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COMMITTEE 5 – TRACK

"Performance Characteristics for Wood Tie Fasteners"

Allan M. Zarembski*

I INTRODUCTION

As railroad freight axle loads and train weights have increased, there has emerged growing concern as to the adequacy of conventional cut spike fasteners for wood tie track. This concern, coupled with the advent of a new generation of wood tie fasteners, has led to a requirement for the development of performance characteristics for wood tie fasteners under present heavy axle load rai1road conditions.

Over the years, the performance of cross-tie fastener systems has been the subject of numerous analyses, investigations and testing. From these investigations have emerged the range of performance characteristics that are required for fasteners under heavy traffic and axle 1oad conditions. These characteristics differ from the European and other lighter axle load applications in that the load environment under which the fastener as well as the ties must perform effectively is significantly more severe in all major areas: vertical loading, lateral load1ng, and longitudinal loading. This is particularly true in many of the North American railroads' non-conventional fastener applications to date. These have concentrated on the severe curvature territories that had been traditional problem areas for wood ties and cut spike fasteners. These areas in turn are the ones in which the most severe traffic 1oadings are operated and for which the tie and fastening systems must perform effectively.

However, even in the high speed passenger applications in North America, the load environment is more severe than that found elsewhere in the world because of distinctly different operating and maintenance characteristics that include the operation of heavy axle load freight cars over passenger tracks. This in turn generates the severe load requirements under which fasteners and ties must perform.

In general, fastener characteristics can be divided into several basic categories representing different aspects of fastener (or railroad) operational requirements. These include: Track Strength and related fastener strength properties, operations and maintenance requirements, and cost/benefit issues. The first of these areas, Track Strength, is directly related to the ability of the fastener system to perform under the railroad loading environment into which it is installed. For North American freight applications, this usually means severe curvature, heavy axle load operations. The next area, operations and maintenance requirements, relates to the practica1 considerations that make for effective track systems because they promote ease of application and matching of fastener- properties and life with the remainder of the track system. The last area, cost/benefit issues, while outside the scope of this paper, can never be avoided in the private North American railroad environment. The benefits that are obtained by the use of an appropriate fastener system must be evaluated in conjunction with their costs. However, it should

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*Director Research and Development, Pandrol, Inc.

be noted that life cycle costs of the system must be evaluated, rather than either first costs or isolated component costs.

It is the purpose of this paper to concentrate on the performance requirements of fastener systems in track from the point of view of examining the role of and the requirements for the fastening system. It is not the intention of this paper to define performance specifications or performance tests, but rather to look at the role of the fastener in the railroad track structure and examine its operating environment, and the functions that it serves. It is left to the operating railroads themselves to extend these performance characteristics and to define specifications from these characteristics based on the specific requirements and circumstances of the railroad. Specifications such as those developed by the American Railway Engineering Association (Reference 1) are designed to help guide the railroad in this area of specifications and specification testing.

II TRACK STRENGTH

Track strength refers to the ability of the track structure and specifically herein, the ability of the fastener system to perform its functions in the railroad operating environment into which it is installed. Thus, this area deals with those fastener performance characteristics which affect the strength of the track structure itself and its performance under all loading conditions encountered in the railroad environment, both vehicular and environmental.

The primary function of the fastening system is to secure the rails to the cross-ties. In order to accomplish this, the fastenings must be capable of withstanding the loads that are applied to the rail and transmitting these loads to the rest of the track structure without excessive movement of the rails and without failure of the fastenings. As part of this function, the fastening system must retain the gage of the track under train operations, i.e. dynamically as well as statically. In addition, the fastenings must facilitate the ready removal of the rails from the remainder of the track structure for ease of replacement as well as performance of additional maintenance activities.

For the purpose of this paper, these performance characteristics have been divided into four basic areas: longitudinal restraint, gage widening/rai1 rollover, lateral shift/track buckling, and vertical dynamics. Each of these areas refers to both a performance area for the track structure as a whole and within it, the performance of the fastening system. It should be noted here that the fastening system is treated as a part of the overall track structure, and as such its performance characteristics must match those of the other track components and of the system as a whole.

A. LONGITUDINAL RESTRAINT

Longitudinal restraint refers to the abi1ity of the track structure to withstand longitudinally applied loads without movement or failure. For fastener systems, this refers to the restraint of the rail from movement in the longitudinal direction. Thus for elastic or other non-conventional fastener systems, the fasteners may replace the traditional wood tie anchors which perform the same function.

Longitudinal forces are induced both mechanically by train action and thermally by changes in ambient (and hence rail) temperature. Mechanically induced forces are developed by the acceleration or tractive effort of the train or by decelerating and braking of the train. While forces as high as 60,000 lbs per rail have been measured. The mechanically induced forces generally are less than 20,000 lbs per rail (Reference 2). Additional rail creep is also generated by the action of passing trains. When this creep is restrained by "hard spots" in the track such as turnouts or crossings, significant longitudinal compressive forces can be built up (Reference 3). The fastenings must restrain these forces to avoid their transmission into these key track structure points.

Thermally induced longitudinal rail forces can be either compressive or tensile in nature depending on whether the temperature is above or below the rail laying (or force free) temperature. Figure 1 shows the relationship between rail force and temperature change note the significant changes in force that occur with temperature. Figure 2 shows the distribution of the axial force along a length of tangent track. This force distribution consists of the two end or "breathing" zones in which longitudinal movement of the rai1 can take place and a central "constrained" zone in which no longitudinal movement takes place. It is generally in the "breathing" zones, which are the ends of the CWR strings that most of the longitudinal movement takes place and for which it is most critical to have good longitudinal restraint characteristics in the fastener. For a more complete description of this phenomenon, the reader is referred to Reference 4.

In the case of curved track, the presence of large longitudinal forces can result in the movement of the curve itself. This is due to the curve attempting to readjust its force free temperature by either moving in (at low temperatures) or moving out (at high temperatures). This curve readjustment causes, in turn, longitudinal movement in the track which must be restrained by the fastening system.

When the temperature decreases and a longitudinal tensile force occurs in the rai1, the possibility of a track pull-apart arises. In the event of a pull-apart, the fasteners act to restrain the ends of the pull-apart from separating and one performance criterion for longitudinal restraint has been a maximum pull-apart gap. Table 1 presents calculated longitudinal restraint requirements for rail gaps of .5 to 2.0 inches. Thus in order to limit a rai1 pull-apart to a one inch gap under a temperature change of 75 degrees F, a minimum restraint of 1800 lbs per assembly would be required.

It should be noted that the largest temperature variations occur between maximum (and minimum) annual temperatures and the laying or force free temperature. This is therefore seen in track gradually over the course of a year. More frequently the fasteners encounter a daily temperature variation which can result in significant temperature variations several hundred times, in a year.

For conventional tie in ballast track, the longitudinal restraint of the fastener does not have to be greater than the longitudinal restraint of the tie in the ballast. In fact, significantly greater restraint beyond the point at which the ties "plow" in the ballast would be unnecessary. Table 2 presents the results of large number of longitudinal resistance tests for wood cross ties in ballast taken on four major U.S. freight railroads (Reference 5). It should be noted that the "average" value of the test data shows that it takes about 3180 lbs to displace a cross-tie longitudinally .08 inches. This value is the point of definition for longitudinal restraint in Reference 5). The largest longitudinal resistance measured on any cross-tie was 4900 lbs. These values correspond to an "average" fastener longitudinal restraint of 1590 lbs and a maximum fastener longitudinal restraint of 2450 lbs. It is worth comparing these values to the AREA concrete tie fastener recommended value of 2400 lbs (l) and the AMTRAK recommended value of 3000 lbs (7).

