AN ENGINEERING PERSPECTIVE

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COURSE INFORMATION

* Course background

Since track is basically the foundation on which the railway operates, it must be maintained at peak operating condition in order to fulfill it's role in carrying the railway to it's destination. Each component of the track structure plays a part in maintaining the integrity of the track structure. The role of the crosstie is three-fold:

- the tie must maintain track surface
- the tie must maintain track alignment
- the tie must maintain proper track gauge

Tie design and performance requirements are directly related to the operating environment in which the crosstie must perform. The operating environment includes such things as: the type of traffic the track must carry, track geometry (curves, grades, track structures, etc.) weather conditions, and maintenance practices.

* Course Goal

The "The Wood Crosstie Seminar" is designed to provide students with the knowledge and understanding of the demands placed on a track crosstie, the function of a crosstie in track, how a crosstie performs this function, care and maintenance of the crosstie, how crossties fail, why, when, where, and how the crosstie must be replaced, and what alternatives there may be to the standard wood tie.

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION ONE

INTRODUCTION

1. Introduction to Wood Crossties

Although the Railroad Track Supervisor has naturally been trained to handle the tasks under his control with the utmost precision, the variable performance of timber crossties has always had to be accepted by him. Being a natural material, timber had to be accepted in the form in which it grows.

However, over the years the performance of timber crossties has been improved by elimination of disadvantages. This has been achieved primarily as a result of the expertise of the sawmiller working in conjunction with the railway:

- by the choice and employment of the most suitable species to meet individual needs of a particular railway

- by altering the dimensions of the crosstie to meet changing needs of performance

- by recognition in the crosstie supply industry of

  1) the conditions which lead to deterioration of timber and

  2) the means needed to combat that deterioration

Traditionally engineers in all types of construction - roads, bridges, ports, railways - made the utmost use of any raw materials near to the work in progress. The obvious choice for crossties was timber, and for over 100 years timber was almost the only rail support used throughout the World. It continues to be an essential material for many railways for transverse ties and longitudinal ties, and in its use for switches and crossings it is still paramount.

Because softwoods grow predominantly in some regions and hardwoods in others, the use of the two types also become broadly regionalized. Mainly by trial and error the efficiency of different species of wood was discovered, as to which ones needed no preservative treatment against rot and insect attack and which ones would meet the mechanical requirements of the railway concerned.

The economic need for improvement in train performance — faster or heavier or more frequent traffic, or perhaps all of these requirements-led eventually to the use of long-welded and then continuously-welded rail which called for increased track stability, for which one answer has been the hardwood tie. In addition to being heavier, hardwood generally has a longer service life than softwood. The lighter weight softwood with its shorter life now has limited use except in certain countries which, for economic reasons, have actually begun to use softwood in place of hardwood.

Railways, which have from the beginning regarded the use of softwood as normal, now often require an improved quality.

In the early development of railways, the demand for crossties was enormous and few producers had the time to concern themselves with improving the quality. High percentages of rejections or early failure were normal and were accepted. However, in time, the discrimination of the engineers led authorities in some of the major supplying regions to draw up their own grading rules to be applied specially to crossties and bridge crossing timbers. Such regions include Australia (dense hardwood), North America (softwood and medium hardwood), and Europe (softwood and medium hardwood), to be followed a long time afterwards by the Far East and then South America (both medium and dense hardwoods). Crosstie producing countries in Africa have adopted one or another of the established forms of grading.

For many years it has been said that supplies of timber world-wide are diminishing and, as large consumers of timber, railways have correctly taken notice of this warning, it was one of the incentives for the development of the concrete crosstie. Looking back, there is no doubt that the way in which much of the timber product of forests has been used has been very wasteful. Only the best trees of the best species were taken and, too late in some regions, it was realized that before very long, the forests would have nothing in them worthwhile to extract. Most regions, however, have a “second chance”. Where practical, a policy of regeneration has been adopted; moreover better care can be, and is being, taken of remaining forest areas. Utilization of previously less popular species, better methods of extracting trees from the forests enabling new areas to be developed, combined with improvements in preservative treatment and improved methods of rail fastening, will enable railways to look forward to a continuing, though reduced, supply of timber for crossties which will give longer service than in the past.

The following is an excerpt from the RAIL DEFECT MANUAL compiled by Sperry Rail Service, that gives some insight into the development of the railroad both in England and in the United States.

History of Rails[1]

The earliest record of the use of track for transportation comes from England, where, in 1604, a railway was constructed from nearby mines to the river Tyne. The tracks were made of wooden rails, which wooden carts with flanged wheels were pushed by men or pulled by horses.

During the eighteenth century, the growth of railways continue in the mining districts of England and Wales. As yet, the steam locomotive was unthought of. Horses or mules pulled the early trains. The ties were originally made of pine or other softwood. To improve the wear quality, a top strip of hardwood was applied. During the middle part of the century, strips of malleable iron replaced the hardwood top. These iron strips were used only to provide a more durable wearing surface; the timber carried the weight and guided the wheels.

First Metal Rail

In 1776, the first all-iron rail was manufactured near the city of Sheffield, England. These rails, called plate rail, were made of iron in sections 3 feet long. Since flanged-wheel carts were not common in

[1] Extracted from “RAIL DEFECT MANUAL” compiled by SPERRY RAIL SERVICE - FOR THE USE OF THE RAILROADS

the south of England nor in Wales, these rails were cast in the shape of an L, the long leg of which rested on the roadbed while the short projected upward. This construction permitted the use of either flanged or common cart wheels upon the track, the upthrust leg taking the place of the wheel flange in the latter case.

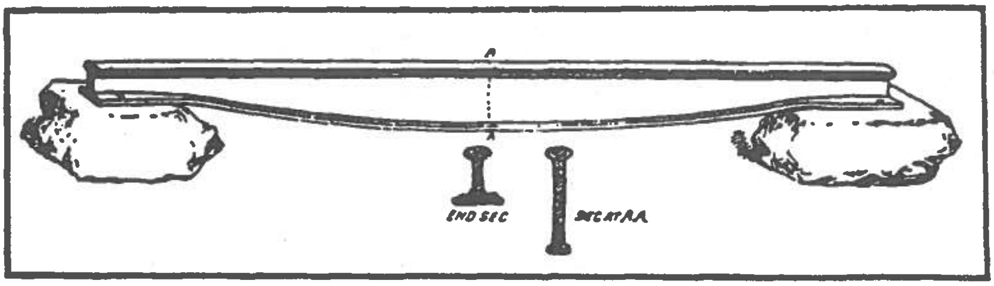

Figure 1-1: Plate rail. 3-feet long, made of cast iron, with an upward projecting flange to accommodate either cart or flanged wheels.

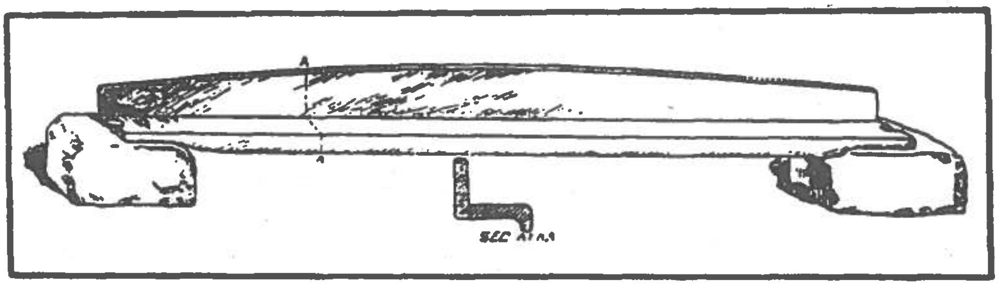

Figure 1-2: Edge rail, made of cast iron in 6-foot sections, for use with flanged wheels.

In 1789 William Jessop, who later built the London-Croydon Railway, developed a new type known as edge rail. Due to its vertical section it was many times stronger than either strip or plate rail. In its earliest form, edge rail consisted of a thin web widening out at both bead and base while the cross section above the supports closely resembled a modern rail section.

First Public Railway

In 1803, the first railroad intended for public use, the Surrey Iron Railway, was opened for operation between the London docks and Croyden. Intended primarily as a public super-highway, the track was laid with flanged plate rail to accommodate cargo wagons or any other conveyance whose owner was willing to pay for the privilege of a smooth fast ride on a hard road.

The early iron rails were spiked directly to wooden sleepers. As loads on the railroads increased, the need for heavier roadbeds became apparent. The most common method of positioning the rails was to set stone blocks along the line to be followed by the track, insert wooden plugs into holes drilled in these blocks and then spike the rail to these plugs. Later, edge rail was supported at each stone block by a cast iron chair. At the beginning of the 19th century the railways, commonly known as tramways, had grown to an impressive size but as yet the carrying capacity and the speed attainable was limited by the strength of the draft animals used for I locomotion. With the growth of manufacturing came a corresponding need of better and faster transportation. The natural result was an effort to improve the railroads.

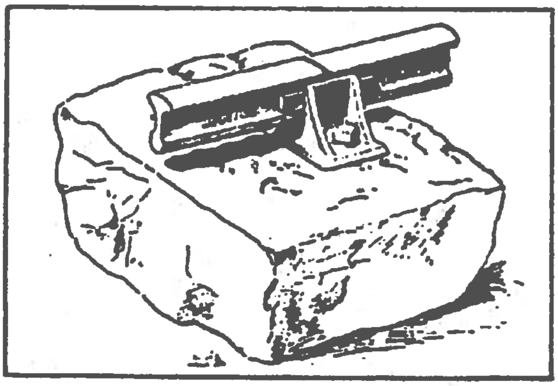

Figure 1-3: Cast iron chair, used to support and join early edge rail.

First Steam Locomotive

Road carriages powered by steam had already been successfully demonstrated. The logical step was to apply steam power to the railroad.

On February 1st, 1804, on the plate rail tracks of the Pennsylvania tramroad in South Wales, a steam locomotive successfully hauled a train of cars. The locomotive was designed by Richard Trevithick. The freight hauled in the cars consisted of several tons of ore for the iron works at Merthyr Tydfil.

In 1825 the Stockton and Darlington Railway in England commenced operation using a steam locomotive designed by George Stephenson. This was the beginning of the commercial use of steam locomotives on regularly scheduled common carriers.

It had originally been planned to lay flanged plate rail on the Stockton and Darlington, but upon Stephenson's repeated recommendation cast iron edge rail was used. This instance marked the adoption of flanged wheels in railway construction.

Origin of Standard Gage

The track of the Stockton and Darlington was laid to a gage of 4 feet 8 1/2 inches-the gage in standard use throughout England and the United States today. The story runs that the width of the Killingworth colliery tramline was 4 feet 8 inches. Since Stephenson, who was the colliery millwright, designed his early experimental locomotives to run on that line, he quite naturally built them to that gage. When he was called upon to design the Stockton and Darlington locomotive he did so to the width to which he was accustomed. The extra half-inch was added to the track width to ease the gage. Stephenson's personal prestige helped to bring about the adoption, after considerable controversy, of the 4-foot 8 1/2-inch gage as the English standard.

The influence of Stephenson's work on American locomotive designs, plus the fact that a number of English locomotives were imported to this country, resulted in the use of the 4-foot 8 1/2-inch gage on the Baltimore & Ohio, several of the New England railroads and on the early Pennsylvania line.

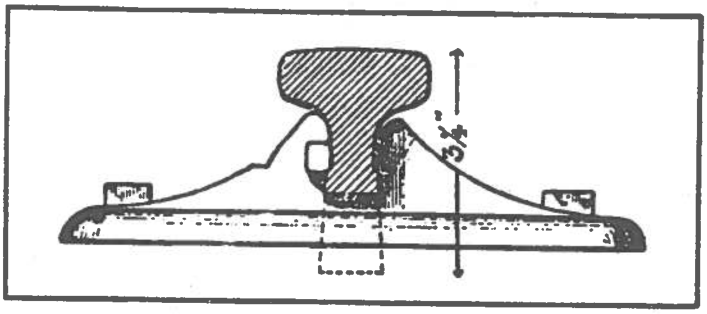

Figure 1-4: Rolled iron edge rail, made in 15-foot sections and supported at joint by cast iron chairs.

The South Carolina Railroad, as well as most of the other Southern lines, was built to a gage of 5 feet. The Erie tracks were built to a 6-foot gage, the Missouri Pacific spaced its rails at 5 feet 6 inches, while the early Jersey & Ohio road used a 4-foot 10-inch gage. Not until many years later did the necessities of interchange force the adoption of a standard gage of 4 feet 8 1/2 inches for all American tracks.

First Rolled Rail

A few years prior to the advent of the steam locomotive, John Birkenshaw, owner of the Durham Iron Works, turned out the first rolled iron rail. This rail had a wide rounded head and a thick web designed to be supported by cast iron chairs at the joints. The rail was rolled in sections 13 to 15 feet long as compared to the 3- to 6-foot length of the cast iron plate and edge rail, and weighed 26 lb. per yard. The first American railway was the Granite Railroad of Massachusetts, built in 1826. This 3- mile stretch of track, from Quincy to Milton, used iron - capped wooden rails, and horses for power.

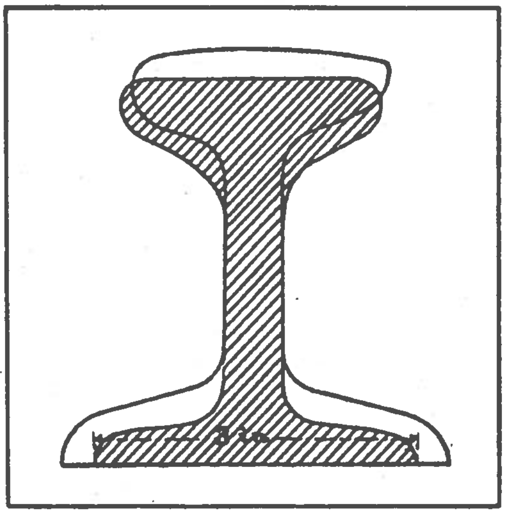

Figure 1-5: Stevens T-rail rolled with convex top and base, designed by Robert L. Stevens in 1 830. Shaded section shows rail as originally designed. Unshaded section shows profile as actually rolled.

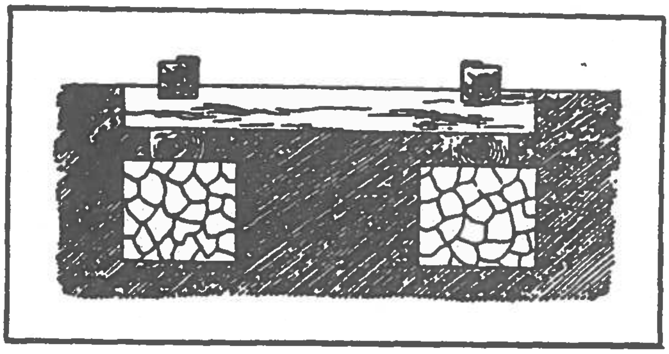

Figure 1-6: Iron strap rail, spiked to wooden stringers and supported by wooden ties over a gravel and wood sub-foundation.

First American Locomotive

In 1831 the "Best Friend of Charleston", the first locomotive to successfully pull a train on American tracks, was placed in operation on the South Carolina Railroad. In the spring of the same year, construction of the Camden and Amboy Railroad in New Jersey was started, using the rolled iron T rail designed by Robert Stevens and rolled in England. This rail did away with the need for expensive cast iron chairs since it could be spiked directly to the tie with a hook-headed spike, also designed by Stevens. The roadbed was constructed according to the English idea of securing the rails to stone blocks.

A shortage of stone, however, resulted in the use of wooden ties similar to those in use today. To the surprise of the railroad world it was found that the use of wooden ties made a roadbed that rode better than did track laid on stones.

American Rail Development

Although rolled edge rail rapidly gained favor in English construction, its use in America was necessarily limited by cost. Until the first American rail rolling mill was constructed in Maryland in 1844, the necessity of importing the British product made the use of rolled rail too expensive for widespread use.

As a result, much of the early American track utilized iron strap rail laid on longitudinal wooden stringers. On the B & O, stone stringers were substituted for the wood. Aside from the fact that the wooden rail had poor wearing qualities, the iron straps that topped it had a pronounced tendency to pull loose from the wooden stringers. This usually happened during the passage of a train, when the iron strip, loosened by vibration, would curl back on itself, causing frequent damage to equipment and injury to passengers. These loose rails were known as "snakeheads" and were a common occurrence.

The first rail rolled at the Maryland mill was a 42-pound iron U rail. A quantity of this rail was used by the Baltimore and Ohio but never achieved much popularity. In 1845, mills in New England and Pennsylvania commenced production of the Stevens T rail. The iron smelted in the United States at this time was inferior to that of England. To provide greater strength, the original Stevens rail was modified in such a way that the head was pear shaped in cross section.

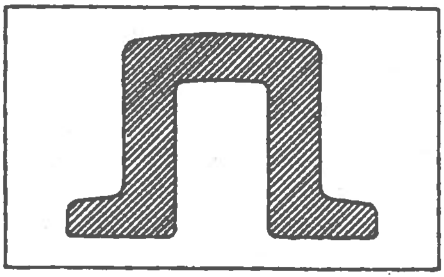

Figure 1-7: Iron U-rail. This was the first type of rail rolled in the United States and was used on the Baltimore and Ohio R. R. in Maryland in 1844.

The difficulty of splicing pear shaped rail led to the development Compound Rail. In laying these rails the two sections were staggered so that at no point did a complete gap occur in the rail. At first this type of rail proved highly satisfactory and provided an exceptionally smooth ride. However, the iron wore badly on the inner surfaces and required frequent tightening of the holding nuts or rivets. No new compound rail was laid after 1860.

In 1848 a rolled iron rail weighing 92 pounds per yard, and having a cross section very similar to that of modern rail, was tested on the Camden and Amboy Railroad. The iron rail proved to be too rigid to withstand batter by the train and the ends soon hammered out. The rails were removed from the tracks and now form part of the building framework of the U. S. Mint in Philadelphia.

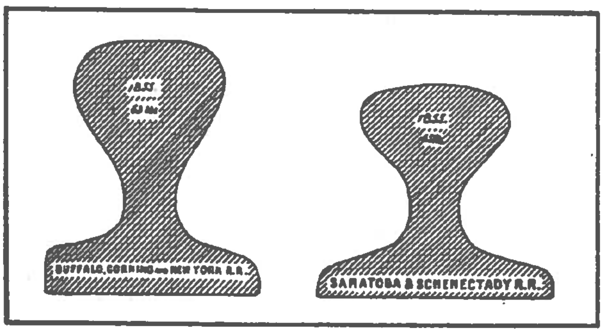

Figure 1-8: Pear shaped rolled iron rail manufactured in Pennsylvania in 1855.

