyi, <u>Beams on Elastic Foundations</u>, University of Michigan Press, Ann Arbor, 1946.

8. Koci, L. and Marta, H., "Lateral Loading Between Locomotive Truck Wheels and Rail Due to Curve Negotiation", ASME, winter Annual Meeting, 1965.

9. Koci, L. and Marta, H., " Wheel and Rail Loadings from Diesel Locomotives", AREA Annual Meeting, 1971.

10. Koci, L. and Swenson, C., " Locomotive Wheel and Rail Loadings - A Systems Approach", Heavy Haul Railways Conference, Perth Western Australia, September 1978.

11. Klinke, W. and Swenson, C., " Tracking and Ride Performance of Electro-Motive 6 Axle Locomotives", 13th Annual Railroad Engineering Conference, Pueblo, CO, 1976.

12. Manos, W. et al, "Development of an Improved Vehicular Loading Characterization Associated with the Gage Strength of Track", AAR Report R-493, August 1981.

13. Weinstock, H., "Wheel Climb Derailment Criteria for Evaluation of Rail Vehicle Safety", American Society of Mechanical Engineers, Paper 84-WA/RT-1, 1984.

14. Zarembski, A. M., "Performance Characteristics for Wood Tie

Fasteners", Bulletin of the American Railway Engineering Association, Bulletin 697, October 1984.

15. Kerr, A. D., "Thermal Buckling of Straight Tracks; Fundamentals, Analyses and Preventive Measures", Bulletin of the American Railway Engineering Association, Bulletin 669, September 1978.

16. McConnel, D. P., Letter to J.O. Born, Chief Engineer Maine Central Railroad, July 1980, describing Federal Railroad Administration/Transportation Test Center tests on U.S. Railroads in 1974.

17. Zarembski, A. M., " Rail Rollover, The State of the Art", Bulletin of the American Railway Engineering Association, Bulletin 664, September October 1977.

18. Mirtchev, M. and Nedjalkov, G., "The Influence of Railway Track Parameters on the Intensity of Side Wear on of Rails on Small Radius Curves", Rail International, April 1981.

19. Choros, J. and Gitlin, I., "Track Component Property Tests, Volume II, Ties, Joint-Bars and Fasteners", Federal Railroad Administration Report, FRA/ORD-80/25, June 1980.

20. Zarembski, A. M. and Choros, J., "Laboratory Investigation of Track Gage Widening", AAR Report, R-395, September 1979.

21. Choros, J., "Laboratory Tests on Three Alternative Track Structures", AAR Report R-614, September 1985.

22. Leshchinsky, D. "Development of Predictive Equations for Lateral Track Behavior", AAR Report R-481, June 1981.

23. Frederick, C. O., "The Effect of Lateral Loads on Track Movement", Railroad Track Mechanics and Technology, Pergamon Press, 1978.

24. Kish, A. et al, "Influence of Vehicle Induced Loads on the Lateral Stability of CWR Track", Federal Railroad Administration Report DOT-TSC-FRA-84-6, November 1985.

25. Kerr, A. D., "Effect of Torsional Fastener Resistance on the Lateral Response of a Rail-Tie Structure", Federal Railroad Administration Report FRA/ORD 78/35, September 1978.

26. Forest Products Laboratory, "Wood Handbook", U. S. Department of Agriculture.

27. Scott, J. F., "Evaluation of Concrete Turnout Ties and Bridge Ties", American Railway Engineering Association, Bulletin 706, May 1986.

Attachment I. Technical Specifications

## PERFORMANCE SPECIFICATIONS
## WOOD TIE-FASTENERS

This specification is intended to provide necessary guidance in the design, manufacture, and use of rail fasteners and their components on timber cross-ties in heavy duty main-line applications. These specifications are <u>performance</u> specifications, and as such, address the ability of the fastener/tie system to carry out its designed functions within the context of the defined loading environment, specifically high curvature, heavy axle load, mainline operations. This specification contains minimum performance requirements of fastener systems based on a range of track design parameters, as recommended by the American Railway Engineering Association. This specification is restricted to positive restraint rail fasteners and specifically excludes cut spike and rail anchor types of fastening systems. Track constructed of tie and fastener systems meeting this specification are expected to provide satisfactory performance over the minimum service life, in track, under current AAR approved maximum axle loads.

Where current specifications or recommended practices of other technical societies such as the American Railway Engineering Association (AREA) or the American Society of Testing Materials (ASTM) are appropriate to this specification, they are made part of this specification by reference.