Finally, it should be noted that the longitudinal restraint performance of the fasteners must be obtained in an active environment, i.e. under the passage of trains. In order to simulate this environment, some railroads have carried out longitudinal restraint testing in the presence of a dynamic excitation, such as that produced by a vibratory motor mounted on the rail (8). While this does not change the longitudinal restraint requirements for in-track performance of the fastener, this type of test has been used to more closely simulate the effect of train dynamics on the longitudinal restraint performance of the fastening system.

B. GAGE WIDENING/RAIL ROLLOVER

Gage widening represents one aspect of the lateral restraint characteristics of the fastener system. Since one of the key functions of a fastener system is to mainta1n track gauge, the ability of the fastening system to withstand applied lateral loads without excessive lateral movement and hence gauge widening is of critical importance.

Gage widening can be defined as any increase in the standard track gauge: of 4' 8 1/2", measured at the gauge point, 5/8" below the top of the rail head (1). Gauge: widening can be caused by any combination of three factors:

(1) Rail Wear: abrasive wear on the gauge face of the rail head, usually on the high rail of curves.

(2) Rail Translation: lateral displacement of the base of the rail relative to the tie.

(3) Rail Roll or Rotation (Reference 9): Any rotation of the rai1 section from the “origina1” vertical axis ff the rail and the corresponding lateral displacement ff the rail head with respect to the rail base (Figure 3).

Rail wear, which is normally associated with the rail and load environment, can be indirectly affected by the fastener system. This has been reported recently in Rail International (Reference 10) where a group of East European researchers presented the results of a study of the effect of fastener lateral stiffness on rail gauge face wear. These results, which are presented in Figure 4, show that for concrete tie-fastener systems, the use of rigid fastening systems can cause significantly higher rail wear than the use of resilient elastic fastenings. Simi1ar behavior can be extended to wood tie track, however, in that case it should be noted that excessively' soft lateral stiffness, i.e. as can occur in spike killed ties, can also result in abnormal rai1 wear behavior.

Rail translation has relatively small effect on gage widening in the case where good tie plate-tie connections exist as in the case of newly spiked track. This is clearly seen in Figure 5, taken from AAR test data (14), where for "new" track conditions, the rai1 translation is less than 10% of the total rail head deflection (0.05 inches). However, as the spike-tie system deteriorates with age and traffic, the magnitude of the rail translation increases. Thus, for ties in "poorer" condition, the magnitude of the rail translation can be 0.25 inches under relatively low loads (Figure 6, Reference 16) and more than 0.5 inches under higher loads (17). In fact, for FRA Class 1 type track, it appears that rail base translation can represent a significant percentage of rail head displacements, as high as 70% for some cases (17).

However, it is generally rail rotation that causes the largest additional gauge widening in an environment of high lateral and longitudinal loadings, such as that found in heavy curvature, severe grade heavy hau1 rai1road territory. In this type of environment, dynamic gauge widening, i. e., the instantaneous increase in gage caused by dynamic lateral loads due to traffic, must be controlled so that the gauge does not increase sufficiently for a wheel to drop in and cause rail overturning and consequently a derailment. As can be seen in Figure 7, in a worst case situation of flange worn wheels, chipped tread, and gage face wear (all within allowable AAR interchange limits for freight cars) a gauge widening of 1.32 inches (exclusive of rail wear) will result in wheel drop in. Noting that 0.25 to 0.50 inches of this can be attributed to rail base translation and/or improper gaging during rail laying, then it can be seen that an additional dynamic gauge widening, such as that due to rail rotation of about one inch could be potentially catastrophic.

It should be noted that rail rotation, as seen in Figure 3, occurs under combined lateral and vertical loading. When the vector sum of the lateral and vertical loads is such that it falls outside the base of the rail, as noted by the dashed line in Figure 3, rail rotation takes place and is resisted at this point by the fastener. For 132 RE rail, this occurs when the ratio of lateral to vertical loads (the L/V ratio) is greeter than 0.65.

In severe traffic environments, dynamic lateral wheel loads as high as 40,000 lbs have been reported and loads in the 20-25,000 lb range have been measured under a variety of operational conditions (11).These loads, however, represent very low probability of occurrence events in the railroad environment. Other attempts to statistically define the load environment have presented lateral/vertical loads combinations to be 39/43.2 kips as a maximum loading combination and 9.7/16.2 kips as a "frequent" loading combination (12).

Laboratory investigation of the gauge widening strength of wood tie and different fasteners reported that it takes between 10,400 and 31,500 lbs of lateral load (with no vertical load) to widen track gauge one inch (13). Figure 8 presents the results of laboratory tests of wood ties with cut spikes that show the lateral and vertical load combinations that can cause 1.00 inch track gauge widening (14). It should be noted that the maximum load combinations referred to above are sufficient to cause one inch gauge widening in conventional wood tie track. Similar lateral and vertical load combinations have been found that will cause two inches of dynamic gage widening in "weakened" wood ties with cut spike fasteners (15).

Finally, it should be noted that the presence of longitudinal loading can also contribute to rail rollover particularly in a curve where a lateral component is present. This becomes quite significant under thermal loading, both in compressive loading (from temperature increases) and in tensile loading (from temperature decreases) where a significant contribution to rai1 rotation forces occurs.

C. **LATERAL SHIFT/TRACK BUCKLING**

Lateral Shift and lateral track buckling represent the second aspect of the lateral restraint characteristics of the track structure. Although these aspects are primarily functions of the tie and ballast, the fastening system does have a secondary effect on the track behavior in this area.

However, even though the fastener performance effect on lateral shift is secondary to the tie-ballast interaction effect, it still exists and it is worth a brief mention. In the lateral plane, the track structure can be considered a frame, with the rails acting as longitudinal elements and the cross-ties acting as transverse elements. Within this frame, the fasteners can be considered as springs, so that variations in fastener torsional rigidity, i.e. the equivalent fastener stiffness in the plane of the track structure, will change the overall lateral strength of the track itself. The analysis for this type of track behavior is presented in Reference 18. Using that analyses and substituting fastener torsional resistance values presented in Reference 19, the lateral deformation of a rail-tie structure (no ballast) was calculated for cut spike type and elastic type fasteners. The results are presented in Figure 7. It can be clearly seen in this Figure that the lateral deformation of the rail-tie structure was significantly reduced with an elastic type fastening system. Thus, noting the dominant effect of the tie-ballast interaction on this behavior, it can be observed that good torsional fastener resistance will further strengthen the track laterally and reduce lateral deformation behavior.

In addition, the fastening system acts to reduce lateral shift under those circumstances in which the curves tend to move in or out laterally due to large temperature variations and the consequential readjustment of the track. In these circumstances, both the longitudinal restraint characteristics of the fastener, as well as the torsional resistance characteristics, come into play in maintaining the integrity of the track.