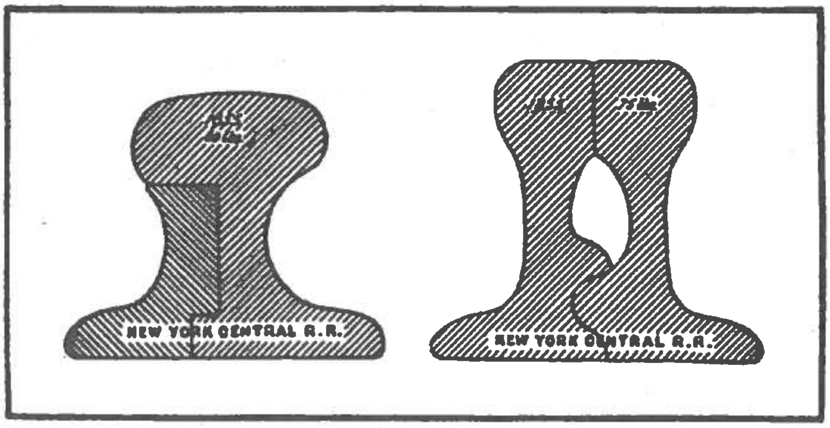

Figure 1-9: Compound rail developed in 1855 in an attempt to simplify joint construction. Maintenance difficulties forced its abandonment in 1860.

First Steel Rail

The first steel rails are said to have been rolled at the Ebby-Vale works in Wales in 1855. The difficulty of obtaining good iron on this side of the ocean led the more prosperous American companies to continue to import steel and iron rails from abroad. In 1865 the first Bessemer steel rails made in this country were rolled in the North Chicago Mills. The first steel rails rolled in the United States were produced in Johnston, Pennsylvania in 1867. Between 1870 and 1873 several experiments were made with steel top rail, a type in which web and base were made of iron, and the head of steel. The lessening cost of steel soon made it more practical to make the entire rail of steel.

By 1900, steel T rail had replaced all other types on the railroads in the United States. From that time until the present, rail development centered about production of heavier rail sections and improved manufacturing processes. Only minor modifications have been made in the shape of the rail. It is interesting to note that the trend toward heavier rail has resulted in the rolling of rail sections of 152 and 155 pounds for use in certain heavy tonnage areas, although the 140 pound section is believed to be the heaviest rail section currently being rolled for general use by any American Railroad.

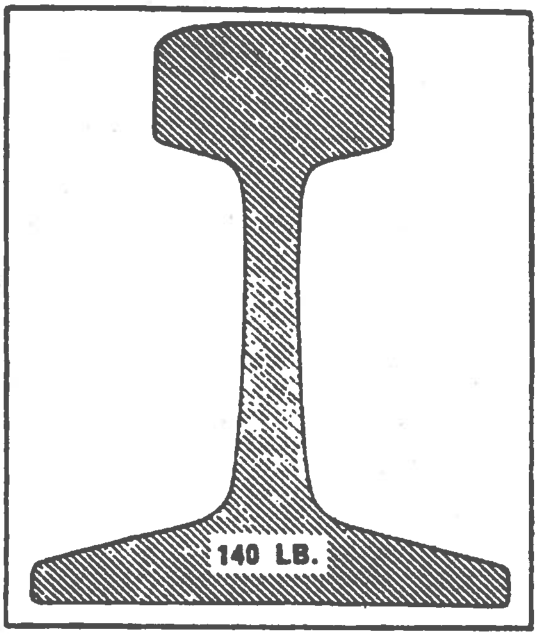

Figure 1-10: 140 lb. Cross Section

This seminar will review the load environment, the function and requirements, the future of the timber crosstie, and finally what alternatives are available. As with any job, the right tool used for the right purpose is always the correct methodology. There is now and always will be a place for timber crossties in the railway industry.

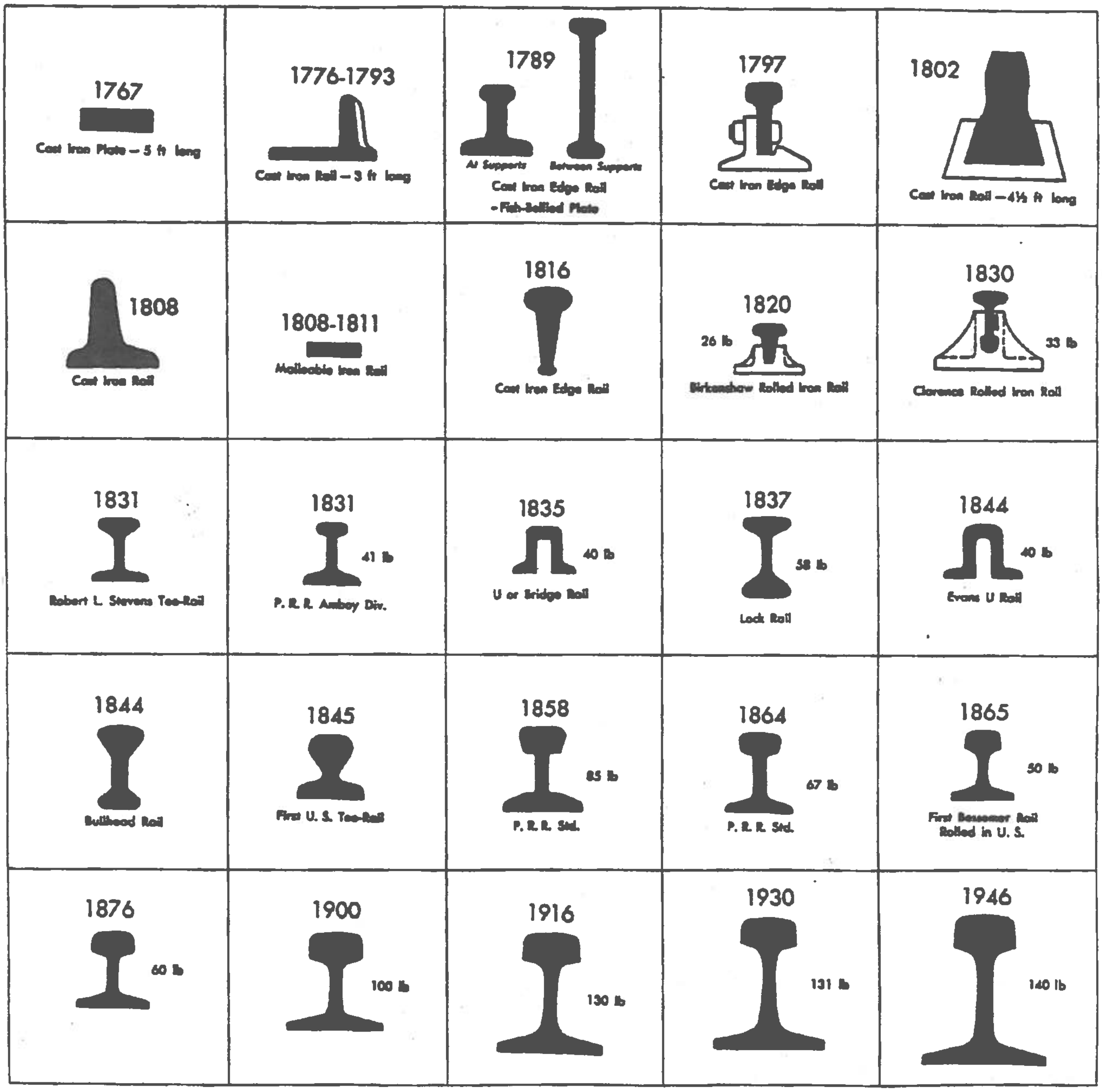

Figure 1-11: Rail Cross-Sections Down Through the Years

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION TWO

RAILROAD OPERATING ENVIRONMENT

2. Railroad Operating Environment

In order to understand the function of the crosstie, it is important to understand the environment in which the tie must function.

This becomes even more important as new generations of freight equipment are developed and introduced into service. Vehicular imposed loadings are generally divided into three categories corresponding to the plane of loading: vertical, lateral and longitudinal. This section will briefly attempt to define the differing levels of vertical and lateral loads imposed on the track structure.

2.1 Vertical Forces

Vertical loading of the track structure consists of the static weight of the freight vehicle and any additional dynamic augments which are superimposed onto this static load. These dynamic augments can be caused by a variety of external factors to include irregularities in the geometry of the track structure, irregularities on the surface of the rail, irregularities on the surface of the wheel, etc. The magnitude of these dynamic augments to the static wheel load is related to the amplitude of the defect, the vehicle operating speed, the unsprung mass of the vehicle and the stiffness of the track, as well as to the vehicle suspension characteristics. Although there have been numerous attempts to analytically characterize this dynamic behavior and its corresponding loadings, direct measurement of the load environment remains an effective technique to define the range of these loadings, as can be expected in conventional railway operating environments.

While measurements of the load environment have been extensively performed over the years, recent research has focused on definition of the loading of the track structure under a broad range of equipment, from 70-ton to 125-ton cars. Using techniques developed for wayside (on the ground) load measurements and vehicle-borne measurements, this recent research has characterized the vehicle/track load environment under a range of conditions and behaviors.

For example, Figure 2-1 presents the results of over 12,000 miles of vehicle testing of a 70-ton box car. As can be seen in this figure, the actual distribution of loading is extremely broad, with dynamic loads greater than 2 1/2 times static levels. At the load level of 1.8 times static, the percent occurrence of this load level was such as to correspond to an occurrence of 2 times every 100 miles. Testing of a 100-ton hopper car produced comparable behavior.

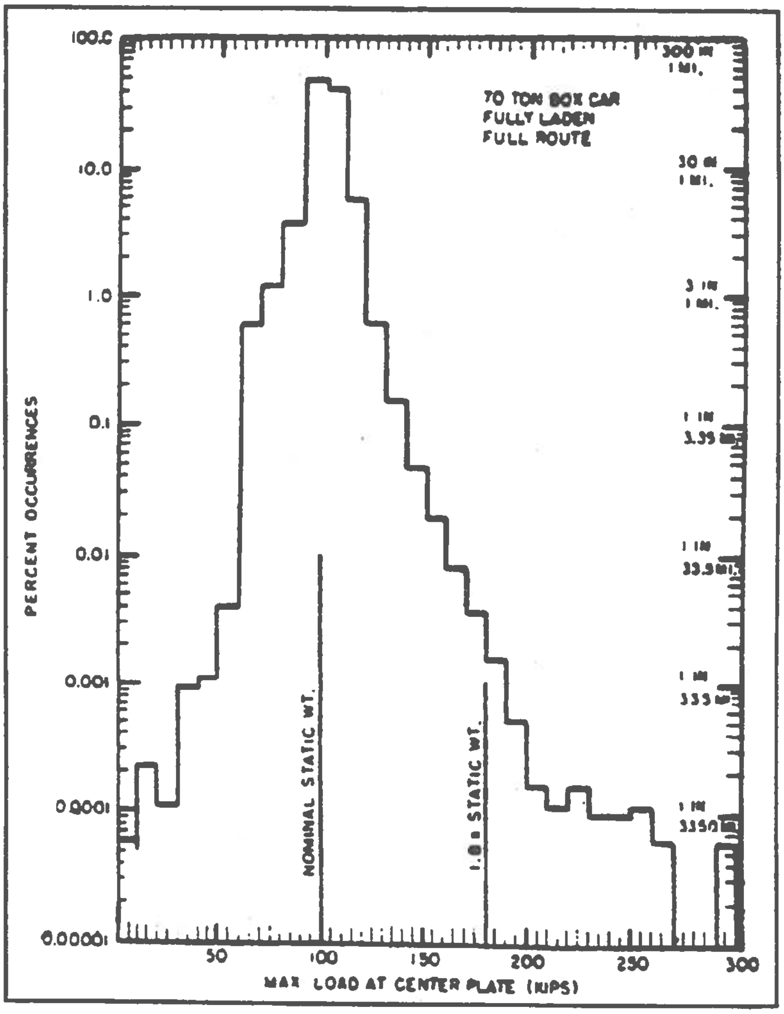

Figure 2-1: Center plate loads for 70-ton box car

Conditions of extremely high loadings were found to occur when controlled "bounce" tests over perturbed track (track with defects deliberately installed) were carried out. These results, which are presented in Figure 2-2 for five different car types, show that peak dynamic loads of between 2 to 4 times the static load were measured under conditions of "bounce resonance". [Note: these vehicles were equipped with conventional suspensions. Vehicles with premium suspensions did not produce as high a level of dynamic loading.]

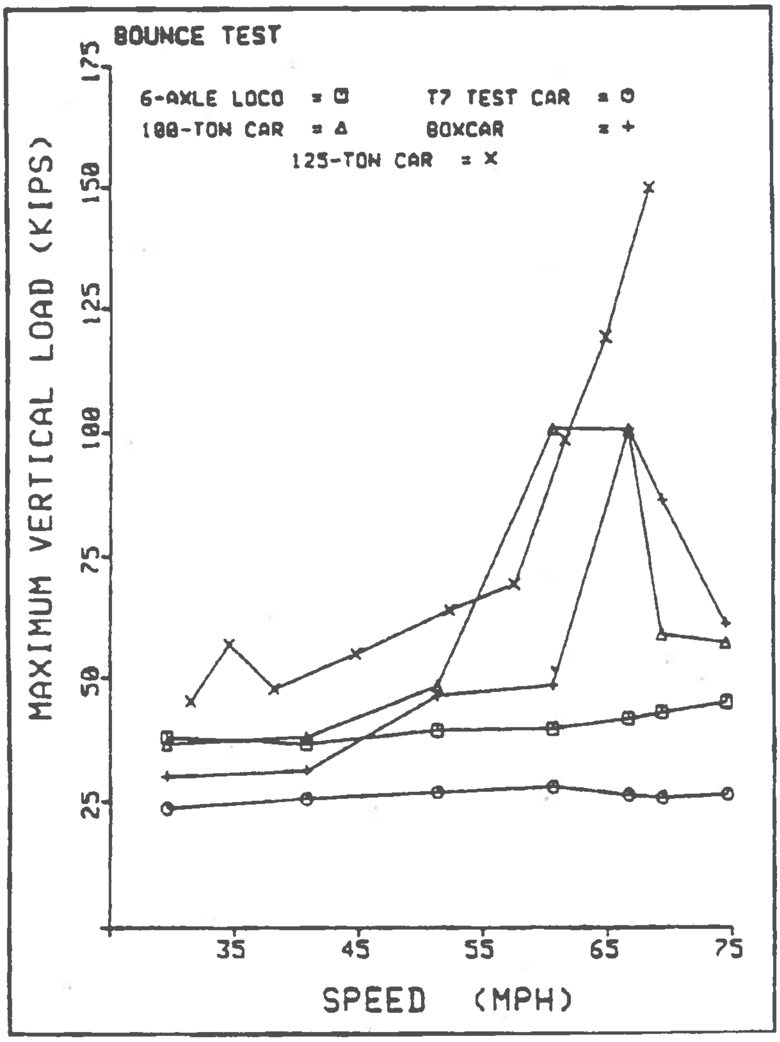

Figure 2-2: Vertical loads - bounce test

Finally, in examining the distribution of vertical wheel/rail loads for operations over controlled track locations [at FAST], the statistical distribution of these loads can be observed (See Figure 2-3). The median vertical loads, i.e. those loads that were exceeded 50% of the time, were found to be approximately 46,000 lb. for the 125-ton car on the high rail, and approximately 37,000 lb. for the 100-ton car. Comparison of these two car types showed that the 125-ton car produced dynamic loads about 20% higher than the 100-ton car in all levels of exceedance except for the very high levels (1% level or 1 axle in 100 level), where the 125-ton car produced higher dynamic loadings.

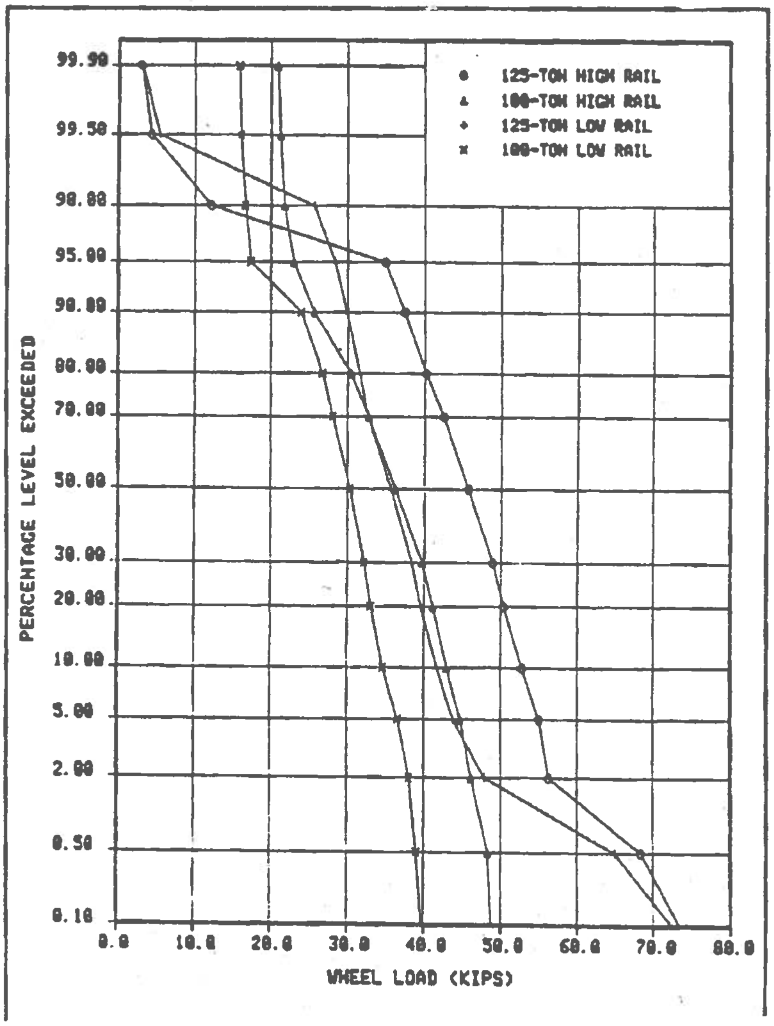

Figure 2-3: Probability distribution of peak vertical rail loads at 40 mph, 100- and 125-ton cars

While these levels of loading must still be translated into effect on track deterioration, a proper understanding of the loadings imposed on the track structure can serve as a foundation for the definition of the strength requirements of the track and help maintenance officers plan their track maintenance programs under varying types of operating traffic.