GENERAL:

The performance specifications defined here-in are divided into two major areas of activity; Track Strength and Track Performance. The first of these areas, Track Strength, relates directly to the ability of the tie/fastener system to adequately and effectively perform its functions under the defined conditions of vehicle and environmental loadings. The second area, Track performance, refers to those non-strength factors that relate to the ability of the fastener system to accommodate itself to railroad practices and operations.

The system specified here-in is a fastener/tie system capable of operating in and performing satisfactorily under conditions of high curvature, high density, heavy axle loadings in mainline North American railroads. This system is designed to function as part of an overall track structure, and as such, requires that the remaining portions of the track structure, not covered in this specification, be of suitable strength and meet minimum performance specifications required for the defined operating environment. Therefore, the remaining portions of the track structure, to include rail, tie (those requirements not covered within the scope of this specification), ballast, sub-ballast, and subgrade must meet or exceed their associated performance requirements, as defined by the American Railway Engineering Association.

The specific loading environment defined for the level of operations towards which this specification is addressed is as follows:

LOADING ENVIRONMENT

The following parameters define the loading environment on which these performance specifications are based.

VERTICAL LOADING

NOMINAL VERTICAL WHEEL LOADINGS (STATIC); Current Association of American railroads (AAR) limits for interchange traffic.

33,000 lbs.

DYNAMIC LOADINGS

Dynamic loading formula for the effect of vehicle operating speed on vertical wheel loads; American Railway Engineering Association

Dynamic load = Static load * (1 + 33V/100D)

where V= speed in mph
D= wheel diameter in inches

Thus for 50 mph and 36 inch wheels, this produces a dynamic wheel load of 48,100 lbs.

Impact Load

Impact due to wheel or rail defects. Based on impacts due to wheel defects (flat spots, out-of-round conditions, etc.) or rail defects (corrugations, engine burns, battered joints, battered welds, etc.) Dynamic multipliers of between 2 and 3 are here-in defined for "significant" defects. A significant wheel defect is defined to be one that exceeds AAR interchange standards or equivalent. A severe rail defect is defined to be a defect greater than 0.050 inches over an 18 inch wavelength.

Therefore design loadings for impact consideration are:

66,000 to 99,000 lbs wheel load.

Underbalance/Overbalance Speed Effects on Curves.

Under operational conditions in which train operation is below or above balance speed, the effect of the underbalance/overbalance speed is to augment the loading on the low/high rail. This effect is based on difference between actual and design/balance speed and can cause an augment to the vertical load of up to 50% (Factor of 1.5).

VERTICAL FASTENER LOAD

Treating the track structure as a beam on elastic foundation (per AREA recommended practice)

Fastener receives 20 to 45% of vertical wheel load (depending of foundation modulus, u)

This corresponds to a fastener vertical load of 21,500 lbs. (dynamic).

LATERAL LOADINGS

LATERAL WHEEL LOADINGS

Lateral wheel loadings are a function of the track curvature, wheel/rail interaction and vehicle/track interaction.

Measured wheel/rail loads for heavy curvature track are:

Steady State Loadings: 16,000 lbs for three axle trucks and
12,000 lbs for two axle trucks.

Dynamic Loading (Steady State + Transient)

35,000 lbs for three axle locomotives.

LATERAL TIE/FASTENER LOADS

Load at Tie:

Dependent on Rail and Fastener stiffness.
Tie receives Between 25% and 50% of wheel/rail force.

Load at Fastener:

Dependent on base friction between tie plate and tie.
Lateral Fastener Load is equal to the lateral tie load minus the Vertical load multiplied by the effective coefficient of friction.
Fastener receives between 20% and 45% of wheel/rail lateral loads.

This corresponds to a fastener lateral load of up to 15,000 lbs. (dynamic).

L/V RATIO

Ratio of Lateral/Vertical Wheel/Rail loads
For locomotive operations ranges from .6 to .8.

L/V ratios greater than 0.6 required for rail overturning.

L/V values greater than 0.8 approach the Nadal limit for wheel climb.

LONGITUDINAL LOADINGS

VEHICLE
BRAKING/ACCELERATION
Peak force= 60,000 lbs.

"normal maximum force"= 20,000 lbs.

ENVIRONMENTAL-THERMAL

For 132 RE rail
at a 100 degree temperature change
Force = 250,000 lbs.

A. TRACK STRENGTH

The key portion of the fastener performance requirement is the strength of the tie/fastener system, i.e., its ability to carry the vehicle and environmental loadings. These strength requirements form the basis of the performance specification.