D. VERTICAL DYNAMICS

The fourth and final characteristic area to be considered under the definition of track strength is the response of the track structure and hence the fastening system to vertical loads. The fastening system must transmit the vertical loads applied to the railhead to the cross-ties and subsequently to the ballast and subgrade below. Since the railroad environment is a dynamic one, as noted earlier, it is the dynamic loads that must be distributed and transmitted to the rest of the track structure.

The vertical load environment of both freight and high speed passenger traffic is one that has been extensively characterized through field testing. Figure 10 presents one such set of dynamic vertical loads for both freight and passenger traffic (20). It should be noted that at the 0.1 percent level (one wheel out of every one thousand wheels) the freight traffic applied a vertical load of over 50,000 lbs. Since the static vertical wheel load for freight equipment is no more than 33,000 lbs and the passenger wheel load considerably less, it is apparent that the dynamic augment to the static wheel loading is quite significant and must be considered in the performance characteristics of the fasteners.

It is worth noting here that a major source of the dynamic augment to the static vertical load is the presence of wheel flats (up to 2 ½ inch flats are allowable under AAR interchange rules) or other wheel anomalies on the equipment. These wheel loads can provide dynamic impact factors of two or more, as can be seen in Figure 11, which presents AAR test data on wheel flat effects (21). In addition, defects on the surface of the rail head, such as engine burns, corrugations, high or low welds, and rail joints, can result in similar dynamic impact effects.

Since the fastening system can provide resilience in the vertical direction in both the up and down directions (the double elastic fastening system) the performance of the fastener during rail uplift under traffic must be considered. Thus it is necessary for the fastener system to have sufficient vertical restraint (or toe load) to support the rai1-tie system during uplift, which can occur under vertical wheel loadings of more than 25,000 lbs (Reference 22). Under these circumstances, each fastening pair must support the weight of the cross-tie and rai1 section without excessive deformation of the fastener and without failure of the fastener components.

III OPERATIONS AND MAINTENANCE

In addition to the track strength performance requirements discussed in the previous section, there are operational and maintainabi1ity requirements that enter into any set of performance characteristics for fastener systems to be used in the rai1road environment. These are the "practical" considerations that make for an effective and easy to use fastener system.

This class of fastener characteristics can be as important as the track strength (performance under load) characteristics discussed previously because they address real issues of concern to the maintenance personnel regarding the use of the system in the field environment.

These characteristics include fastener life and fastener maintainability. This section will address these characteristics from the point of view of the end user and the job which must be performed, i.e. performance characteristics, rather than from any specification or individual fastener features point of view.

A. LIFE

Fastener life simply defined refers to the period of time or cumulative tonnage until the fastener or its individual components must be replaced.

It can be argued that selection of a "suitable" fastener life is an economic criterion rather than a true performance criterion; however it obviously falls into that category of "practical" issues that must be addressed in the railroad environment.

The life of the fastener and its components is very significantly effected by the operational environments that were described in the previous section.

Another consideration in fastener life characteristics is that the fastening system must exhibit its required performance characteristics in situations which may call for its repeated removal and reassembly in the field as is the case when the rail is transposed or replaced frequently on sharp curves in heavy tonnage territory or when frequent destressing is carried out.

This leads to a requirement for the reassembly and reuse of the fastener components without loss of performance (as defined previously in track strength). Component failure can therefore be defined to be the point where the fastener's performance characteristics drop below appropriately defined levels, or when the component physically fails and is unable to carry out its functions. Thus, clip failure can be defined to occur either when the clip fractures or when it loses enough "toe-load" as to be unable to maintain the defined level of longitudinal restraint.

A commonly used fastener life standard is that life equal to the life of rai1 in tangent track under heavy tonnage types of operations; this can be 500 MGT of cumulative traffic or 25 years at 20 MGT annual traffic. Under 100 Ton car traffic, this translates to over 15 million loading cycles (axles) for the fastening system.

B. **MAINTAINABILITY**

Maintainability, as discussed in this section, refers to those characteristics of the fastening system (as opposed to individual fastener features) that provide for ease of use and operation in the field.

Thus, an important characteristic in this area is the capability of being easily installed and removed by local maintenance forces with a minimum (or no) specialized insertion and removal tools, preferably with regular hand tools. This should be performable by the general maintenance of way worker and should be readily integratable with other maintenance activities. This feature is extremely important from the point of view of enabling immediate response by local maintenance forces to spot or local problems.

In conjunction with this, the fastener system should require only a minimum of adjustment so that proper installation to achieve the required performance is automatically obtained and improper installation minimized. This should also minimize the need for periodic readjustment of the fastener system in track.

In addition, the fastener system should be capable of mechanized installation and removal, in conjunction with large maintenance operations. This can result in significant labor and productivity savings, which while not a performance characteristic, is an important practical feature.

Another "feature" which is of real practical significance is the ability to see and rapidly inspect as many of the fastener-components as is practical. This is invaluable in facilitating regular inspection of the fastener in conjunction with other routine inspections and activities.

Finally, another consideration is the ability to resist catastrophic failure, i.e. survivability and minimum performance in the event of a derailment.

As noted earlier, these characteristics, while not necessarily being considered as true performance characteristics, do address fundamental issues of concern to the maintenance personnel who must work with the track, and hence the fastener system.

IV COSTS AND BENEFITS

The final category of fastener characteristics is one that addresses not just the physical performance of the system in track, but also the overall cost of the track system. This issue is of real concern to the private freight railroads of North America in that they must operate in an environment that minimizes cost and maximizes measurable benefits. Thus in the final analysis any benefits that are obtained by the use of an appropriate fastener system must be evaluated in conjunction with their costs, which in the railroad environment must be life cycle costs.

It is beyond the scope of this paper to address the issue of costs and benefits. Rather it is sufficient to mention this is as an important issue, which can be considered a "performance" issue when the railroad environment is viewed as a cost center. However, for more detailed investigations into the costs and benefits of tie fastener systems, the reader is referred to References 23 and 24.

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TABLE 1 – Fastener Longitudinal Restraint for Pull a Part

RAIL BREAK "GAP" (INCHES)	RESTRAINED LENGTH OF TRACK ON EACH SIDE OF GAP	TIE SPACING	LONGITUDINAL RESTRAINT PER FASTENER
(INCHES)	(FT)	(INCHES)	(LBS)
0.5	86	19.5	3627
0.75	129	19.5	2720
1.0	172	19.5	1314
1.5	258	19.5	1360
2.0	344	19.5	907