2.2 Lateral Forces

Lateral forces which act upon the track structure are introduced by the curving of the freight equipment, the development of lateral instabilities or the response of the vehicle to lateral track irregularities. During curving, lateral forces can arise due to creep of the wheel set or to flanging of the wheel set, generally on the high rail of the curve. Lateral instabilities, most particularly truck hunting, are a function of the vehicle characteristics and speed. Finally, in a manner analogous to that of the vertical case, track irregularities can cause lateral loading. The amount of lateral force generated depends on the amplitude and shape of the defect, the speed of the vehicle and the track and vehicle characteristics.

As in the case of vertical loads, measurements of the lateral load environment have been extensively performed over the years. Recent research, however, has focused on the loading of the track structure under heavier, 100-ton and 125-ton freight cars, using wayside (on the ground) load measurements and vehicle-borne measurement techniques.

In the case of vehicle curving, standard North American freight cars equipped with conventional three-piece trucks rely on the flanging of the wheel sets to guide the vehicles around curves. This, in turn, generates significant wheel/rail forces which are related to the degree of curvature, the super-elevation of the curve, the speed of the equipment (or alternately the unbalanced super-elevation) and the condition of the wheel and the rail profiles.

Figure 2-4 presents the mean lateral loads (and corresponding vertical loads) generated by a 100-ton hopper car negotiating a 5-degree curve. Note that as the vehicle speed increases above balance speed, the lateral load on the high rail increases (as does the vertical load on the high rail) with a maximum measured value of approximately 13,000 lb. Also note that at speeds significantly below balance speed (10 mph), the lateral loads on the low rail were as high as 14,000 lb.

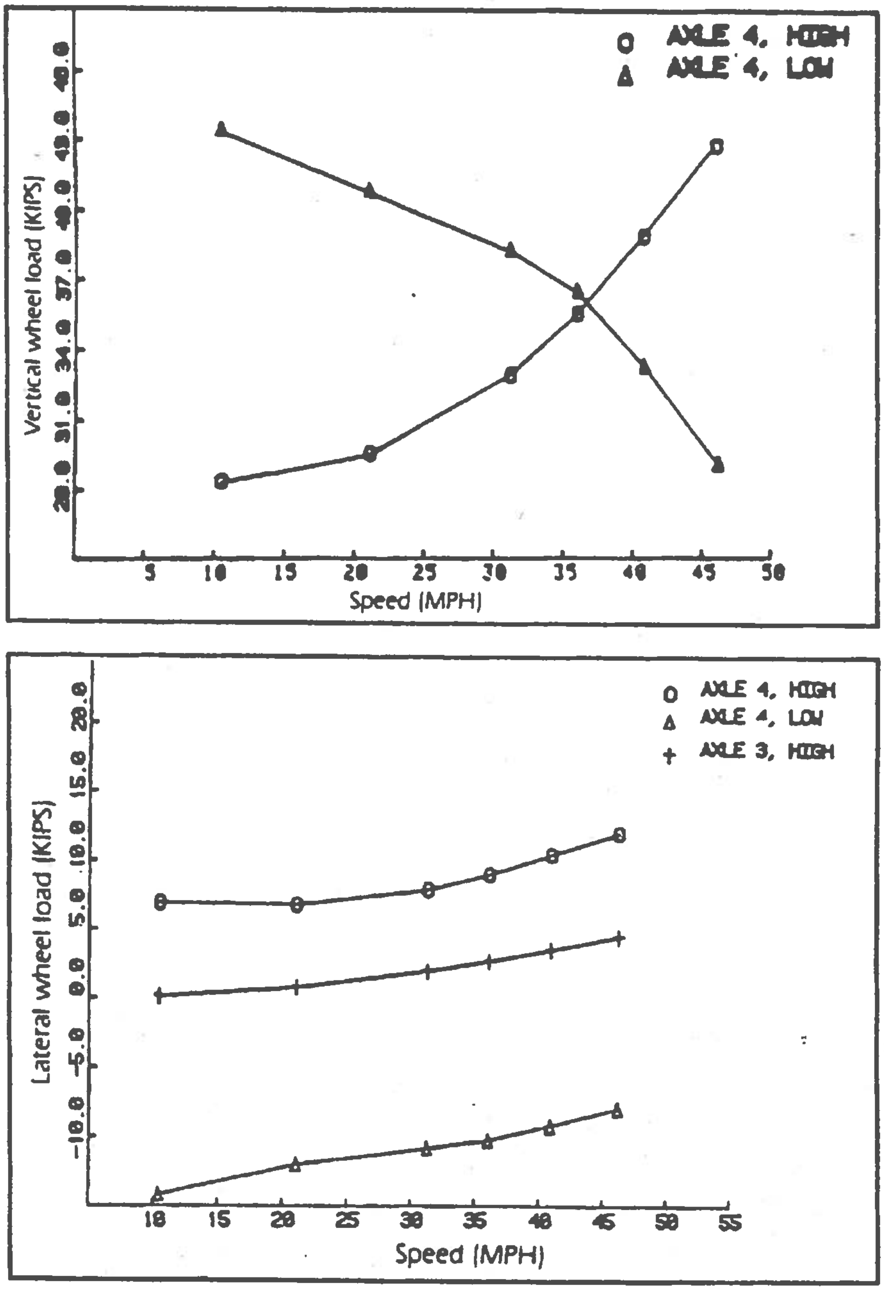

Figure 2-4: Wheel loads versus speed, 100-ton loaded covered hopper car, 5-degree curve.

Figure 2-5 presents the maximum lateral loads generated by a 125-ton hopper car negotiating the same 5-degree curve. Note that the vertical loading on the high rail increases with speed with a corresponding unloading of the low rail. The minimum lateral loads are of the order of 15,000 lb. on high rail and over 20,000 lb. on the low rail. (These dynamic loads and as such they include both steady-state and transient loadings.)

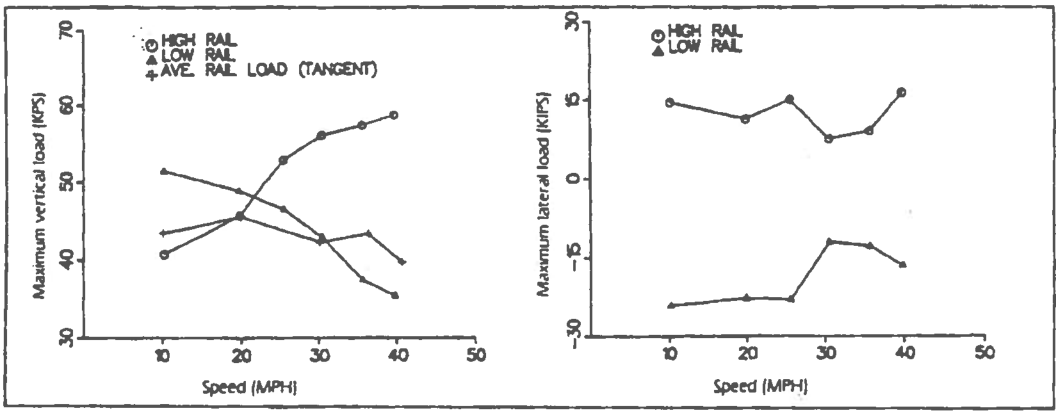

Figure 2-5: Maximum vertical and lateral rail loads versus speed, 125-ton covered hopper cars.

In the case of truck hunting above a "critical" speed, self-induced oscillations of the wheel set generate large lateral motions and corresponding large lateral forces even on tangent track. These lateral loads, which occur under empty as well as loaded cars (though at different threshold speeds), have been measured at over 15,000 lb. for empty 100-ton equipment. Figure 2-6 presents this behavior. Note the dramatic increase in lateral loads corresponding to the onset of hunting.

Although the values presented here are by no mean an exhaustive set of lateral loadings, they indicate the magnitude of the loads imposed by conventional freight traffic, an understanding of these lateral loads imposed onto the track will better help to define the structural requirements and maintenance need of the track structure.

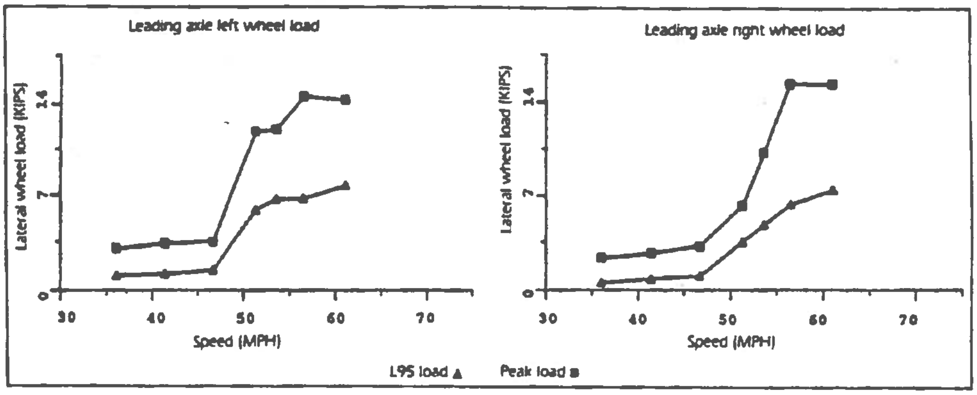

Figure 2-6: Hunting of empty hopper car.

Note: This section was primarily based on Transportation Research Board Paper 88-0598, "An Overview of Wheel/Rail Load Environment Freight Equipment Suspension Dynamics:' a report of research formed by Semih Kalay and Albert Reinschmidt of the Association of American Railroads. All figures used in this section were similarly drawn from the report.

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION THREE

RAILROAD TRACK DESIGN

3. Function and Design Criteria of Railroad Track

The two main functions of the track structure are: a.) to support the applied loads, and b.) to act as a guideway for railway vehicles.

3.1 Supportive Role

The supportive track structure is composed of four main components: rail, ties, ballast and subgrade. Each component contributes to the over-all vertical strength of the structure, and each has a role to play in the support mechanism.

The last section dealt with the loading environment that the track structure must exist in. Loads applied by railway vehicles include: live loads of cars and locomotives, dynamic loads from impacts and other motion effects, centrifugal loads on curves, lateral loads from hunting, nosing, and from lateral components of live and dynamic loads, and longitudinal loads from wave action under the wheels. However, there are more forces at work in the track structure than just those being applied by the traffic. In-track forces include: dead loads of rails, ties, ballast and fasteners, thermal loads (especially in continuous welded rail) that can be vertically, laterally or longitudinally applied.

It should be understood, however, that the track structure cannot be analyzed properly apart from the dynamic influence of the traffic on it. The two form a system wherein a change in either one is reflected in a response by the other. For example, trains impart forces through wheel and axle loads, braking, accelerating, poor mechanical condition (wheel flats, out-of rounds etc.), sway, concussion, buff, draft, hunting and so on. The track imposes reciprocal effects on the train from curvature, superelevation, low joints, uneven cross-level, poor alignment, warp, twist, sags, crests and other geometry and unstable subgrade conditions.

It is with these forces in mind that the theories and techniques for track design and analysis have been developed. Talbot gathered the various formulas developed by such people as: Winkler, Zimmerman, Timoshenko, Meacham, Tayabji, Thompson, and Caldwell into a unified set of equations that are still used today for the design of the track structure and track components.

Talbots formulas are based on the track structure acting as a continuous, elastically supported beam. The main formula is the deflection equation:

$$y = \frac{P}{(64EIu^3)^{1/4}} e^{-\lambda x}(\cos\lambda x + \sin\lambda x)$$

where: y = track deflection in inches

P = wheel load in pounds

E = modulus of elasticity of rail steel = 30 X 10^6

I = moment of inertia of the rail in inches to the fourth power

u = modulus of elasticity of the track support (track stiffness modulus) (the amount of load in pounds on a 1-in. length of rail required to depress the track by 1-in.; it is a lumped parameter combining tie, ballast, and subgrade stiffness in one term)

e = 2.7183

= $(u/4EI)^{1/4}$ = damping factor

x = distance to any point on the deflection and bending moment curves in inches

EI = flexural rigidity of the rail

Using this base formula and the following limiting criteria, rail size, tie dimensions, and ballast depth can be optimized for the load environment they will be exposed to.

a. Subgrade can support up to 20 p.s.i.
b. Mainline track should not deflect more than 1/4 inch under traffic
c. Minimum tie spacing shall be 19.5 inches for tamping purposes

3.2 Track as a Guideway

Flanges on the inside of railway vehicle wheels prevent the wheels from running off the rails when lateral forces are applied. Lateral forces such as centrifugal forces in curves and impact forces due to hunting, draft and buff are transmitted to the track structure through the wheel flange (or wheel tread to rail head contact friction). The main track components that are effected by these lateral forces are: rail, crossties, fasteners and ballast.

Lateral forces acting on the track structure tend to affect track integrity in several ways:

- Gauge spread
- Rail roll-over
- Track misalignment

Specifications and standards set limits on the amount of lateral variation that can be tolerated based upon speed and tonnage ratings (track-T Class) that the particular track structure will be exposed to. These limits are generally established by the railway with the maximum limits, (safety limits) set by the Federal Railway Administration (Track Safety Standards part 213).

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION FOUR

CROSSTIE DESIGN and SPECIFICATION

4. Function, Design and Specifications of the Crosstie

A prime function of cross ties is load distribution. The tie load on ballast has a direct effect on required ballast depth. Unit load distribution, p_a, in the ballast pressure equation, is a function of tie bearing area, tie spacing, and the portion of wheel load borne by each tie. These are closely related to tie size and design.

4.1 Load Distribution

For a given tie load the value of p_a, the average load distribution in pounds per square inch, is a function of tie width, tie length, and the extent of the tamping zone. The tamping zone varies with tie length, but a sufficiently close approximation of bearing area length can be taken as two-thirds of the tie length. The total bearing area is the product

$$A'_b = 2/3 \times L \times b$$

The unit load on the ballast will be the tie load divided by the bearing area of the tie, $2P/A'_b$, and the unit load or pressure on the ballast will be

$$p_a = 3P/bL$$

where;

- p_a = unit tie pressure on ballast (it should not exceed 65 psi for wood ties and 85 psi for concrete ties)
- A'_b = total bearing area of a tie in square inches
- L = tie length in inches
- b = tie width in inches
- P = wheel load on one tie in pounds; 2P is the axle load on one tie.

For greater precision in bearing area calculations the effect of tie thickness can be included. A thin tie tends to increase the initial bearing area. The AREA Manual (1980-1981 revision, p. 22-3-19) presents the equation for the bearing area under one rail as

$$A_b = b(L-60)\left\{1 - \frac{0.018(L-60)}{t^{0.75}}\right\}$$

where: A_b = bearing area under one rail = $A'_b/2$
t = tie thickness in inches.

4.2 Tie Width

Increasing the tie width, length, or both increases the bearing area and reduces p_a and therefore the required depth of ballast to meet subgrade requirements. When comparing the relative bearing capacities of different tie widths in terms of an 8-in-wide tie and the ultimate load capability, that is, at the point of the tie being forced into the ballast, and uniform ballast support is assumed, a 10-in. tie will bear 51% more load than one 8 in. wide, and a 12-in. tie 120% more. A 10-in. tie compared with 9-in. ties will carry 1.51 - 1.20 divided by 1.20 or 25% more load. The modulus of support has, in effect, become 25% stiffer. If the modulus were 2100 lb./in./in. with a 9-in. tie, it would be 2625 lb./in./in. with a 10-in. tie.

The evident advantages of wider ties may be offset by the greatly increased cost and scarcity of such large timbers. One solution, not yet widely adopted, is the use of laminated ties. In one design boards about 1 in. thick and of desired width are glued together to give the necessary depth. Strips of plywood may be similarly bonded together. Another design that has a good in-track record assembles two or three full-depth sections by gluing and/or doweling with three-spiral steel dowels. Three 7 in. by 4 in. sections thus joined utilize small-sized stock to make a 7 in. by 12 in. tie. Dowels are preferably installed in green wood for greater resistance to withdrawal. Ties wider than 9 in. may pose problems in hand-tamping the full width, but concrete ties having a 12-in. base have been tamped with little difficulty, using modern tamping equipment.

4.3 Tie Length

The effect of tie length on bending moments, and hence on allowable wheel loads, and on the effective bearing areas is fairly obvious. A tie longer than 8 ft 6 in. is less than optimal in bending strength but gives increased bearing area and load distribution. Further, the longer tie, 9 ft 0 in. today, with more wood buried in the ballast, offers greater resistance to displacement, be it lateral, vertical, or longitudinal. It provides better track anchorage; however, its initial cost is also greater.

4.4 Tie Spacing

Early designers assumed wheel and axle loads to be evenly distributed over three ties. More recent practice has assumed that 40% of the load is carried by each of the two ties nearest the wheel. The actual distribution will, however, vary with tie spacing, as shown in Figure 4-1 where two evaluations of the load versus tie spacing have been plotted. It follows that tie load distribution will reflect wheel/axle load distribution. To compare a 9-in. tie at 20-in. spacing with a 10-in. tie at 24-in. spacing the ultimate carrying capacity of the 10-in. tie would be 25 more, as before, but the wheel load increase would be 0.46 (from the chart in Figure 4-1) divided by 0.40, or 1.15, a 15% increase. The combined effect, 1.25 divided by 1.15, would be 1.08, that is, an 8% increase in stiffness. The effective u of 2100 becomes 2268 lb./in./in. The wider spacing has, however, lessened the improved effects of greater tie width. With the new value of u, track deflection can be computed. As before, a stiffer modulus reduces track deflection.

Calculations conducted by Magee showed that (1) the tie bearing area has an important effect on the elasticity of rail support and rail deflection, but (2) it did not significantly affect the tie reaction. A composite curve for the deflection curve under the adjoining trucks of two 100-ton cars showed a deflection of 0.22 in. with 20-in. spacing, and 0.34 in. with 30-in. tie spacing.

In summary, the increased bearing area obtained through the use of wider and/or longer ties and closer tie spacing produces stiffer track and less rail deflection, as well as less strain on the subgrade and a lesser required depth of ballast. The same study later concluded that irregularities in track cross level and surface are more a function of the ballast and subgrade characteristics than of tie arrangement. Also, Talbot noted a greater variability in track modulus from tie to tie as the track became compacted by traffic.