There are four basic areas of track strength performance:

- Longitudinal Strength
- Lateral Strength
  - Gage Widening Resistance
  - Lateral Shift Resistance
- Vertical Strength

For each strength area a performance requirement, defined as an ability of the tie/fastener system to resist external loading, must be specified.

Defined Values.

For each performance parameter two sets of values are defined here-in, a "new" value, its strength when it is new, and an "old" value" which is its strength after being in traffic. This value is based on the life of the fastener/tie system. For mainline track a minimum life of 500 to 700 MGT is defined, corresponding to the life of rail in tangent track under heavy axle load conditions. For 33,000 lb. wheel loads, this translates into 15,000,000 to 21,000,000 loading cycles. (Note, for low tonnage track, a supplemental life of at least 20 years in track is defined. In this definition, minimum life is attained at the time that either parameter, cumulative tonnage or years is track, is first reached. However, for the purpose of this specification, high density track will generally result in the cumulative tonnage life being reached first.)

In addition to the above defined values, a third value, "repeated applications", is defined, which represents the strength of the fastener system after multiple removal/applications of the fasteners. This requires that the fastener be capable of withstanding multiple removal/applications during the course of the above defined "life" without excessive loss of strength. This minimum strength after repeated applications represents the required minimum strength value after 6 repeated removals and replications. Note, for mainline curves, this could be 4 to 8 times during the life of the tie.

The fastening system and its individual components must be resistant to corrosion and decay (due to radiation, moisture, temperature variations and corrosive chemicals, as can be encountered in a range of track conditions found in North America). The life of these components, and specifically the strength of the of the fastener/tie system must meet the defined component life specifications based on strength levels and tonnage history. In no case should the component life be less than that of the other parts of the track structure, subject to the same environment.

The following defined track strength parameters shall be obtained for a full range of component tolerances, as defined by the manufacturer. Therefore, these values must be obtained, not only for the nominal tolerance range but for the full range of maximum and minimum tolerances, on each component, when that component is incorporated as part on a complete fastener assembly.

I. LONGITUDINAL RESTRAINT

The ability of the fastener system to provide longitudinal restraint to the rail and prevent rail movement or creepage. Loading is due to train action; braking or acceleration and to thermal (temperature) changes in the rail. Large rail compressive and tensile forces result from temperature changes (both daily and seasonally) with a defined range of -30 to +150 degrees Fahrenheit.

MINIMUM

The minimum longitudinal restraint necessary to prevent excessive rail end gap in the event of pull-apart. It is also to prevent excessive rail movement (longitudinal). Particularly important in a critical "failure" situation in the event of a pull-apart or rail break where the break or gap must be controlled to avoid an excessive gap in the rail. Based on a 132 lb. rail and 19.5 inch tie spacing for a 75 degree temperature change (such as would be encountered in a large portion of continental US) the required minimum restraint per rail seat is:

for a 1" gap 1814 lbs/rail seat
for a 3/4" gap 2720 lbs/rail seat

MAXIMUM

The longitudinal restraint of the rail/tie fastener system should not be significantly greater than the resistance of the tie in the ballast. There is no need for the longitudinal fastener strength to be significantly greater than the tie/ballast strength since any excessive fastener strength could never be used.

Based on tie/ballast resistance data a resistance of 4900 lbs. per tie or 2450 lbs per rail seat is an effective maximum limit. This corresponds to a value of 1500 lbs/ft. per rail seat.

The fastener must maintain a longitudinal restraint value 1200 lbs/ft. per rail seat even after 15 Million cycles and through 4 multiple removal/insertion cycles.

Note: values are in lbs. per track foot, to allow for variation in tie spacing.

Note: this is a static value, without any dynamic excitation of the track structure. The dynamic longitudinal restraint should be no less than 75% of the static longitudinal restraint values.

## II. LATERAL GAGE RESTRAINT

A key fastener function is to maintain track gage under loading, i.e., to prevent dynamic gage widening. Gage widening can be due to rail wear (generally outside the scope of the fastener although affected by fastener stiffness), rail translation (lateral movement of the base of the rail), and rail rotation (rotation of the rail, i.e., overturning).

Based on lateral and vertical wheel/rail (or tie/fastener) loadings. A lateral fastener loading of 15,000 lbs. will be defined under a simultaneous fastener vertical load of 21,500 lbs. This corresponds to an L/V ratio of .70. Note; the potential for rail overturning exists at this L/V, however, it is below the wheel climb limit.