RAIL WEIGHT = 132 RE

MAXIMUM TEMPERATURE CHANGE = 75° F

TABLE 2 – 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

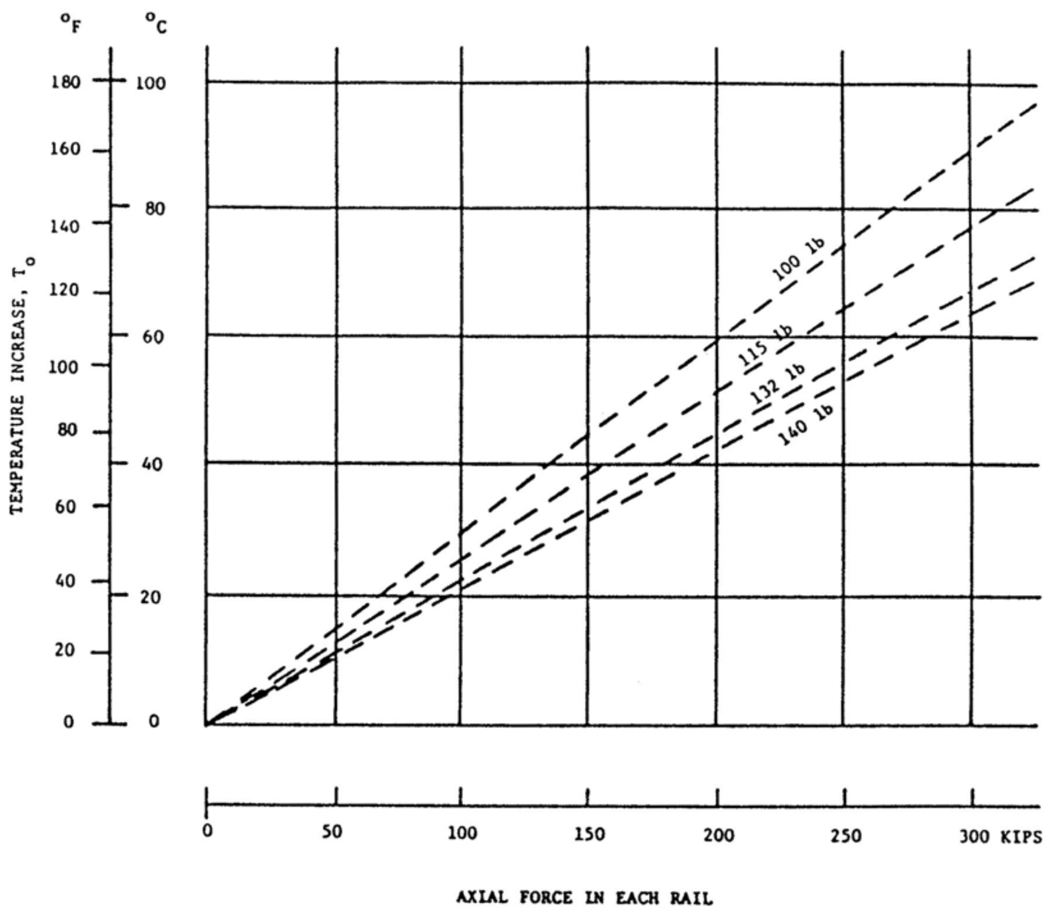


FIG. 1. Rail Temperature Increase vs Axial Force in Rail

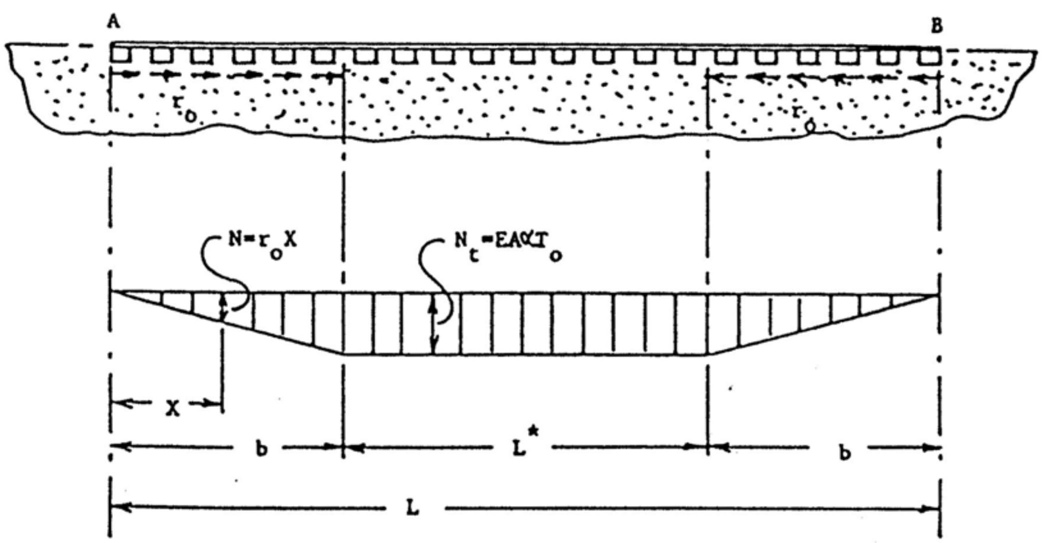


FIG. 2. Axial Force Distribution in a Track of Length L

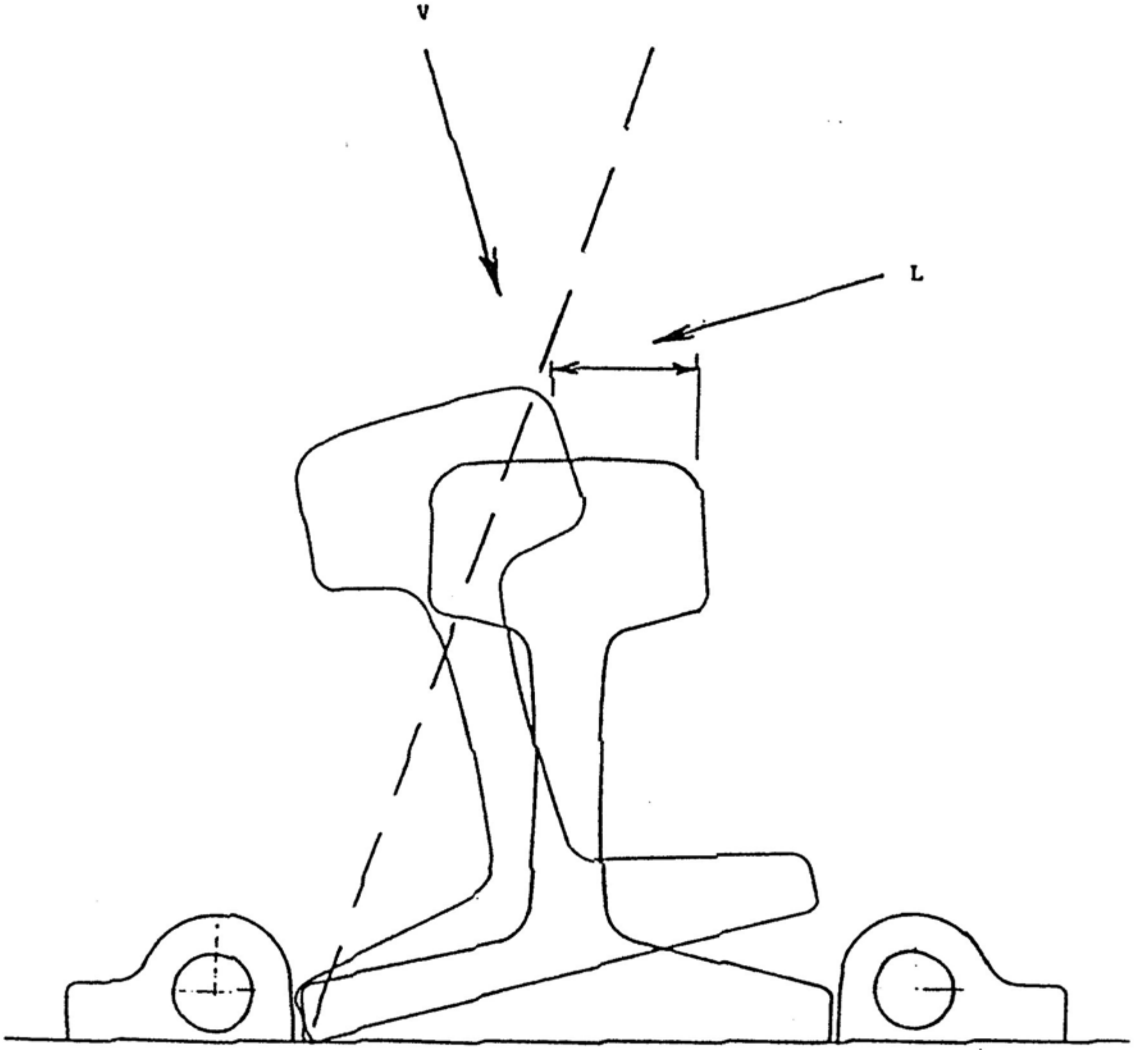


FIG. 3. Rail Rotation Under Lateral and Vertical Loading