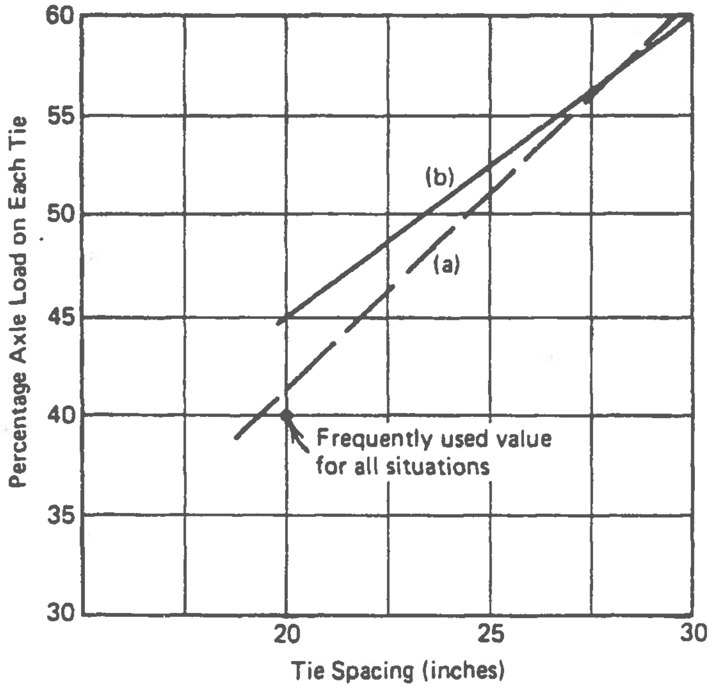

Figure 4-1: Tie load distribution versus tie spacing: (a) generalized distribution using, 132 lb. rail, u = 2000; (b) for use with concrete ties [Manual for Railway Engineering (Fixed Properties) rev. ed., AREA, Washington, D.C., Figure 1.1.2.3.1., p. 10-1-6].

The design decisions are largely economic-higher costs for ties and installation versus greater track stability and lengthened maintenance cycles. For heavy-duty track 19 1/2 -in. tie spacing (24 ties per 39 ft of rail) and a 7 in. x 9 in. x 9 ft. 0 in. tie size are the current maximums. The high costs of tie wood in the higher size ranges and of additional ties have not seemed to warrant the additional expenditure for anything larger. (Concrete ties may have a wider base, but they usually have a wider spacing.) There is, unfortunately, a lack of transfer functions or properly documented experience to indicate just how much longer a maintenance cycle can be extended by the use of enhanced tie support areas; hence it is difficult to make economic comparisons.

4.5 Tie Depth

Equation for Bearing Area (A_b) has already noted the effect of tie depth on the bearing area A_b and the bending stresses.

The depth or vertical thickness of a tie is limited to a minimum practical value of 6 in. Ties that are any thinner are likely to be split by the size of the spikes necessary to secure sufficient holding capacity. You should also note that depressions under the ends of the tie and eventual center binding result from flexibility. It is evident that the flexure and bending moments should be minimal. Since, according to the properties of beams, stiffness varies as the cube of the depth, a greater tie thickness will reduce the flexure and bending moments. This was recognized when a thickness of 7 in. was recommended by the AREA and adopted as a standard by most railroads. A greater thickness, it is true, would give still more stiffness. However, the need for this increase has not yet been recognized as being of more value than the offsetting additional cost of material and increases in weight.

4.6 Why Timber?

With the object of keeping long-term annual cost of a crosstie as low as possible while maintaining the standards of efficiency required, the railroad engineer will consider:

- the suitability of timber for the task
- the initial cost of timber, its anticipated life
- whether the timber is readily available or whether it must be imported
- methods of track-laying available

These considerations will have various orders of priority depending on conditions in the area concerned and the purposes that the railway serves in that area. The decision of what material to use may be made primarily on a question of cost or, if imported, on the foreign import duty, exchange rate, and availability. A compelling reason for using the material available within the country may be the employment of indigenous labor and this could dictate the quality of the product and consequently the standard of performance which can be achieved.

Timber can be favorably considered where any of the following apply:

- it is available in the right quality and at an acceptable price, whether from a local or an outside source

- labor is cheap and plentiful to carry out construction

- conditions, either physical or economic, make problematic the use of mechanized track laying or mechanized maintenance

- there is jointed track; also at all rail joints timber is the best support material to withstand the shock of batter on the rail ends

- there is electrical insulation needed for power or signaling

- a series of points and crossings is joined by short lengths of plain track

- there are critical clearances in tunnels

- the job entails spot tie renewals or replacement of individual switch or crossing ties

- the requirement is for switches and crossings

- the anticipated service life accords approximately with the life of one, two or more rails

- a reason or reasons exist for not using another form of sleeper, for example the ground or the atmosphere contains chemicals harmful to steel or concrete

- where fire would present a serious hazard such as under ground, or where the ties are subjected intermittently to burning or acid substances such as steelworks and chemical factories, in which dense durable untreated hardwoods are used

- secondary use or recovery value is anticipated

4.7 Specifications

When choosing a timber tie for track installation, there are a number of specifications that must be considered before ordering. Tie specifications should include the following:

- Grade of tie
- Type of wood
- Required machining
- Anti-splitting devices
- Tie coatings

Grade of Tie: We have discussed the development of tie dimensions, and depending on the use (type and weight of traffic etc.), we know what grade to use for the application. In general, we consider the following grading:

7" Grade - Height: 6 3/4 - 7 1/2 inches
- Width: 9 - 9 1/2 inches (with 1" wane allowed in rail seat area)

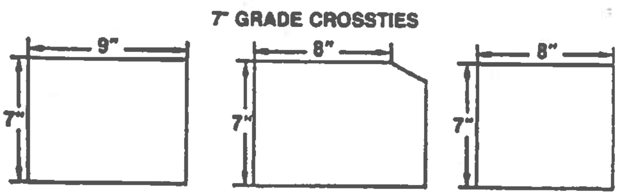

Figure 4-2: 7" Grade

6" Grade - Height: 6 - 6 3/4 inches
- Width: 8 - 8 3/4 inches (with 1" wane allowed in rail seat area)

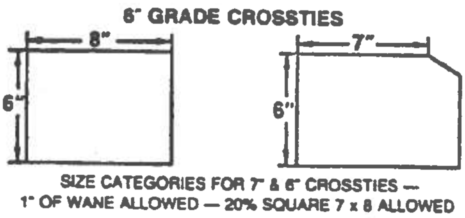

Figure 4-3: 6" Grade

7" Grade ties are used on track with heavier traffic and 6" Grade ties are used on lighter traffic lines. They may be 8, 8.5 or 9 feet in length depending on the specifications of the railroad. All measurements are to be taken between 20 - 40 inches from the center of the tie, and follow the specification category of 1 - 5 as per Figure 4-4.

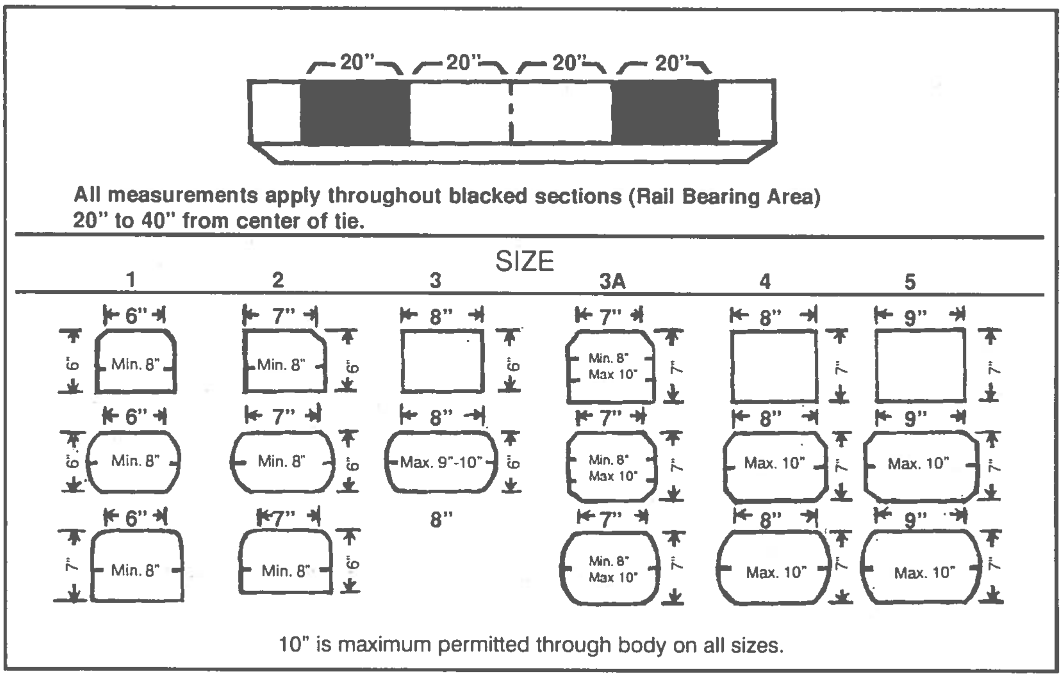

Figure 4-4: Application of Crossties Specifications

It should be noted that there are other tie grades and sizes used, but using the AREA nomenclature allows us to differentiate between mainline and branch line use. In addition, "Rehab" ties are available which are used ties that have had spike holes plugged, possibly been adzed and had a re-application of preservative. These ties are available at a lower cost and may be fine for light duty application.

Type of wood: The type of timber used is classified as Hardwood or Softwood.

> Softwood: The term "softwood" refers to needle bearing trees. The softwood tie may be used in various classes of track. It is more resistant to rotting than hardwood.
>
> Hardwood: The term "hardwood" refers to leaf-bearing trees. The hardwood tie may be used in various classes of track. It is more resistant to plate cutting, gauge spreading and spike hole enlarging, and it transmits load better than softwood. However, with this classification, birch, cottonwood and silver maple may be classified as hardwood, but there is a great deal of difference between the strength of these woods and that of oak.

There is generally a large variance in design strength between the two wood types. For example, dry oak has a design strength of 550 psi; for wet oak 365 psi, whereas, the design strength for dry pine is 415 psi and for wet pine, 275 psi.

Hardwood and softwood ties must not be mixed on the main line track except when changing from one type to another.

Machining: When ties are adzed, bored, branded, grooved, incised, or trimmed, the operations required by any machining order shall be carried out before air seasoning, or immediately prior to preserving, in accordance with the machining specifications in AREA Chapter 3, Part 1.5.

> Adzing: Removal of wood under the rail seat to ensure proper height, flatness and squareness with the opposite rail seat.
>
> Boring: The pre-boring of spike holes in the tie for the acceptance of spikes. Generally done for hardwood ties from top to bottom, not always done for softwood ties but may be a universal bore pattern.

Grooving: The practice of using ribbed tie plates on hardwood ties requires the rail seat area under the plate to be machine grooved to accept the rib. Tolerances must be the same as for boring.

Incising: Ties (especially hardwoods) are incised to a depth of 3/4 inch prior to treating to improve the penetration of the preservative across the grain of the wood.

Trimming: Tie ends are cut a preset distance from the rail seat area of the line side of the tie to allow proper lining of the ties when installed.

Branding: Many ties are custom branded on the ends, top to bottom to indicate: wood, treatment, weight of rail for boring pattern, year, size, fabrication plant, and/or Railway.

Anti-splitting Devices: Used to control the splitting of wood ties, generally one of three types a) a strip of steel applied by driving into the end of the tie, b) a steel dowel applied parallel to the wide face of the tie, transverse to its length, or c) a steel multi-nail applied by driving into the end of the tie. Both a) and b) types are used prior to treating the tie to control the onset of the split end. The multi-nail (or gang nail) type is used to prevent the widening of an existing split or to prevent a split from occurring after the treatment process.

Tie Coatings: A topical application that offers protection to the tie from weathering, and splitting in service. Generally a solvent type bituminous or other suitable material that fills cracks and splits and maintains a suitable pliable, waterproof coating on the top, sides, bottom and ends of the tie. The application is generally pressure impregnation (and may be in combination with incising if hardwood is used), but may be immersed or surface applied.

Such preservatives as Creosote, coal tar, Pentachlorophenal, copper naphthenate, ammoniacal copper arsenate and chromated copper arsenate are used for this purpose. Generally these coatings control weathering, splitting, and rot from fungi. Continued experimentation with the use of Borate, a water soluble fungicide has used Borate in a solid rod which is inserted into prebored holes near the rail seat, or as a dip. However, since the borate is water soluble, the tie must still be treated with a non soluble coating to preventing leaching of the borate. No matter what treatment is used, care must be taken in handling treated ties since many preservatives may cause skin irritations and are potentially toxic or carcinogenic. Disposal of treated ties must be done only within the guidelines of the Environmental Protection Agency.

WOOD CROSSTIES
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STUDENT HANDBOOK

SECTION FIVE

TIE FASTENING SYSTEMS

5. Fastening Systems for Wood Crossties

In previous sections, we have reviewed the loading and operating environment in which the wood tie must perform and discovered that the track structure is subjected to extreme vertical, lateral and longitudinal forces. In order to maintain it's geometry, the track structure must restrain these forces. The process of force transmission is from the rail to the tie, from the tie to the ballast section and finally to the subgrade. The components needed to transmit the forces from the rail to the tie are the fastening systems.

In America, the two basic types of fastening systems used on wood ties are: 1. Cut spike and anchor, and 2. Elastic fasteners. Each fastening system has its own component make-up with each component in the system performing a particular task.

5.1 Cut Spike and Anchor

The components comprising the cut spike and anchor fastening system are: tie plates, cut spikes, and rail anchors.

<u>Tie plates:</u> A tie plate causes the load being transferred from the rail to the tie to be spread out over a greater area than would be the case if the rail were laid directly on the tie. It is not uncommon to see cases where tie plates become embedded in the ties so that the tie plates are below the top of the ties. This condition is generally described as "plate cutting". It is most common in tracks carrying a high density of traffic. This condition would occur in relation to the rail base if tie plates were not used and it would develop at a much faster rate.

As an example, suppose the load on a rail is such that when a wheel is directly over a certain tie, the load going from the rail to the tie is 24,000 pounds. Suppose that the rail base is 6-inches wide, no tie plate is used and the tie is 8-inches wide. The total bearing area of the tie receiving this load is the 6-inch rail base times the 8-inch tie width. The pressure on the wood can be calculated as follows:

$$\frac{24{,}000 lbs}{6-in \times 8-in} = 500 - lbs \cdot per \cdot square \cdot inch$$

Next, consider the same load on the same tie. This time a tie plate is used which measures 8-inches by 12 inches. The pressure on the wood is:

$$\frac{24{,}000 lbs}{8-in \times 12-in} = 250 - lbs \cdot per \cdot square \cdot inch$$

Although the total load on the tie is the same, the pressure on any particle of wood has been reduced by one half. This can have a considerable effect on the life of the tie.

The size of tie, plate has tended to increase over a long period of time just as the weight of rail has. This, too, has been done to better meet the demands of ever increasing loads moving over the track structure. The situation on most railroads is such that there are in use a number of different sizes and types of tie plates. There are a number of different characteristics to look for to recognize the various types of tie plates available.

One thing to check is the size of the tie plate. This can be determined by measuring the length and width of the tie plate. It should be noted that the majority of today's plates are 7 3/4 inches wide, and as a result, plates can be specified by length and spike hole punching alone. Never choose a tie that is narrower than the tie plate under which it is to be installed. This will lead to plate bearing anchors which can cause sheared off spikes, and a loss of track integrity.

Another characteristic to look for is whether the tie plate is of the single- shoulder or the double-shoulder type. Although the present trend is to double-shoulder tie plates, many plates in track are of the single-shoulder type. Shoulders are the raised lips on the top of the tie plate intended to contact the outside edge of the rail base. Single-shoulder plates are designed for a shoulder on the field side of the rail only. Double-shoulder plates have shoulders for both the field and gauge sides. Figure 5-1 shows both a single-shoulder tie plate and a double shoulder tie plate.

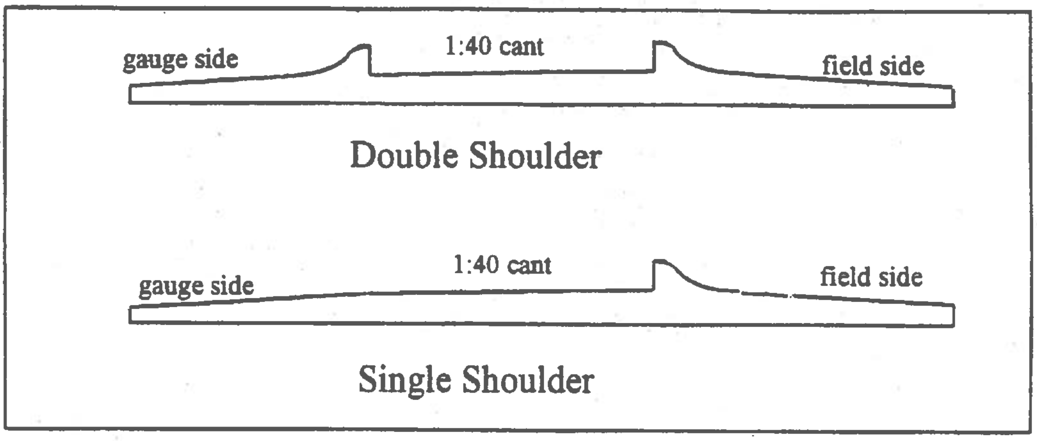


Figure 5-1

Most tie plates are designed for one particular width of rail base. This applies to all double-shoulder tie plates, and is determined by measuring the flat width between the two shoulders. On single-shoulder plates, it is determined by measuring the distance from the inside edge of the shoulder to the nearest edge of the hole for the gauge side rail-holding spike. Some single-shoulder tie plates can accommodate rails of more than one base width. This is done by providing more than one hole for a rail-holding spike on the gauge side. The holes are different distances from the shoulder to provide the necessary clearance for various rail-base sizes for which the tie plate is intended.

Still another consideration in classifying tie plates is the hole punching for insertion of spikes. Such holes can be classified into four categories: there are gauge side and field side rail-holding spikes and there are gauge side and field side plate-holding spikes. Figure 5-2 shows the different type of plates with both A and B punching configuration.