The following deflections are based on this defined load level.

Rail wear. In general, rail wear is effected by the fastener system only in that of a change in the fastener rotational resistance (torsional strength or overturning strength) will affect the dynamic wheel/rail lateral interactions and thus the gage face wear. Therefore the defined fastener torsional resistance to minimize rail wear is:

Range of torsional stiffness = 1500 to 4000 in-Kips/radian.

### LATERAL MOVEMENT

This is based on rail translation, i.e., lateral movement of the base of the rail (no rotation).

Under above loading should be, for new condition, less than 0.060 inches.

Old condition less than .10 inches.

### RAIL ROTATION

This is based on rotation of the railhead, i.e., relative movement of the rail head w.r.t. rail base.

Rail rotation is given in lateral movement of the railhead (in inches) w.r.t. rail base. Note, for total dynamic gage widening (under load), rail rotation (inches) must be added to the rail translation.

Under above loadings, for new fastener/tie system, railhead deflection w.r.t. rail base, should be less than .25 inches.

For "old" system, should be less than .4 inches.

DYNAMIC GAGE WIDENING

This is the total gage widening of <u>both</u> rails under loadings. Note, for total dynamic gage widening (under load), rail rotation (inches) must be added to the rail translation for both rails.

NOTE: The following values do <u>not</u> include rail wear. They are based on a new railhead only.

Total dynamic gage widening, new, should be less than .4 inches. Old should be less than .75 inches.

## III. LATERAL SHIFT/BUCKLING RESTRAINT

Lateral track resistance is primarily related to the tie/ballast resistance. Improving the resistance of the tie in the ballast, (through modification of the tie/ballast system which is outside the scope of this specification) provides a significant increase in resistance to lateral shift. However, the fastener system provides a secondary effect in that it affects the frame strength of the track, and consequently its lateral resistance.

### TORSIONAL RESTRAINT

The in-plane torsional resistance of the fastener (i.e., the torsional resistance about the vertical axis, such that prevents the "slewing" of the ties) directly affects the frame strength of the track structure. Variation in this torsional resistance, will affect the lateral deformation of the track under load, but the effect of this stiffness, is generally an order of magnitude (factor of 10) below the effectiveness of the tie ballast interface.

Range of in-plane torsional resistance= 3000- 5000 in-Kips/radian

An additional effect on track buckling, associated with fastener/tie systems is the longitudinal resistance of the system, as already discussed. Once again, the tie/ballast resistance is the dominant influence with the tie/fastener resistance playing a distinctly secondary role, unless the fastener longitudinal restraint is less than the tie/ballast restraint, and rail slippage occurs.

## IV. VERTICAL PERFORMANCE

Vertical strength refers to the ability of the tie/fastener system to respond to loadings in the vertical plane.

### UPLIFT STRENGTH

Uplift strength is the resistance of the fastener system to vertical forces. These can be due to either the vertical component of the rotational forces (see Section II) or to the vertical uplift forces due to the track "uplift" wave, and the corresponding ability of the fastener to support the remainder of the track superstructure (ties on up). Note: an alternate design, which allows the rail to "float", such as cut spikes, does not require any resistance to the uplift wave, since in this case the rail floats within the bounds provided by the fastener. However, there is no longer any longitudinal restraint provided by the fastener in this case and so an external system, such as the rail anchor must be used.

The effect of track uplift, due to the track acting as a beam on elastic foundation, provides a force of approximately 600 to 850 lbs/foot of uplift, depending on the track modulus. (Note, this corresponds to 20% of the effective downward force) However, for wood tie track, this is more than the weight of the rails, ties, and fasteners. This weight is of the order of 350 to 450 lbs/foot. This is the corresponding pullout resistance.

However, the force require to resist overturning forces, i.e., the uplift component of rail rotation, based on the loading values presented earlier is of the order of 6667 lbs. per individual fastener.

Based on the above, the uplift resistance or pullout resistance per railseat is 6667 lbs.

### STATIC STRENGTH

The static strength of the tie/fastener system is based on the crushing strength of the wood under the applied vertical loading. This is used to determine the minimum bearing area of the fastener system on the tie.

Noting the crushing strength of hardwood ranges from 300 to 500 lbs/square inch, the above defined loads requires a fastener bearing area of at least 75 square inches.

### DYNAMIC STRENGTH

As noted above, dynamic fastener loads (vertical) can be as high as 21,500 lbs and dynamic impact loads (very short direction) of the order of 66,000+. These forces must be transmitted through the tie/fastener system without failure of any tie or fastener component.