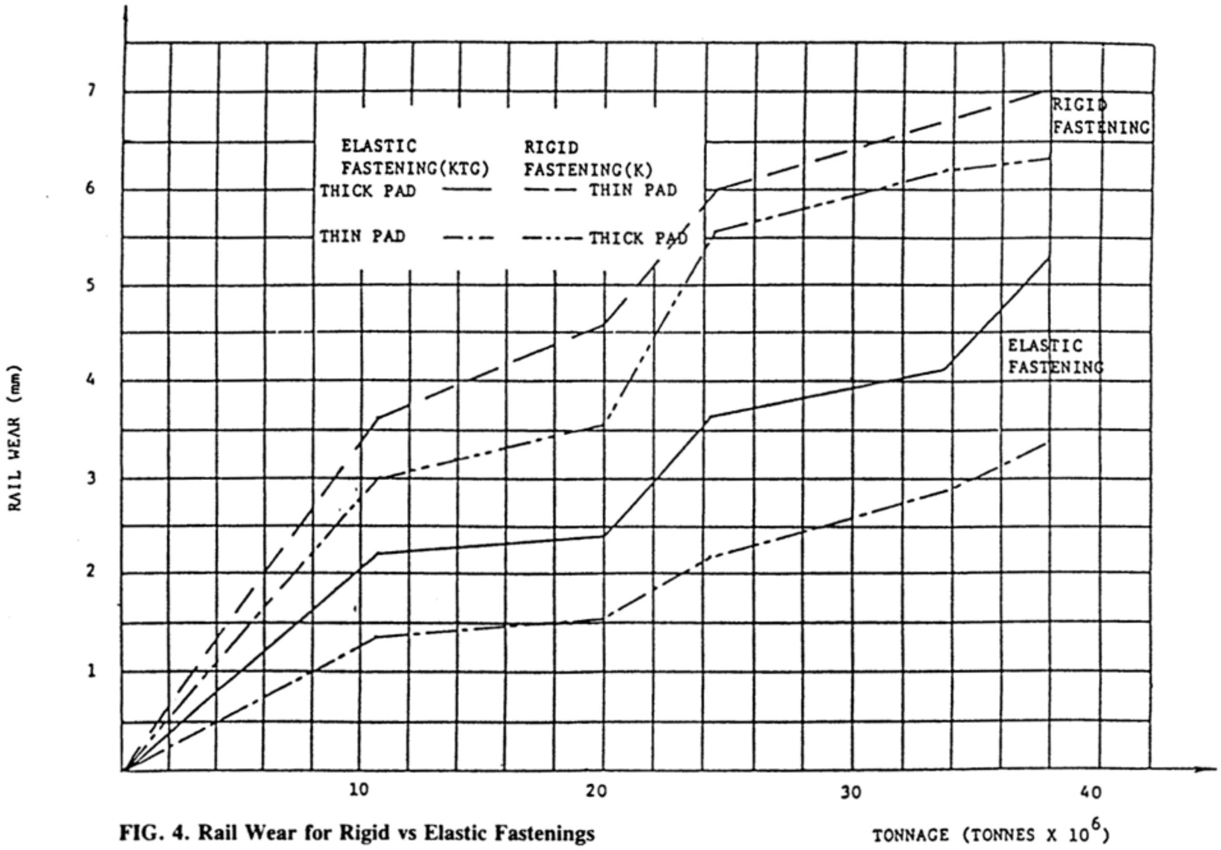


FIG. 4. Rail Wear for Rigid vs Elastic Fastenings

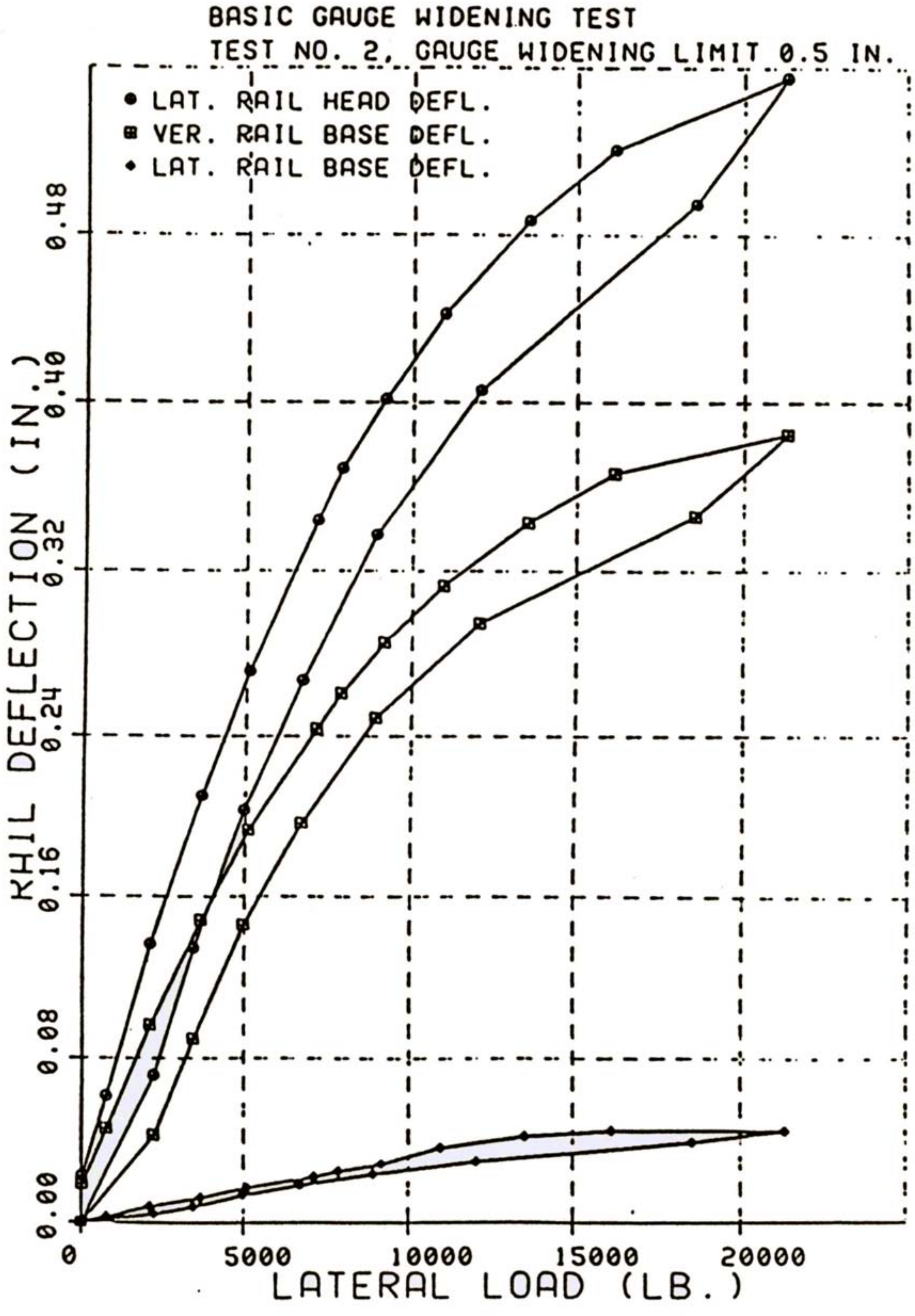


FIG.5. Graph Showing Various Rail Deflections vs. Lateral Loads for Zero Vertical Load

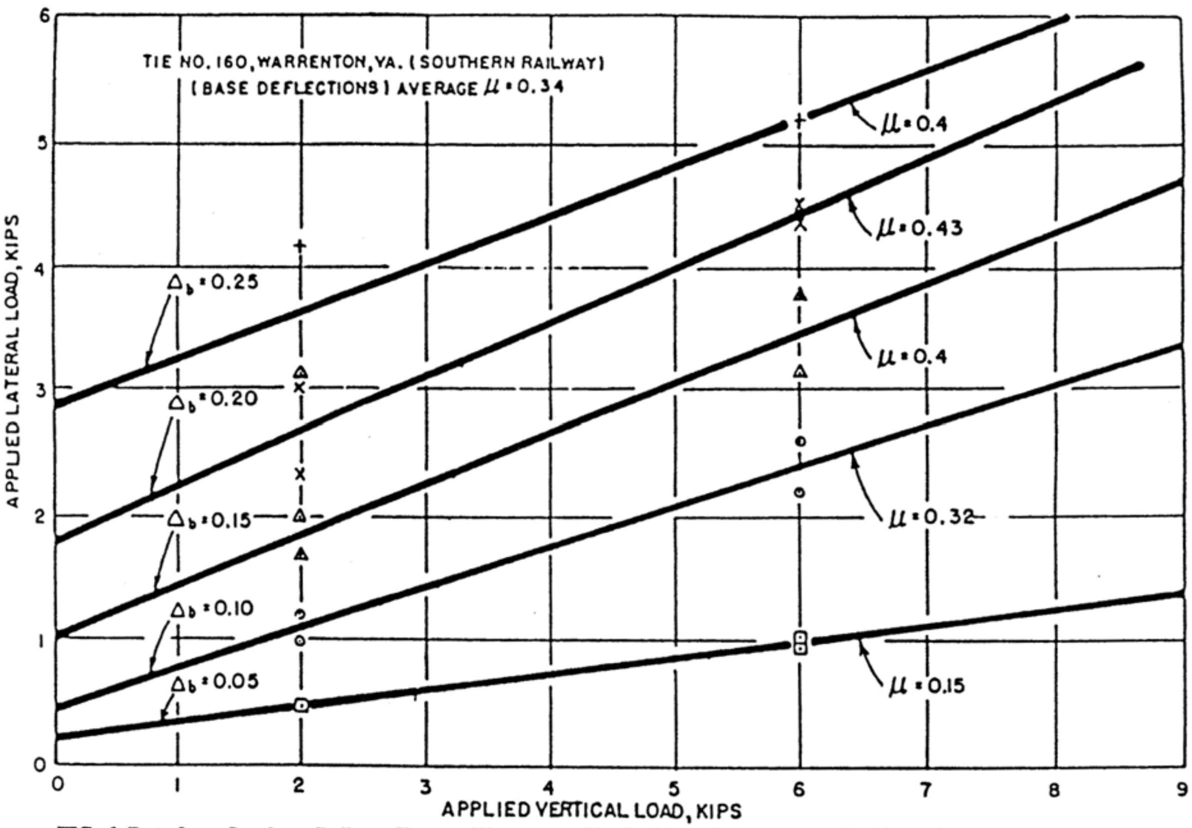
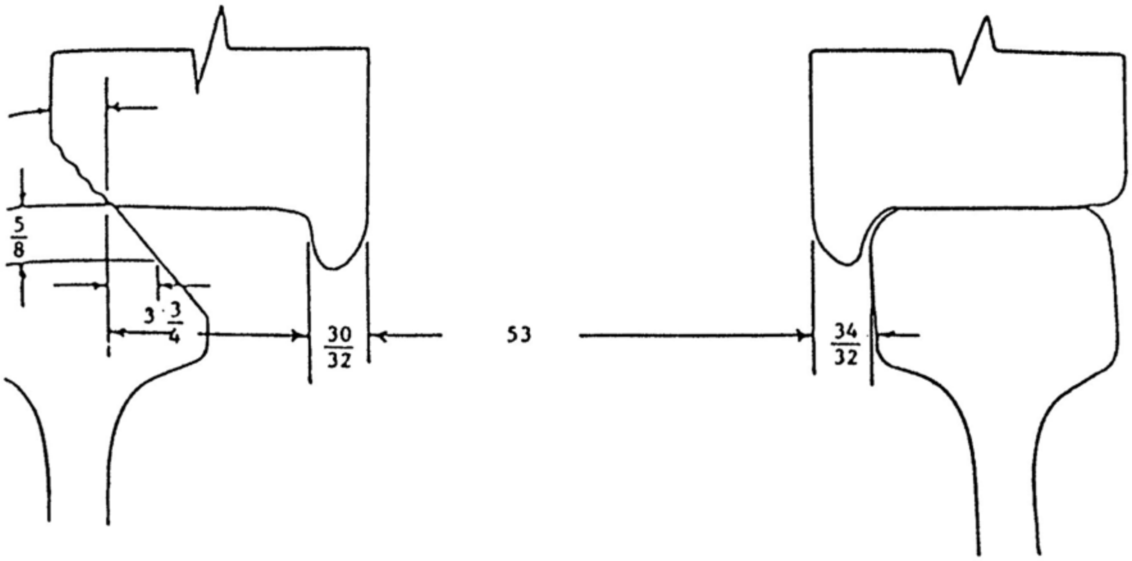


FIG. 6. Data from Southern Railway Tests at Warrenton, Va. Rail Base Deflections at Tie No. 160



THICKNESS SUM OF 2 WORN FLANGES *	$\frac{64}{32}$
BACK TO BACK OF WHEEL FLANGES (MIN)	+53
AVAILABLE TREAD CHIPPED WHEEL**	+ 3 $\frac{21}{32}$
	58 $\frac{21}{32}$
GAGE WEAR AT TOP OF RAIL	$\frac{27}{32}$
RANGE OF MAXIMUM DYNAMIC GAGE SHORT OF DERAILMENT	57 $\frac{26}{32}$
NOMINAL GAGE	56 $\frac{16}{32}$
ALLOWABLE DYNAMIC GAGE WIDENING	1 $\frac{10}{32}$ (1.32) INCHES