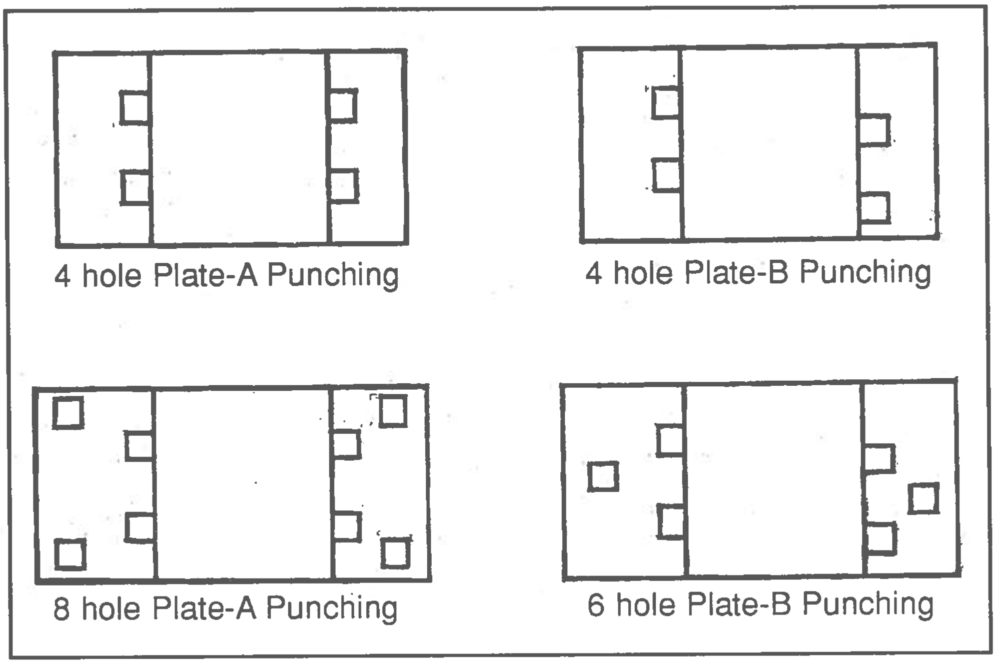


Figure 5-2

One more thing that must be considered in the use of tie plates is the cant of the rail seat. Formerly, all tie plates were designed so that the base of the rail would be parallel to the top of the tie. All of the newer tie plates are canted, usually with a slope of 1:40 (but sometimes with a slope of 1:14 or 1:20). Figure 5-1 illustrates the cant of the tie plates, and the proper gauge and field side orientation. The rail seat is designed so that the field side of the rail base is slightly higher than the gauge side of the rail base. This results in the entire rail being slightly tilted towards the center of the track.

While this has certain advantages (such as improved contact between wheel and rail), the important thing to remember is the relation of one type of tie plate to another. It is poor practice to use flat and canted tie plates interchangeably. If this is done, the rail cannot be seated uniformly on both types of tie plates. This can result in a tendency for the rail to twist, or possibly break, and for the development of plate-cut ties and bent tie plates. To further complicate the problem, some railroads use tie plates with different cant for different applications. It is of great importance that the railroad not mix the various tie plates within the same track segment. For example, mixing tie plates with a 1 to 20 cant, with tie plates having a 1 to 40 cant is just as bad as mixing flat tie plates with those having a 1 to 40 cant.

Cut Spikes: Cut spikes (Figure 5-3) are commonly 9/16 in. square by 5 1/2 inches long or, 5/8 in. square by 6 to 6 1/2 inches long as measured from the chisel tip to the under side of the head. Cut spikes are used in two different capacities, plate holding and rail-holding. Rail-holding spikes are intended to hold the rail in place. In most situations, one gauge side and one field side rail-holding spike are required per tie plate. Some railroads require the use of a second gauge side rail-holding spike under certain conditions. Where this is done, the main purpose is to provide additional restraint against the possibility of a rail being rolled over or pivoted about the field side of the rail base by loads imposed. When this is required, it is usually on curves, particularly sharp curves. Sometimes it is specified in territory with heavy traffic or at locations which have had a history of such problems.

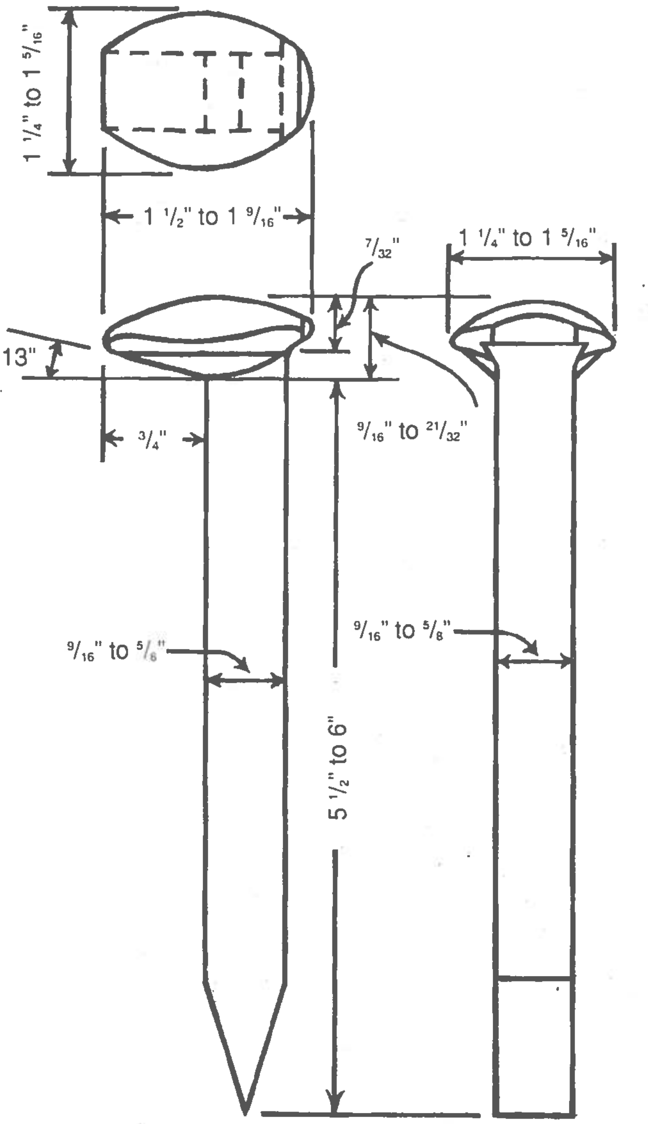


Figure 5-3

Plate-holding spikes, where used, have two purposes. If properly driven into a sound tie, plate-holding spikes secure the tie plate firmly to the tie. This reduces the tendency for the tie to become plate cut which exists when movement occurs between the tie and the tie plate. Another advantage of plate-holding spikes is increased gauge holding capability. When lateral wheel loads tend to spread the rails or widen the gauge of the track, the field side of the rail base bears against the field side shoulder of the tie plate. The amount of restraint against this movement which the tie plate provides is dependent upon the total number of spikes in the tie plate and the soundness of the tie. Some railroads do not have traffic conditions which justify the use of plate-holding spikes. Some may require their use under certain conditions, especially on curves. Where used, either one or two plate-holding spikes per tie plate may be specified. Most railroads have their own specifications for spiking, both as to the number required, and the pattern of placing them in relation to each other. Spiking patterns are important because the relative location of one spike to another can affect the tendency of a tie to develop splits and to slew away from its right-angle position in relation to the rails.

Improved variations on the cut spike that have been developed or imported from Europe in recent years include the Sandberg anchor spike, the gooseneck spike, and single and double elastic spikes, some combined with lock or spring washers.

Rail Anchors: While the tie plate and cut spikes transfer the vertical and lateral forces from the rail to the tie, there is one other type of force placed on the track structure which the tie helps to resist. This is the longitudinal force which tends to make the rails move lengthwise, that is to slide in the tie plates between the spikes. There are a number of conditions under which this tends to happen. They are generally related either to the traffic which moves over the track, to changes in temperature, to grades and to braking. Since it is the rails which tend to move, it is necessary to provide some means of securing the rails. This is done by devices known as "rail anchors".

There are a number of types of rail anchors in use (see Figure 5-4). Most of them are clipped around the base of the rail. They are applied at a point on the rail where one edge of the rail anchor will bear snugly against the side of the tie. Other types of anchors are secured through a tie plate hole as well as to the base of the rail. Some fasteners perform the dual functions that are normally performed by rail holding spikes and by rail anchors as well. Most of these require a special type of tie plate, to which the fastener is secured. When this is done, it is essential to have fasteners connecting the tie plates to the ties. Such fasteners are usually of a special design that imparts greater holding power than conventional spikes.

In the latter cases, the fasteners are capable of resisting rail movement in both directions. Conventional rail anchors can only resist rail movement in one direction. It is necessary to provide anchors on both sides of ties (box anchoring) if there is a likelihood of rail movement in either direction. The AREA specifies that the amount of resistance that must be offered by the anchor is 5,000 lb. longitudinal force, however, once an anchor has been applied a few times, it looses its holding capabilities. It is a better assumption that a standard anchor will hold 1,300 lb. force on average.

Whatever method is used, the rail is - in effect - anchored to the ties to prevent this type of movement. If movement of the rail is to be prevented, the ties must also be prevented from moving. This is a job which the ballast must perform. The amount of resistance which will be developed between a tie and the ballast which surrounds it, depends upon some of the same conditions which determine the resistance to lateral movement of the track. This includes the bond between the bottom of the tie and the ballast, the amount of ballast in the cribs, the spacing between the ties, the type of ballast and whether the ballast is compacted or loose. In addition to all of these conditions, which are variable, the loads which tend to make the rail move can also vary widely. The recommended practice is to anchor enough ties so that there will be enough resistance to prevent movement of the rail. This is generally accepted as 200 feet of boxed anchored ties on Continuously Welded Rail (CWR) territory.

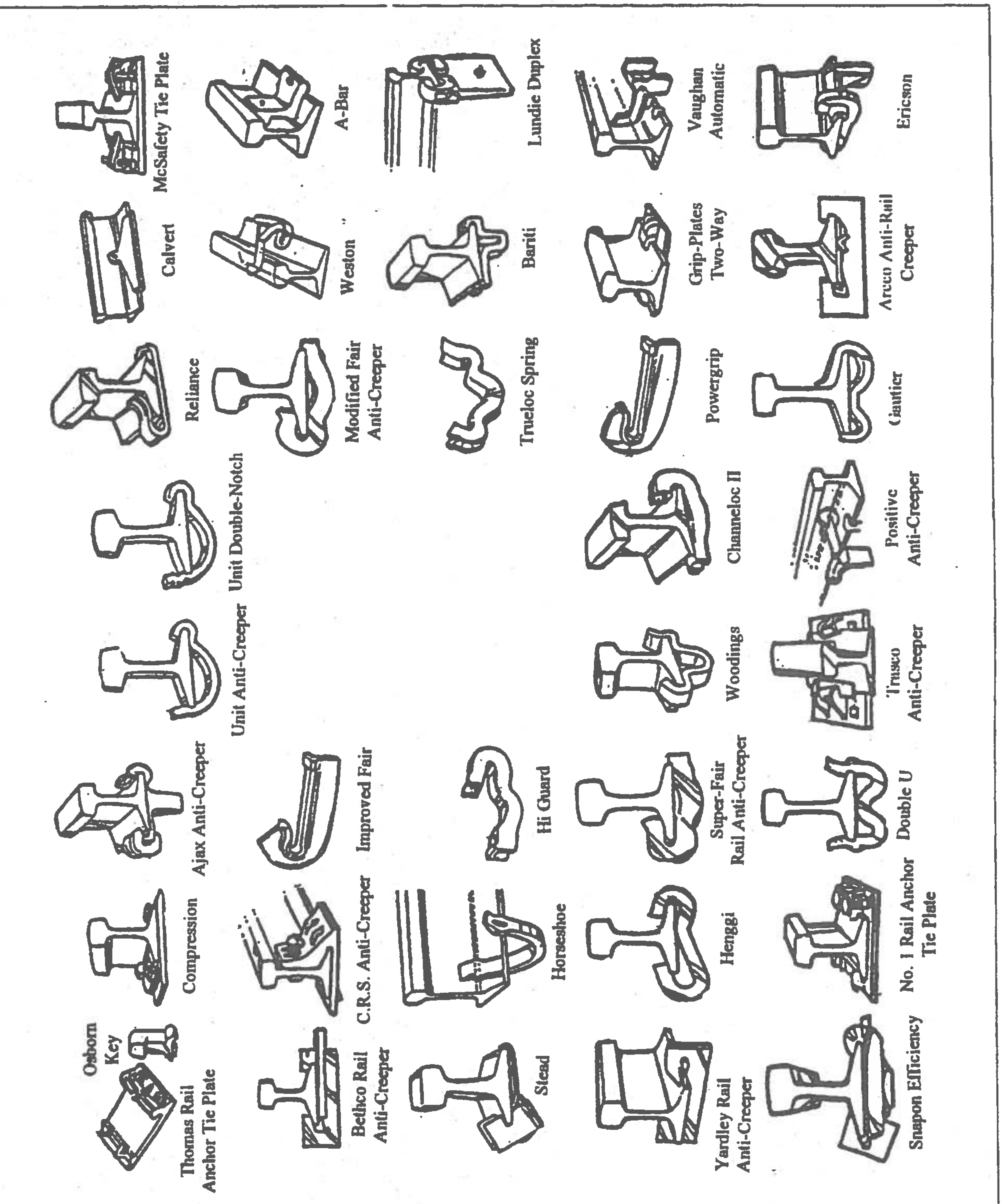


Figure 5-4 History of Rail Anchors

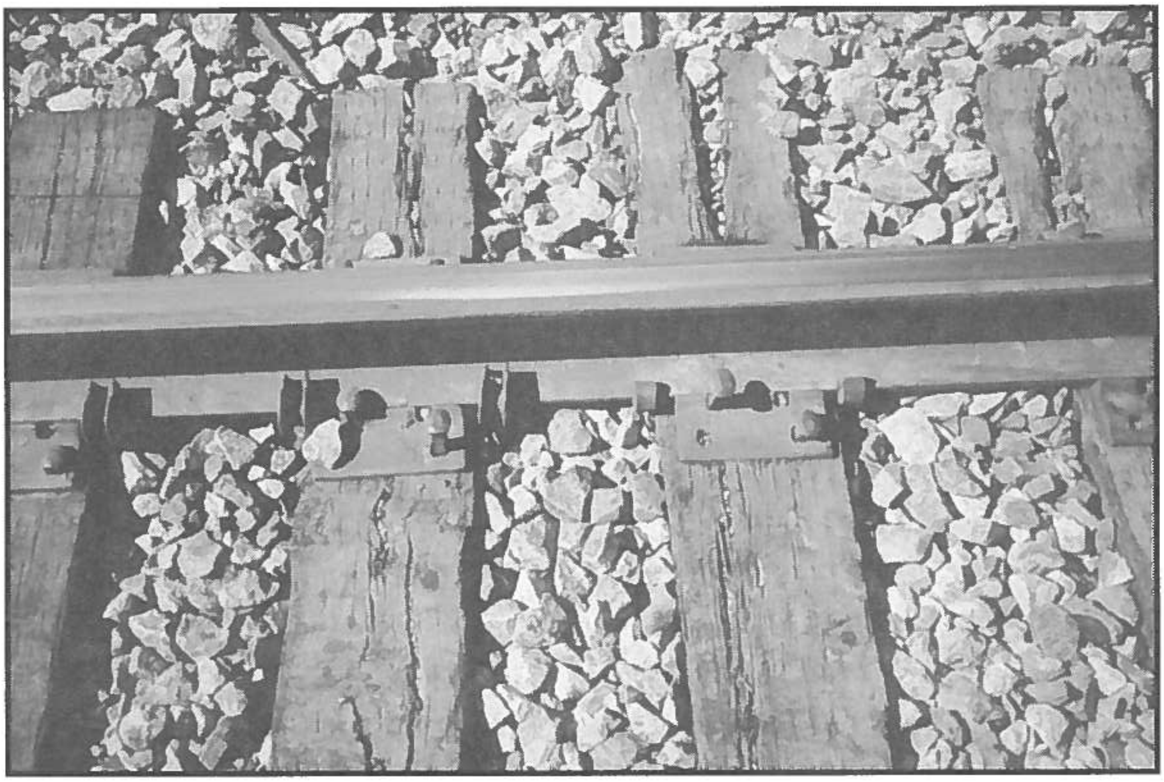
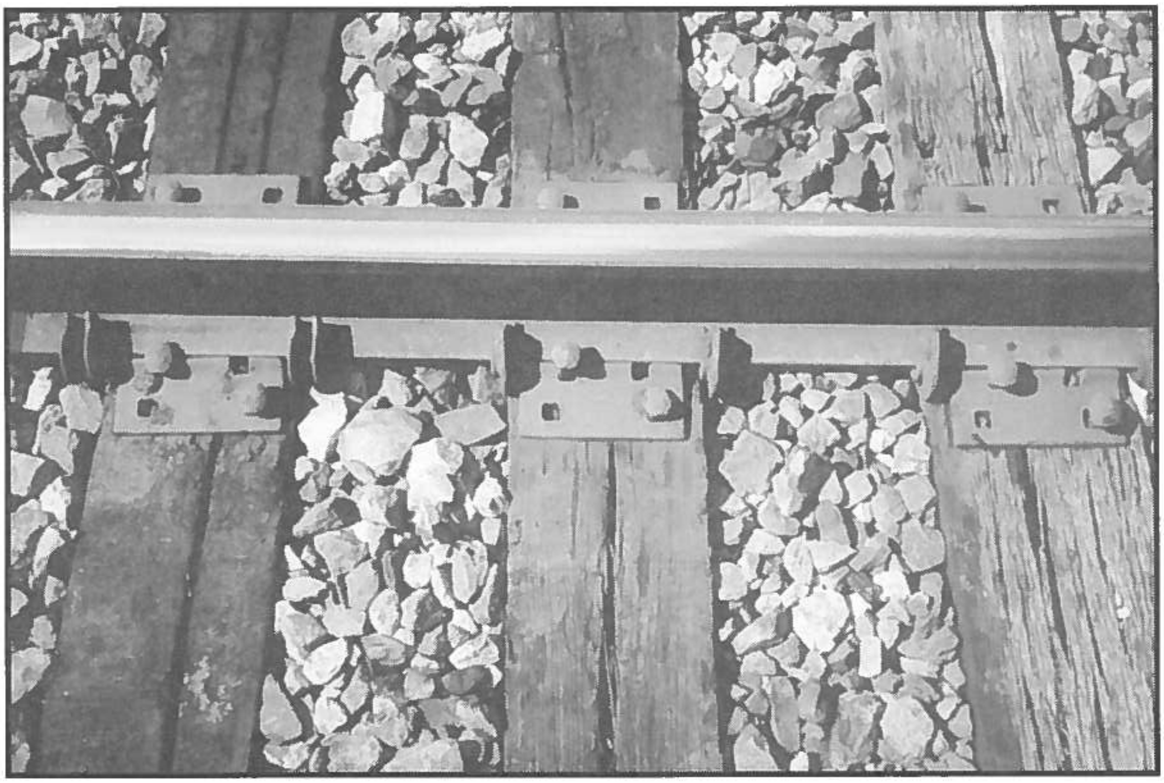


Photo 1: Anchors - channel lock & unit

Photo 2: Anchors - channel lock & fair



5.2 Elastic Fastners

The need to reduce respiking (and spike killing the wood ties) from rail renewals, transposing and gauging track, as well as the need for a fastener that resists gauge widening, and rail roll-over, has been the driving force to develop elastic fasteners for wood tie installations. Elastic fasteners for wood ties come in many different shapes, makes and models, and basically have three components: a clip, a hold-down plate (complete with shoulder) and a plate to tie fastener. One of the first examples of this type of fastener is the German GEO plates and fastenings (Figure 5-5a), a stiff-bolted lug device. The compression clip type elastic fastener (Figure 5-5b.) has had several modifications in which a bolt is used to hold the clip tight to the rail base. A more broadly accepted type of fastener is the Pandrol® Clip type (Figure 5-5c). All designs perform a rail anchoring function, eliminating the need for rail anchors, and thereby reducing the over all cost of the system.