In the case of wood ties, the tie itself, acts as a resilient pad to reduce the effect of these impact forces. Thus these dynamic effects are immediately reduced.

In general the allowable strength of the wood tie, is significantly greater than the dynamic loading, because of this resiliency. Therefore, the issue of wood tie "cracking' does not enter into any design consideration.

However, the dynamic strength of the fastener system must be such that it can endure short duration dynamic impact loads of up to 66,000 lbs. vertically, for a duration of 15 milliseconds, without component failure.

B. PERFORMANCE

The second set of performance characteristics relate to the ability of the fastener system to accommodate itself to railroad practices and to use by "typical" railroad personnel.

I. LIFE

SYSTEM PERFORMANCE

As noted earlier, fastener systems must be capable of maintaining a defined level of performance after 1,000 MGT or 30 Million cycles of loading (at 33,000 lbs. wheel load per cycle).

At the conclusion of 30 Million cycles or 1,000 MGT, the above strength values must be at a level equal to 90% of the strength levels defined above or at the "old" parameter strength value for all strength categories.

In addition, it must maintain the above defined levels of performance after removal and reinsertion 6 times. At this time, the measured strength values must be equal to 90% of the strength levels defined above for all strength categories.

COMPONENTS- PERFORMANCE AND LIFE

Individual components should not be evaluated as to their strength or performance. Rather this should be performed at the tie/fastener system level. If the system meets the above defined performance levels than the components will be deemed acceptable, provided no visible breakage or component failure is observed.

ELECTRICAL INSULATION

The fastener/tie system must provide adequate electrical isolation of the rail to prevent interference with signal systems and deterioration of the fastening system through electrical leakage. The resistance for a wet and dirty environment for the fastener/tie system must be at least 20,000 ohms.

Note: the natural electrical resistance of the wood cross-tie is such that it should provide sufficient electrical insulation without the need for additional external fastener components.

## II. MAINTENANCE CONSIDERATIONS

These considerations relate to ease of use and acceptability by railroad forces. These are unquantifiable factors that enter into the design of the fastener system.

### EASE OF USE BY LOCAL FORCES

Fastener system should be ready installed or removed by local forces in the field (referring to the rail hold-down only.) Note: it is not necessary for the field forces to remove or install the fastener to the tie, this can be done on a pre-assembly or factory assembly basis. However, it is important that the local forces be able to readily remove and install the rail hold-down portion of the system, so as to allow for various field maintenance activities.

This should be capable of being performed in the field, by local forces, using convention (or a very limited number of specialized) hand tools.

However, system should be resistant to tampering in the field by unauthorized personnel using rocks or other crude tools.

Fastening system components should be readily identifiable, as to their location and direction of installation so as to avoid improper installation of components and assembly of system.

### POTENTIAL FOR MECHANIZATION

The fastener system, specifically the rail removal and installation feature, should allows for mechanization of the rail installation and removal process. This should specifically permit the development and use of production fastener inserters/removers within the overall context of a railroad production gang.

### FIELD ADJUSTMENT REQUIREMENTS

The fastener/tie system should not require any period adjustment (i.e., bolt tightening or retorquing) after the initial installation and adjustment. The system should be installed and should maintain its performance at the above defined performance levels without any additional attention on the part of the maintenance forces.

### EASE OF INSPECTION

Fastener system should allow for ease of visual inspection of all key parts by local inspections. This should include ability to observe all components for breakage and or movement from "proper" position.

ENVIRONMENTAL EFFECT

The fastening system must retain its ability to perform (as defined previously under track strength) for the entire range of environmental conditions encountered in the railway to include rain, ice, snow, heat and cold.

III. DERAILMENT AND DAMAGE

DERAILMENT PERFORMANCE

Fastener system should have a high "survivability" rate in the event of a derailment and should maintain a minimum "emergency" level of performance. This level is defined to be 40% of the above defined performance characteristics.

Fastener system should allow for the replacement only of those parts of the system damaged during the derailment, while retaining "undamaged" components as much as possible.

The fastener should avoid any damage to other track components, in the event of a derailment, such as "nicking" of the rail.

VULNERABILITY TO FIELD DAMAGE

Fastener system should not be vulnerable to damage in the field due to existing classes of maintenance equipment. Particularly, "low" maintenance equipment, such as brooms and ballast spreaders should not cause damage to the fastener system nor should they result in displacement or removal of the rail hold down fasteners themselves.