* Assume that opposite wheel flange has half the allowable wear surface

** Chipped rim is unusual under normal conditions but it could exist under AAR Rule 41

FIG. 7. Maximum Track Gage—Worn Wheel Flanges and Chipped Rim Wheel on Curve Worn Rail

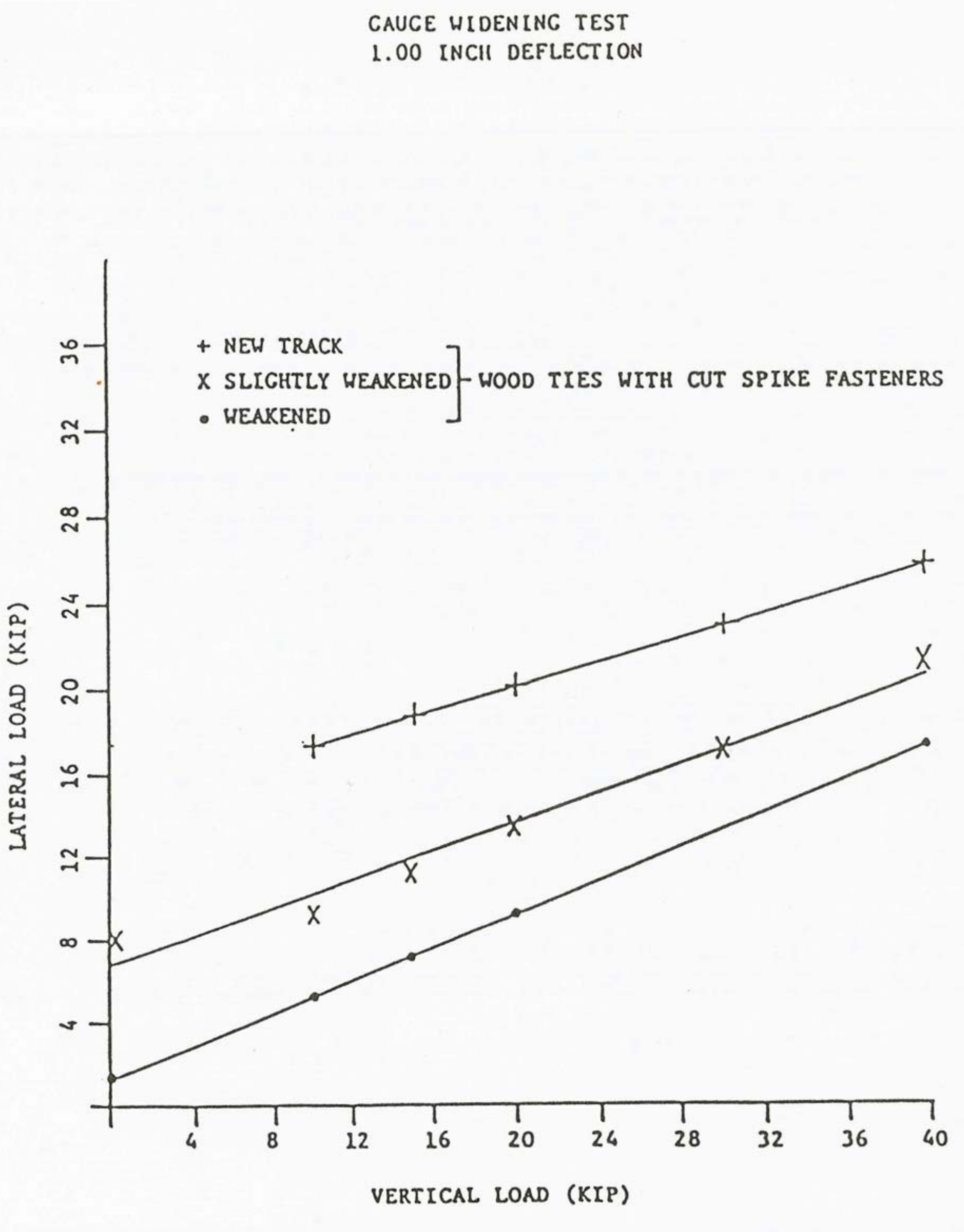


FIG. 8 Vertical-Lateral Load Combinations For 1.00 Inch Gauge Widening in Wood Tie Track