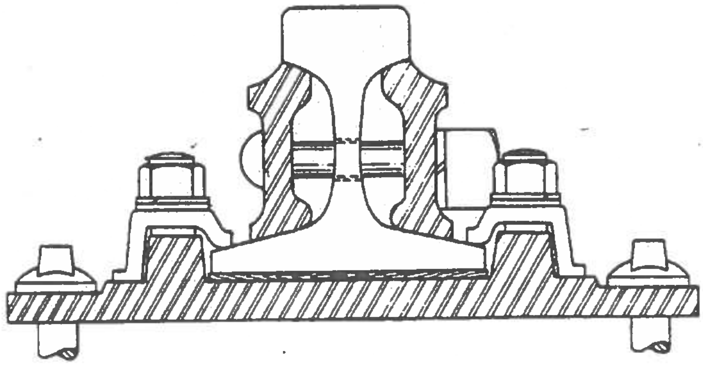


Figure 5-5a

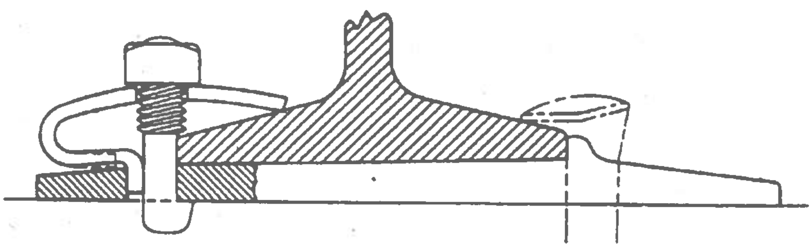


Figure 5-5b

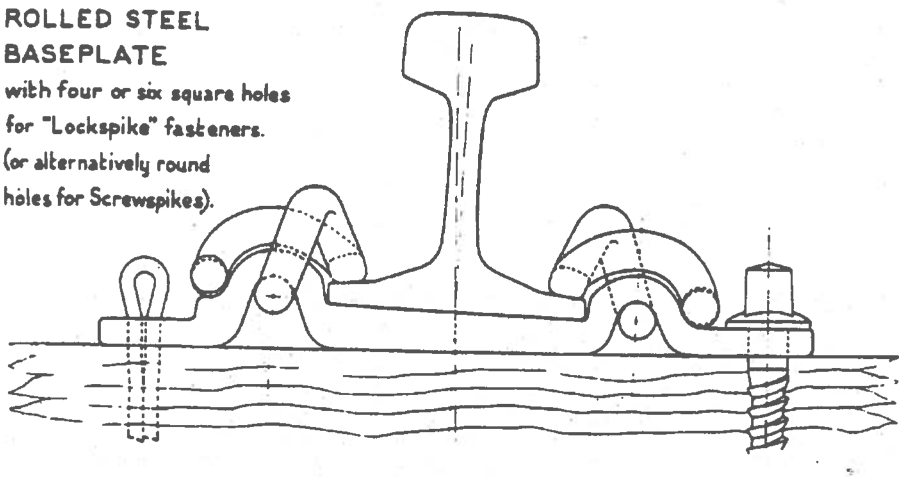


Figure 5-5c

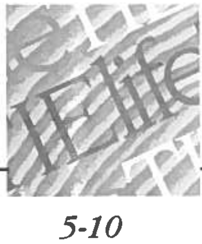
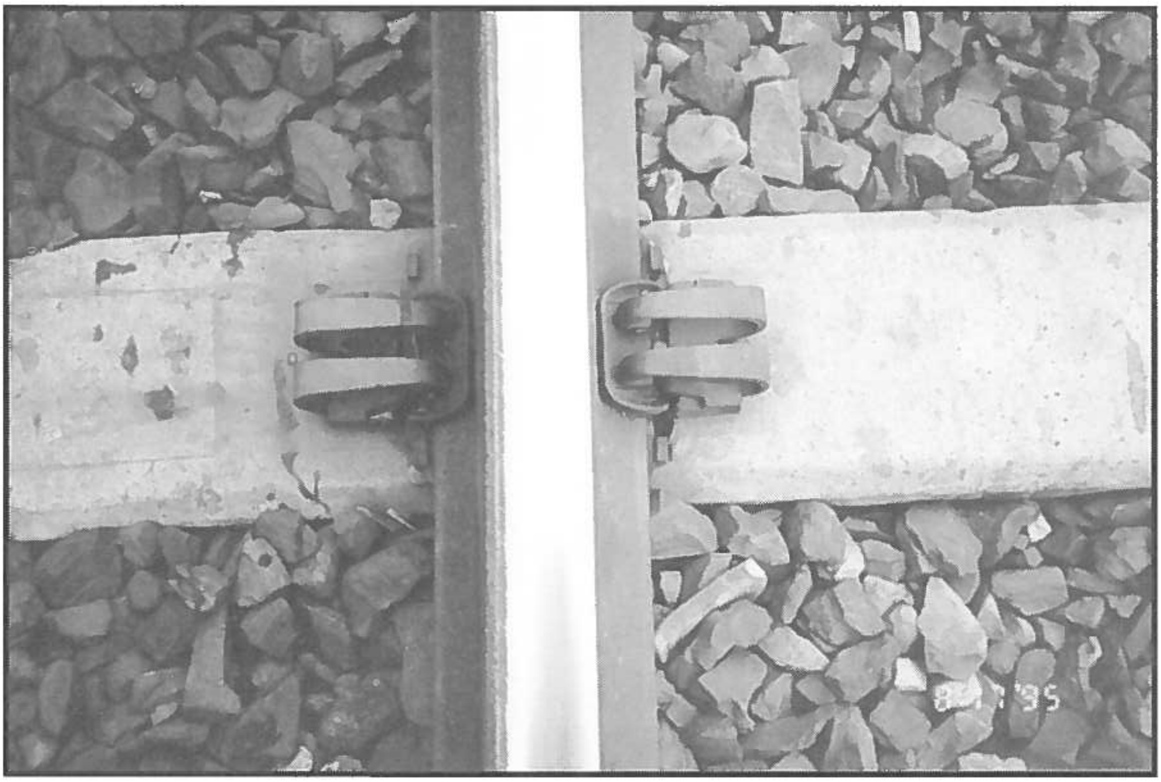


Photo 10: Burned tie

Photo 11: Concrete tie - McKay fastener



WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION SIX

THE FAILURE MECHANISMS

6. Tie Failure Mechanisms and Replacement Criteria

6.1 Wood Tie Failure Mechanisms

The failure of wood ties may be categorized into three different mechanisms: 1. Mechanical wear, 2. Environmental conditions, and 3. Damage.

1. Mechanical Wear: Failed ties in this category include: Plate cut tie, spike killed tie, worn tie, anchor cut tie.

- Plate cut: Movement of the tie plate, laterally due to gauge spreading forces or longitudinally due to train braking/ accelerating or thermal expansion/contraction of the rail, can lead to plate cut ties.

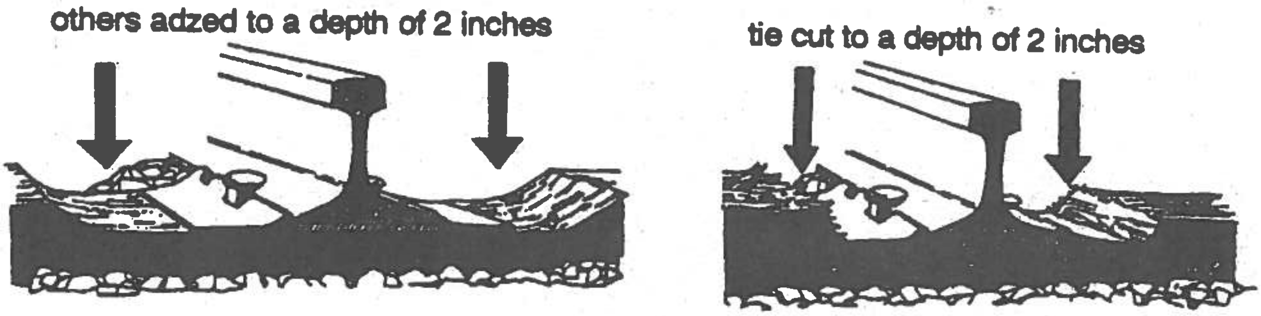


Figure 6-1

- Spike killed: Spikes that no longer have the capability to hold the tie plate from moving laterally or prevent the rail base from lifting, indicate the presents of a spike killed tie. Constant lateral/longitudinal forces that elongate or widen the spike hole, or spikes that have been removed and replaced several times (as in the case of high frequency of rail change out or spike lining of track) may contribute to spike kill. In addition, ties may split if the holes are plugged too many times, and this situation may also be labeled as spike kill.

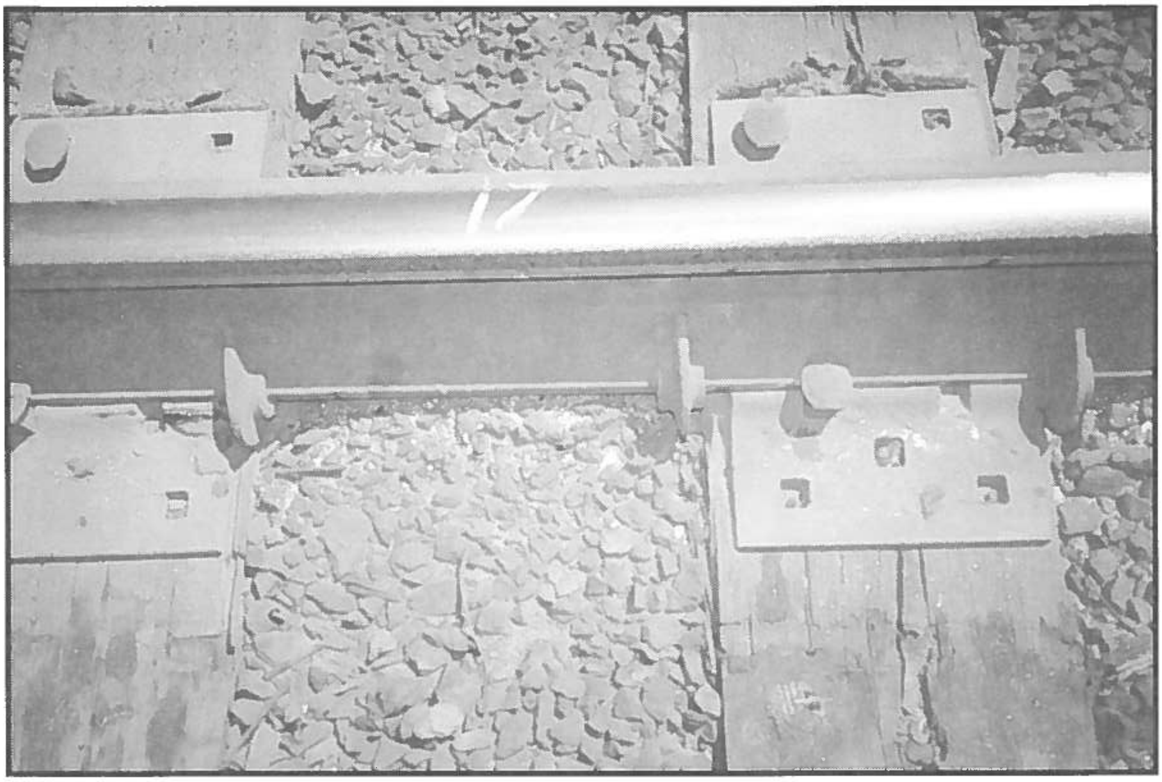
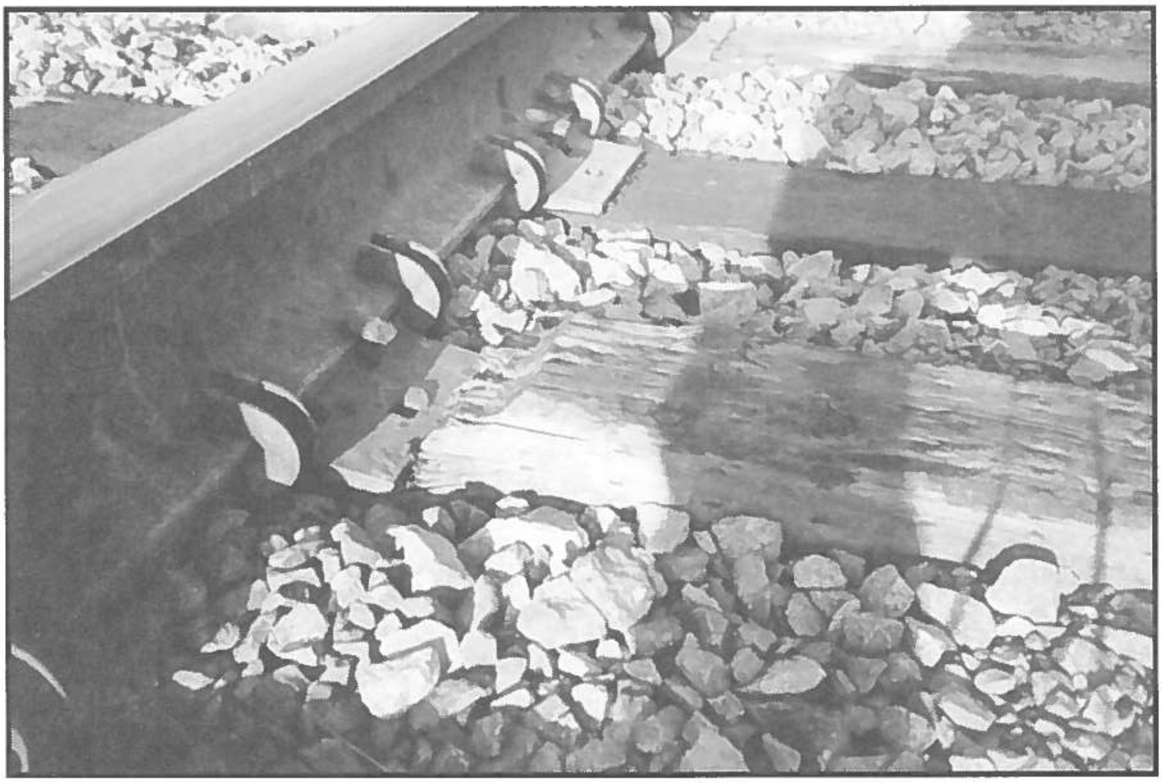


Photo 3: Plate cut tie - beginning

Photo 4: Plate cut tie - severe



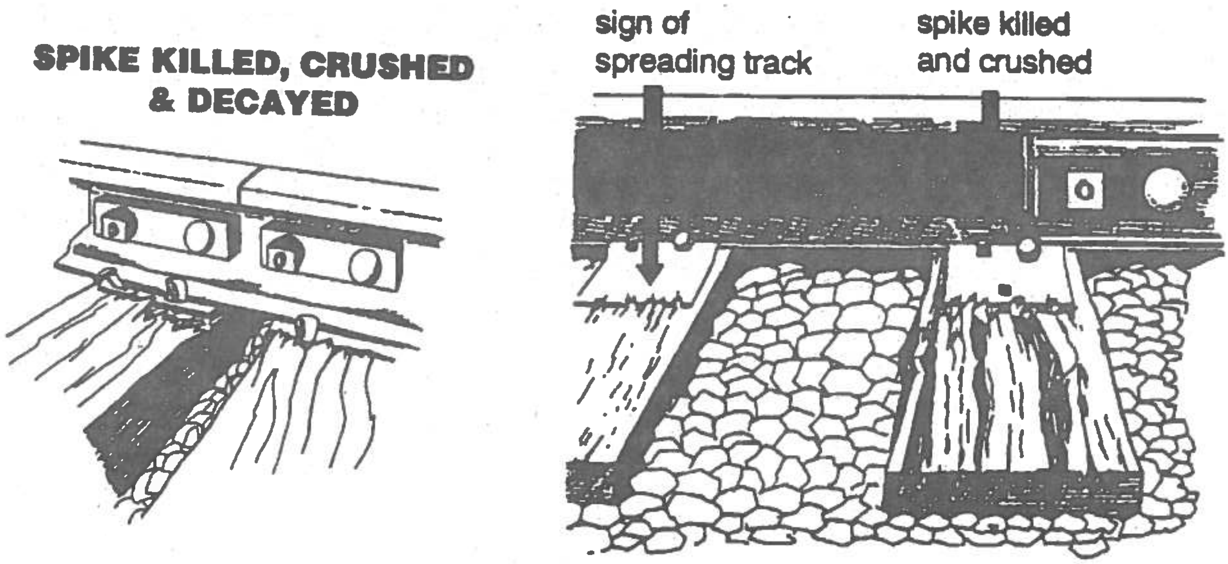


Figure 6-2

- Worn: Tie movements in the ballast section, either laterally or longitudinally, can cause the tie to become rounded resulting in poor surface, line and the inability to hold spikes. This tie condition will be classified as worn.

- Anchor cut: High longitudinal rail forces will cause the rail anchor to push against the tie to transmit the forces through the tie into the ballast. This action can cause the rail anchor to wear away the side of the tie until the anchor rests against the tie plate. This is an anchor cut tie, and if allowed to stay in track will lead to spike kill and plate cutting. For this reason, it should be noted that rail anchors made to rest against the tie plate, such as the Reliance Type, should not be used.

2. Environmental Conditions: Failed ties in this category include: Split tie, split tie end, decayed tie, crushed rail seat, warped.

   - Split: Over time, ties subjected to wet/dry cycles, or freeze thaw cycles can develop splits that can migrate from one end of the tie to the other. Splits can also be the result of improper drying of the green wood before treating. In either case, once the split starts, it will generally progress, and widen with time. The introduction of rain, ice and ballast into the split will wedge the opening further apart until the tie can no longer support the load or hold the spikes.

TIE SPLIT END TO END

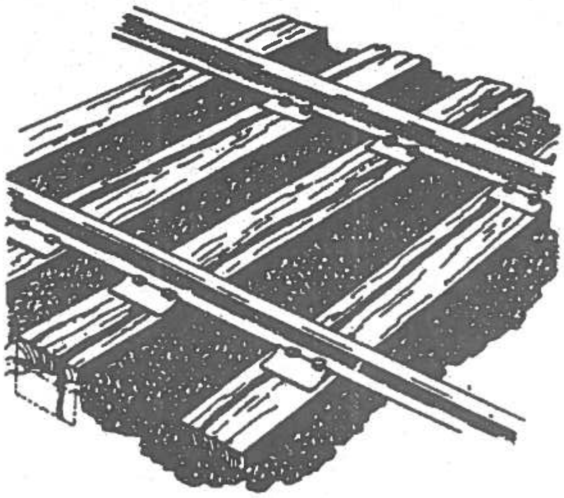


Figure 6-3

- Split tie end: The split tie end may be the result of all of the above noted causes or in addition, could be the result of excessive tie plugging, or rail seat crushing. A split tie end is only a problem if the split migrates to, or emanates from the spike hole. If it affects the spike holding capability of the tie, the tie should be removed.

- Decayed: Exposed wood fibers caused by a tie split or a puncture from mishandling or damage, can be attacked by air-borne fungal spores. The spores begin to grow in the moist wood fibers and the roots of the fungus will break down the wood fibers into pulp. Eventually the tie can no longer hold spikes, gauge or surface.

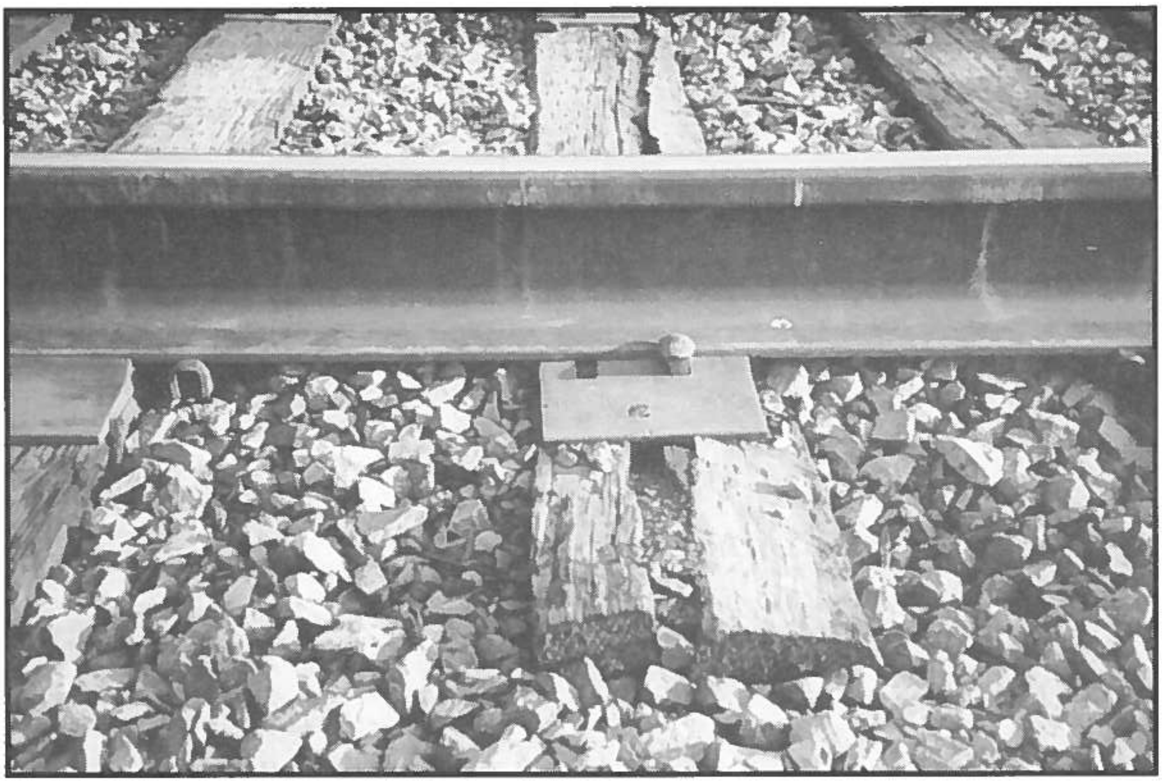


Photo 5: Split tie

Photo 6: Split tie

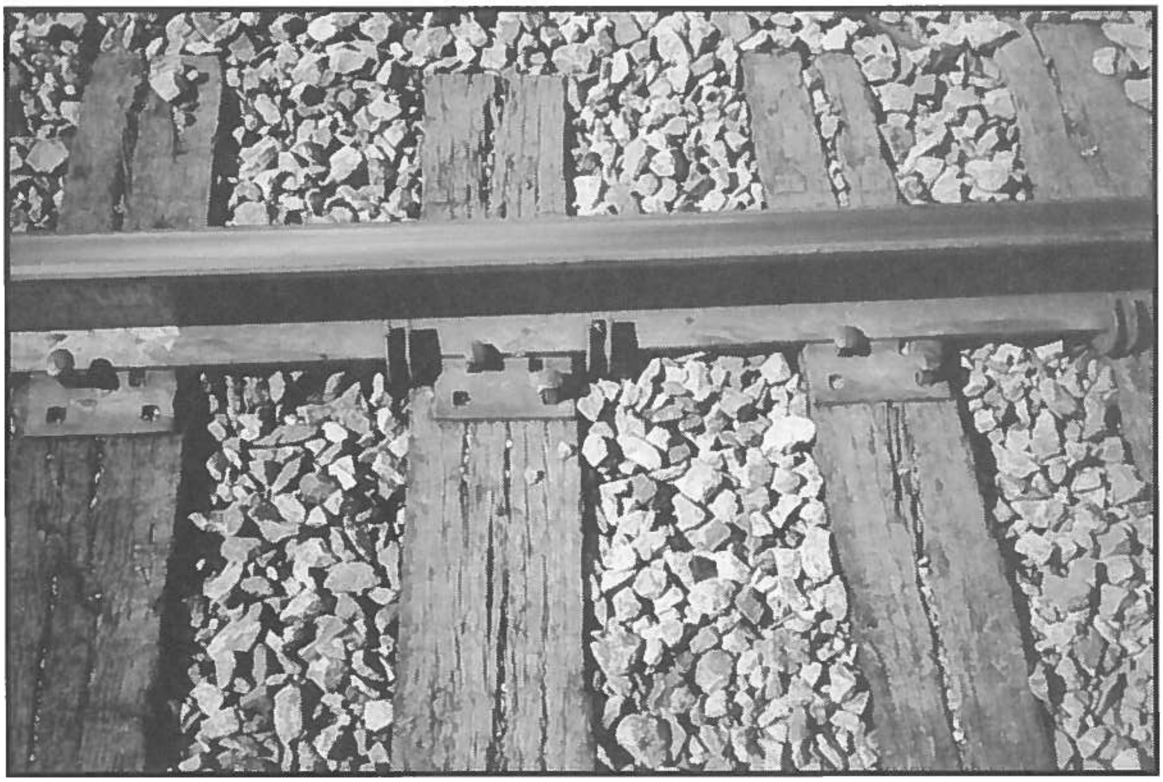


Photo 7: Split tie

DECAYED TIE PROGRESSED UNDER THE TIE PLATE

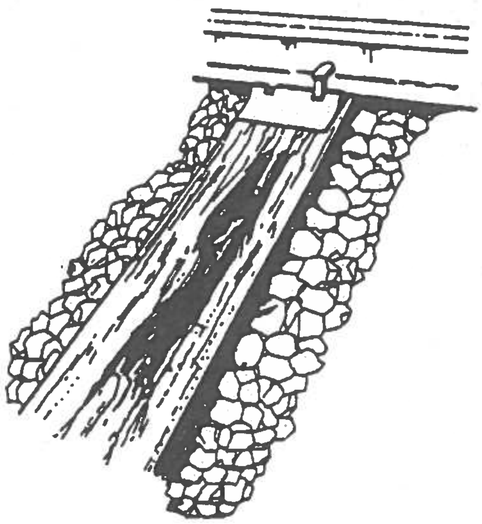


Figure 6-4

- Crushed rail seat: Crushing of the rail seat can be caused by any combination of decay, break down of the wood fibers by iron oxide, and rail seat loading. When this condition progresses to the point where the tie can no longer support the load or hold a spike, it must be removed.

- Warped: Improper drying of the green tie prior to treatment, especially hardwood ties, may result in the tie twisting like a corkscrew from end to end. This can happen in the track or on route from the treatment plant. If it occurs enroute, the tie must be adzed on the rail seats before installation which will expose the wood fiber. If it occurs in track, the tie could crack or split, or cause surface or line defects in the track.

3. <u>Damage:</u> Failed ties in this category include: Broken tie, burned tie, damaged tie.

- Broken: Center binding or end bearing ties can crack or break under load causing the tie to lose it's ability to hold line, surface or gauge.

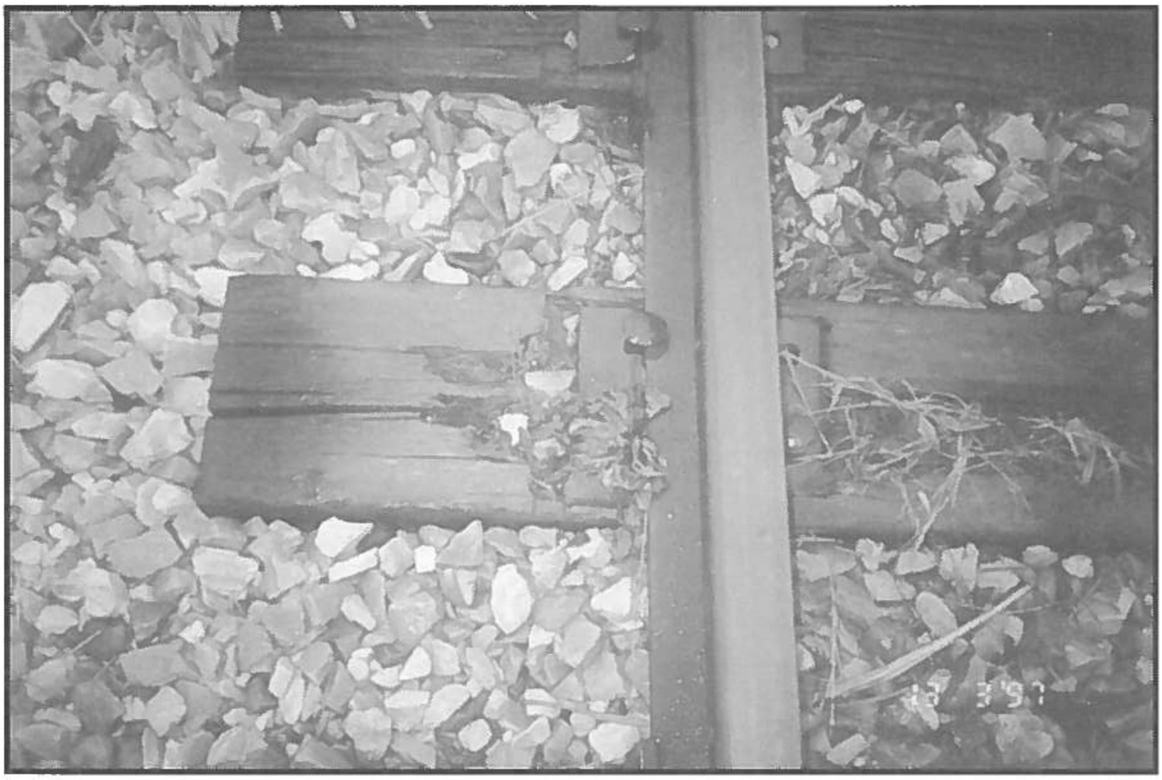


Photo 8: Decay tie

Photo 9: Broken tie

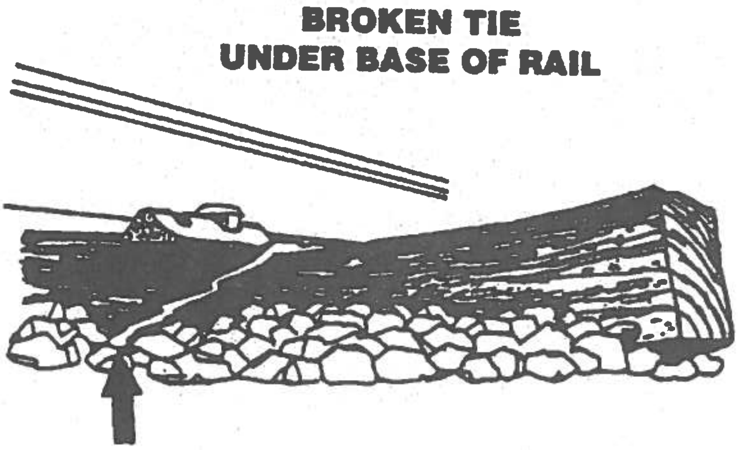


Figure 6-6

- Burned: Ties can be ignited by a spark from a brake shoe, a lit fusee, a grass fire, or in many cases, hot metal from rail grinding operations. If the burn is deep enough it can impact the integrity of the tie and replacement is required.

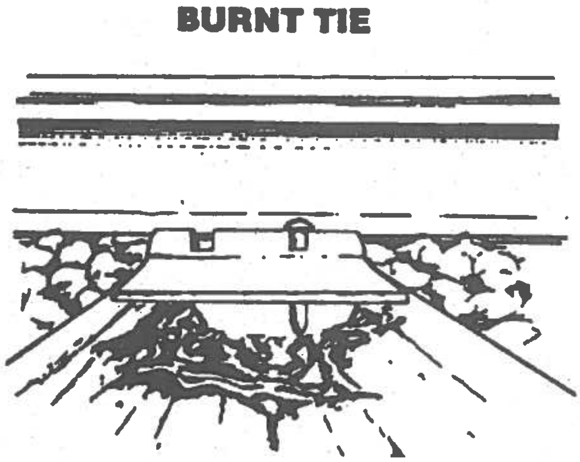


Figure 6-7

started by fusses, grass fire, or brake shoes

- Damaged: A tie that is damaged by a derailed wheel, dragging equipment, fire, or some other deleterious means to a depth of 2 inches or more, should be replaced.

4. FRA Requirements:

CLASS	MINIMUM EFFECTIVELY DISTRIBUTED NON-DEFECTIVE CROSSTIES PER ANY 39' OF TRACK
1	5
2&3	8
4&5	12
6	14

6.2 Concrete Tie Failure Mechanism

The failure of concrete ties may be categorized into two different mechanisms: 1. Mechanical wear, and 2. Damage (Figure 6-8).

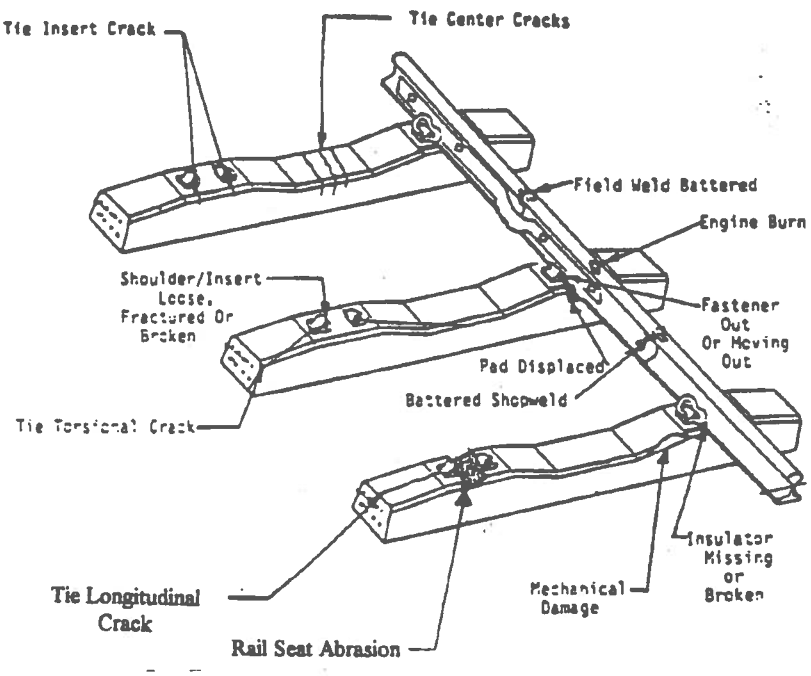


Figure 6-8: Concrete Tie Failure Mechanisms

1. Mechanical Wear: Failed ties in this category include not only the tie itself, but also the fastening systems, since failure of the fastening systems result in loss of electrical integrity, loss of gauge, and loss of longitudinal strength: Worn/broken or missing insulators, worn or loose shoulder castings, worn or missing pads, bottom abrasion, and rail seat abrasion.

- Worn/broken or missing insulators: Movement of the rail in the rail seat both laterally as well as longitudinally can cause the insulators (especially on the field side) to be abraded or crushed over time. The portion of the insulator between the shoulder casting and the rail base (referred to as the post) can be worn away allowing the rail base to contact the shoulder casting. This results in loss of electrical insulation as well as wide gauge. The insulators must be replaced when this condition occurs.

- Worn or loose shoulder castings: If the insulator is not replaced once the post has been worn away, the rail base continues to cut into the shoulder casting resulting in loss of shoulder strength, and wider gauge, and could result in shoulder failure.

- Worn or missing pads: Vertical loads, as well as longitudinal rail movement can abrade or crush the tie pad or even move the pad off the rail seat. If this happens and the rail is allowed to contact the concrete rail seat, rail seat abrasion or aggregate fracture can occur resulting in rail seat failure. This can be aggravated by the presence of high impact loads from improperly maintained wheels, a rail joint, or badly surfaced welds.

- Bottom abrasion: Concrete ties will, over time, become abraded by rubbing action against the underlying ballast. This will result in a loss of depth and bearing area under the tie that could cause the tie to fail under load. The loss of concrete on the bottom of a tie will not adversely effect the integrity of the tie until enough material has been removed that the prestressing wires are exposed. Once this happens, the tie should be removed.

- Rail seat abrasion: The actual cause of rail seat abrasion is not fully understood, but one theory is that silts or fines, mixed with water, find their way under the tie pad. With each passing wheel, the mixture creates a suction between the tie pad and the concrete rail seat which draws the cement out of the concrete, exposing the aggregate. The exposed aggregate penetrates the tie pad and is subject to abrasion and fracture upon making contact with the rail base. This process results in a lowering of the rail seat which in turn causes a reduction in toe load from the rail clips. Lateral loading on the rail accelerates the abrasion on the field side of the rail seat resulting in wide gauge due to rail roll. If this occurs, the rail seat must be repaired or the tie replaced.

2. Damaged Ties: Failed ties in this category include: Broken shoulder castings, frozen and broken-in-place hold-down clips, broken ties.