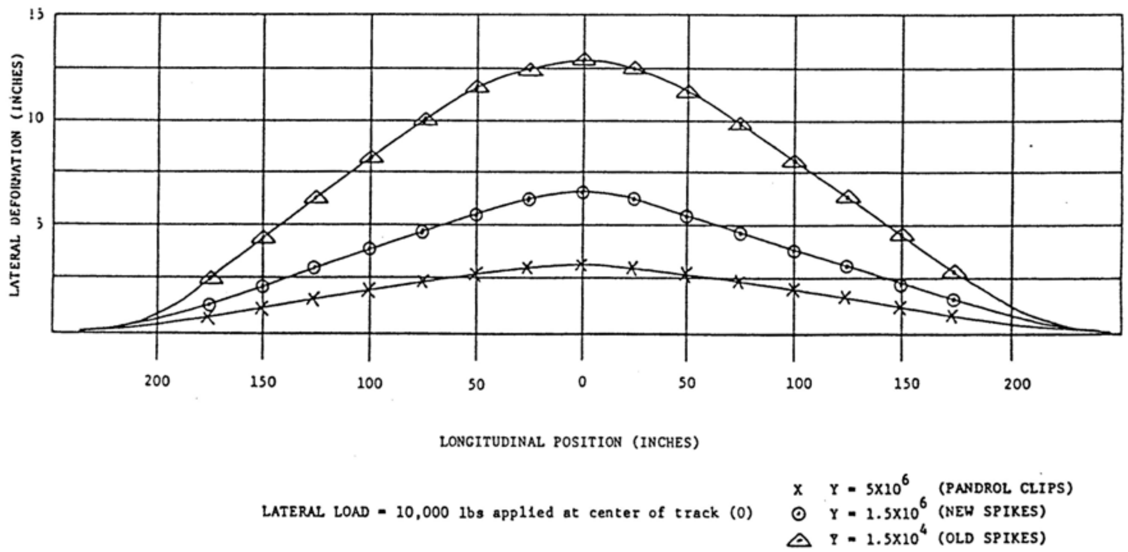


FIG. 9. Lateral Deformation of Track (No Ballast) Effect of Fastener Stiffness

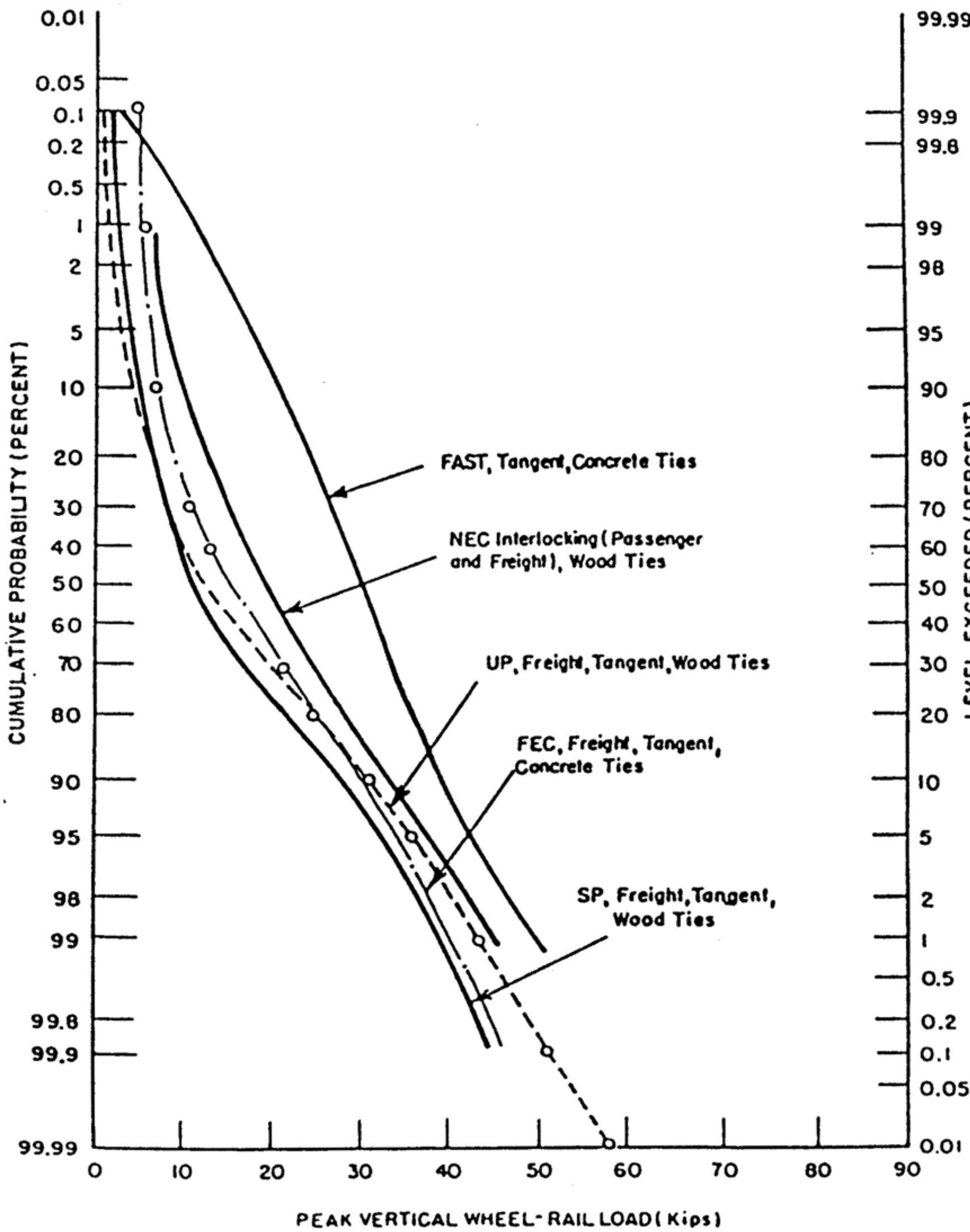


FIG. 10. Wheel-Rail Load Spectra

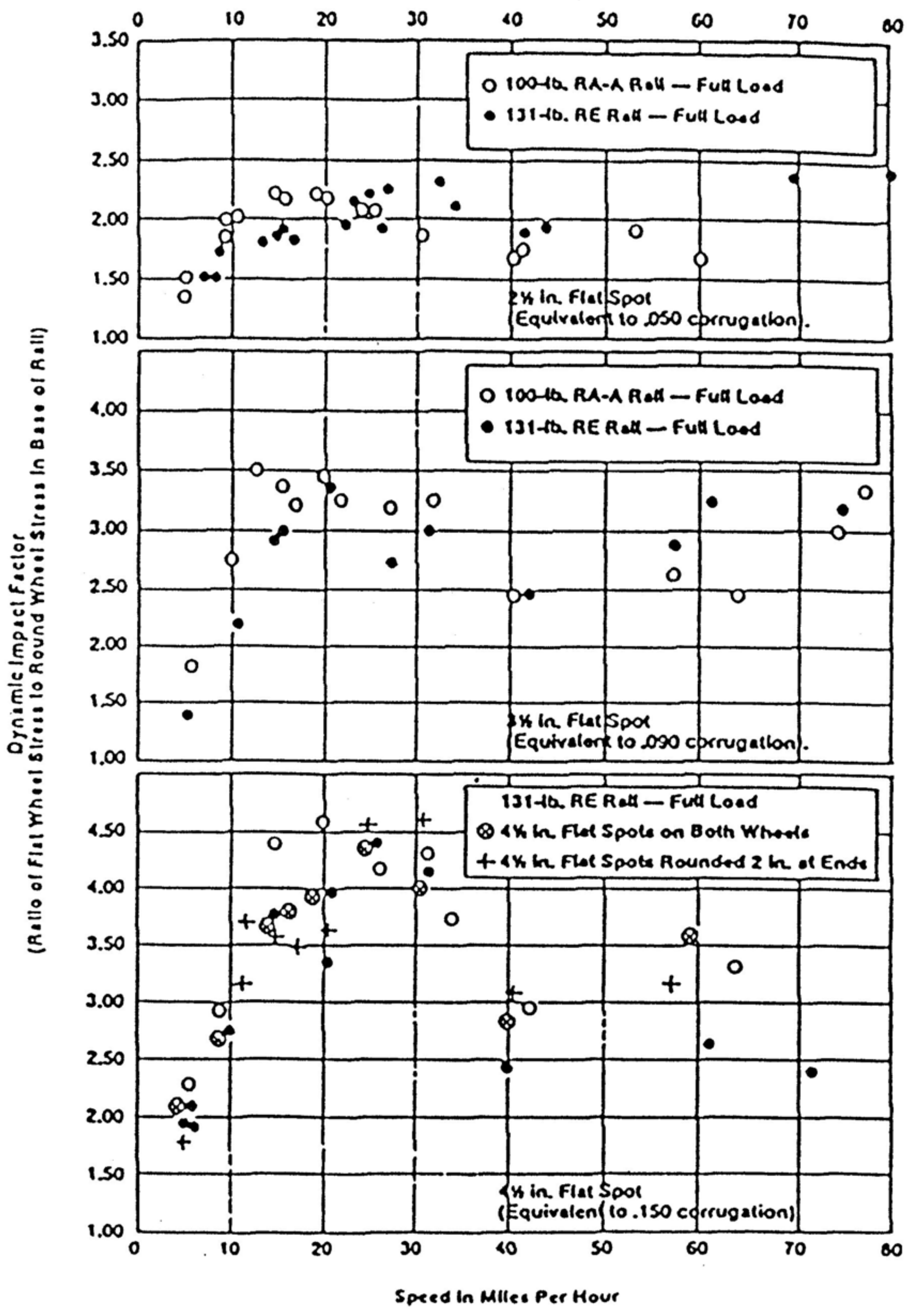


FIG. 11. Ratio of Flat Wheel Stress to Round Wheel Stress in Base of Rail at Various Speed. Fully Loaded Car, 100 lb. and 131 lb. Rails.