- Broken shoulder castings: Dragging equipment, a derailed wheel or mishandling of the tie can result in the shoulder casting being struck. The casting can be broken off from the insert or the stem may become loosened inside the tie. In either case, the tie has failed and must be replaced.

- Frozen and broken-in-place hold-down clips: Dragging equipment, a derailed wheel or over driving can result in a broken clip. If the portion of the clip inside the shoulder casting cannot be removed, the tie must be replaced. In some cases, if ballast is allowed to remain covering the clip and shoulder, the clip can rust inside the shoulder. Removal of the clip may become impossible without breakage of the clip and/or the shoulder. Should this occur, the tie must be replaced.

- Broken ties: Dragging equipment, a derailed wheel, or a falling rock can smash a concrete tie. In addition, severe skewing of a tie can result in the tie splitting end to end through the shoulder inserts. Concrete ties that become center bound, putting the tie into reverse flexure will also break in the middle. Ties in this condition must be replaced (Figure 6-9).

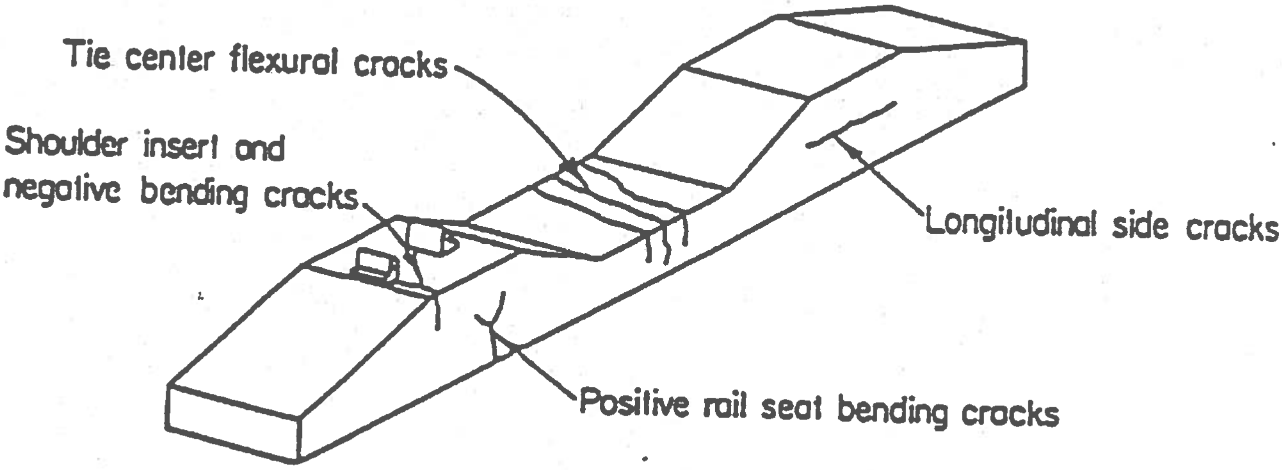


Figure 6-9: Typical Flexural Cracks Found in Concrete Ties

6.3 Steel Tie Failure Mechanism

The failure of steel ties may be categorized into three different mechanisms: 1. Mechanical wear, 2. Fatigue failure, and 3. Damage.

1. Mechanical Wear: Failed ties in this category include: rail cut shoulders.

   - Rail cut shoulders: Longitudinal movement of the rail can cause the rail base to cut into the shoulder of the tie resulting in loss of hold down ability and wide gauge.

2. Fatigue Failure: Failed ties in this category include: cracked shoulders, failed welds, cracked ties, broken clips.

- Cracked shoulders: Continuous flexing of the clip and shoulder under traffic can result in a fatigue failure of the shoulder, the shoulder insert or the shoulder weld.

- Failed weld: If the shoulders have been welded onto the tie, the weld can fatigue fail and allow a stress crack to develop on both sides of the weld point.

- Cracked ties: Ties can crack under the rail seats or alone the base of the tie towards the middle due to flexure. This can occur if the tie has not been properly tamped and maintained.

- Broken Clips: Broken clips do not necessitate the need to change out the tie; however, they are an indication of a problem which may require attention. Breakage that occurs for no apparent reason, can many times be traced to improper tamping of the tie. Unlike other ties, the steel tie requires special tamping procedures. Automated tamping tools must be adjusted to force the ballast up into the center channel of the tie from one end to the other. That is, the tamping tools must push crib ballast in and up into the tie, and the center of the tie must be tamped with the same procedure. If this is not done properly, the tie will not hold line or surface and the extra loading on the clips as the tie sags, may cause breakage. This condition is especially prevalent in turnout ties.

3. Damaged Ties: Failed ties in this category include: broken or missing shoulders, bent ties.

   - Broken or missing shoulders: Dragging equipment, one wheel derailment or mishandling of the tie can result in broken shoulders.

   - Bent ties: Again, dragging equipment or derailment can strike and bend a steel tie. Due to the nature of construction and installation, this occurrence is rare and seldom results in a loss of integrity.

Photo 12: Concrete tie - Pandrol e-clip

Photo 13: New cedrite tie

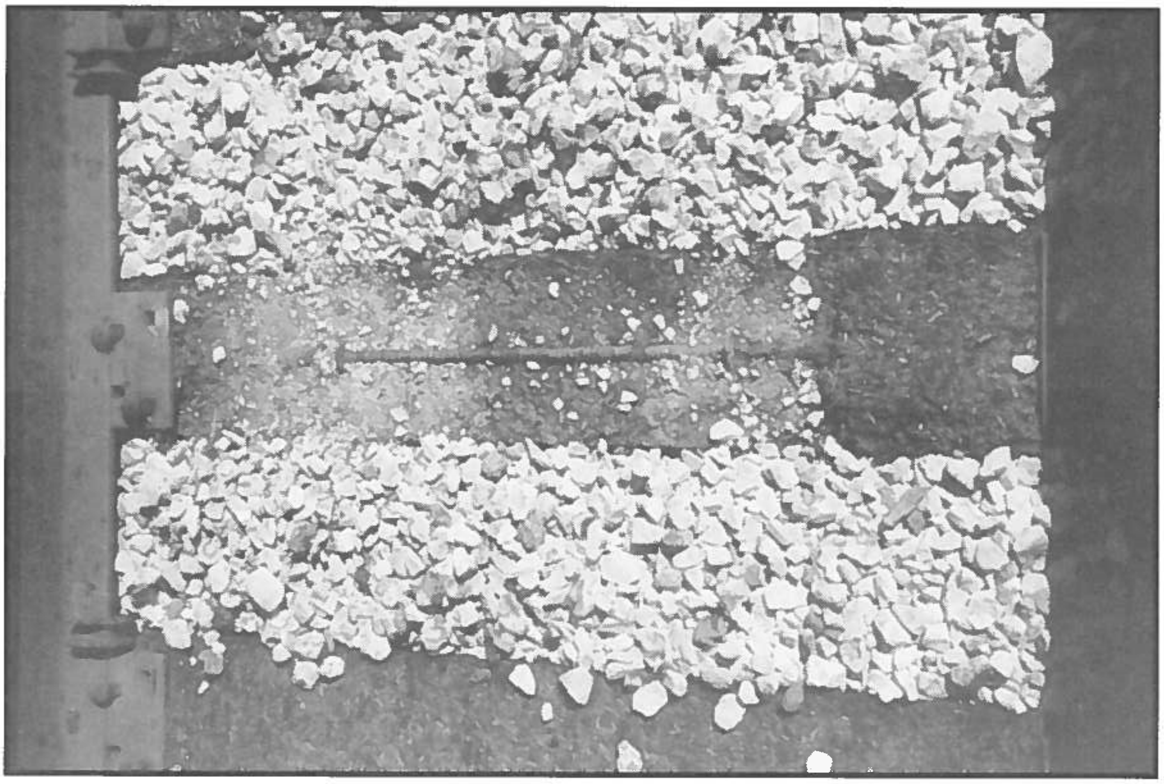


Photo 14: Failed cedrite tie

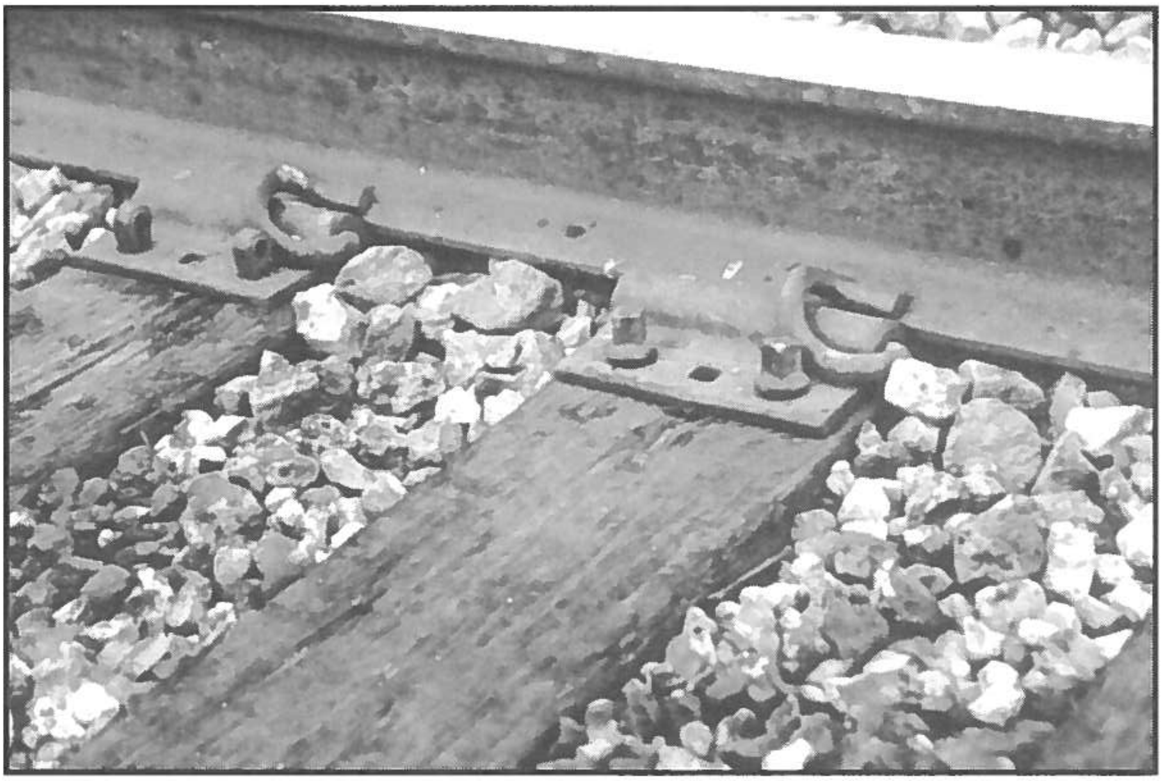


Photo 15: Parallam Ties with Pandrol plates & Clips (left with lock spike, right with screw spike)

Photo 16: Ladder sleeper arrangement proposed for high speed rail - Japanese design

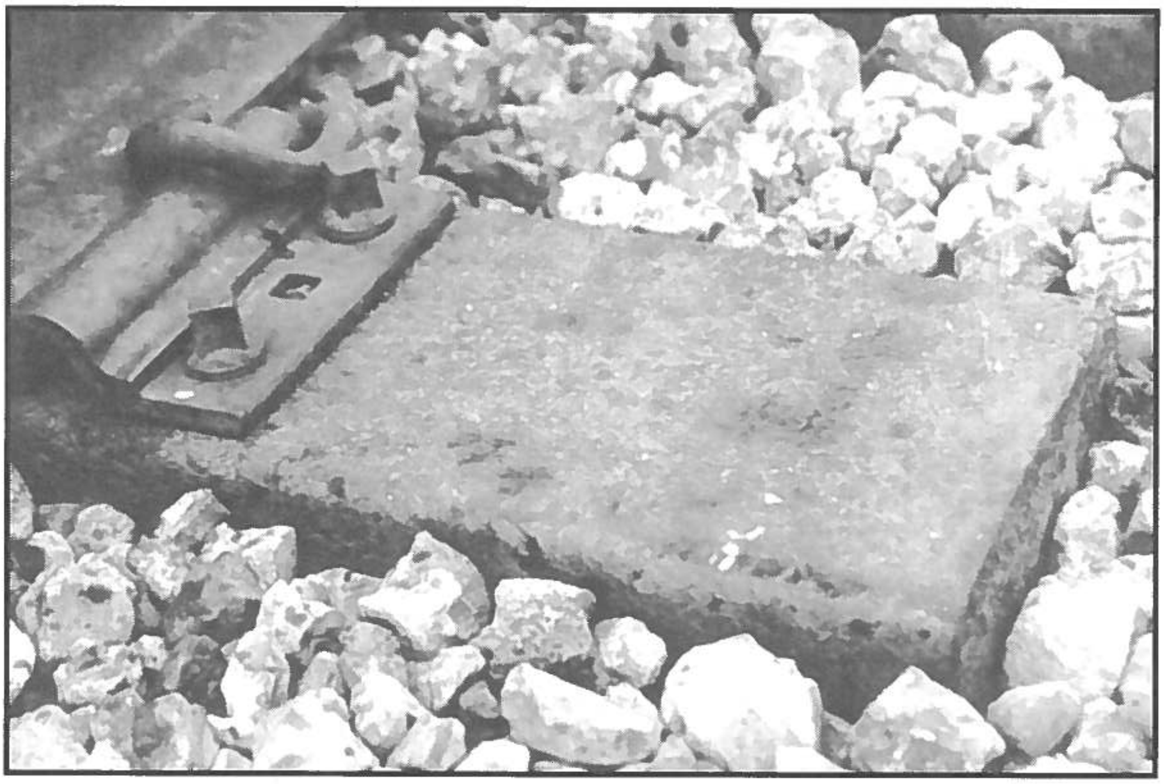


Photo 17: One of many plastics based ties under development

Photo 18: One of several steel tie designs

WOOD CROSSTIES

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STUDENT HANDBOOK

SECTION SEVEN

CROSSTIE MAINTENANCE

7. Railroad Handling of the Crosstie

The railroad generally does not get involved with the wood tie until after it has been cut, sawn and treated. However, once the ties are prepared for shipment, handling of the ties by the railroad should be done with care to preserve the ties integrity.

The American Railway and Maintenance-of-Way Association (AREMA) has recommended specifications for proper Crosstie Maintenance.

7.1 AREMA - SECTION 5.10
Care After Preservative Treatment (1975)

Ties treated in excess of those needed at the time on line should be stored at the treating plant until required in order to provide better care and a more flexible supply than is practicable when surplus ties are stored along the right-of-way.

It is recommended that treated ties be stored as steel-strapped or wired tram bundles. Stacks of bundles should be started on treated sills and should be separated with treated strips for efficient life truck or crane rehandling.

It is important that treated ties be handled carefully and in such a manner that the protective sheath of preservative-treated fibers will not be broken, thereby exposing untreated heartwood to infection and insect attack. An incision made by a pick or fibers broken by the mis-blow of a maul may provide an opening through which decay may enter.

7.2 AREMA - SECTION 5.11 Distribution (1985)

Conditions effecting the distribution of ties in various localities differ so greatly that it is impractical to single out any procedure as universally superior. Careful study by all departments concerned is required to determine the best method of moving ties from each point of storage.

As a rule, it is more economical to load ties to cars directly from treatment, thereby saving one handling. Although direct loading is highly desirable, seasoning schedules may often require the storage of treated ties and rehandling will be necessary.

Tram bundles of treated ties are usually crane loaded, crosswise, into a gondola car. Each tie is then hand discharged, end first, over the wall of the gondola, to a point along the right-of-way opposite the tie to be replaced.

Several roads have successfully employed gate and/or shelved, bulkhead flat cars for treated tie distribution. These cars hold a greater number of ties than the average gondola. By opening gates at various levels, ties need not be elevated before being unloaded by hand.

Ties will be shipped from treating plants for usage under three general conditions:

A large number of ties for renewal in connection with mechanized maintenance work over a several consecutive mile work location. These ties are best handled in special tie cars designed for this purpose, facilitating rapid unloading with minimum maintenance labor and greater safety. Ties should be unloaded at the point of usage to avoid labor expense in stacking or rehandling. Time between unloading and insertion should be the minimum practical to avoid damage to ties due to exposure to elements.

A small number of ties to separate locations for use as on-line emergency stock or spot renewals. Handling can be in special tie cars or in such other cars as the railroad has available.

A large number of ties shipped for use in construction work. The loading and handling method should mesh with the construction situation. Banded bundles can be used if ties are to be transferred from railway cars to trucks. Special tie cars are practical for adjoining track construction.

Ties should be carefully handled in a manner which will prevent breaking or bruising. Ties should not be discharged from cars onto rails or rocks. If a tie pick is used, it should be inserted in the end only.

Treated ties not needed for immediate use should be solidly stacked and may be covered with cinders or earth for protection against weather.

7.3 AREMA - SECTION 5.12
Care During And After Installation (1985)

Ties should be carefully handled from the right-of-way to the point of insertion, guarding the vulnerable treated exterior.

Ties should be protected from excessive abrasion under the rail by the application of tie plates of sufficient area and thickness to distribute the traffic loads adequately. The least damage to ties as well as the smoothest track result from the use of plates having bottoms which do not necessitate the impact of traffic to seat the plate.

In order to economically enjoy the longest and most satisfactory service life from treated wooden ties, highest standards of surface and sub-surface maintenance must be practiced.

Ties should be adzed only in cases of necessity, as when rail is relayed, plate size changed or when the damage from a derailment involves the removal of splinters and crushed wood fibers. Whenever deep adzing of the treated surface takes place, steps should be taken to protect the adzed surfaces with a penetrating preservative paste or a preservative treated pad. Some states may require the applicator supervisor to have a permit for handling of pesticides.

Treated tie plugs should be driven into used spike holes; but not into prebored holes into which spikes anchoring of the rail.

Damage to ties from slewing as a result of rail creeping or running should be prevented by adequate anchoring of the rail.

Ties of the species and size best suited for each location should be selected. Ties made from the denser hardwoods should be used in sharp curves, steep grades, at ends of open-deck bridges and where tonnage is excessively heavy.

Treated ties should be placed in track with the wide surface nearest the pith, down.

Ties should be laid square across the track; i.e., at right angles to the rail.

Care should be taken to set the drive spikes at right angles to the tie surface, straight down.

7.3 AREMA - SECTION 5.13 Renewals (1975)

Although differences in operational organizations and physical conditions on the various railroads make it impractical to formulate a procedure that is applicable everywhere, no phase of track maintenance is more important than the selection of the ties to be renewed in a given year. Improper tie renewals over a period of years are sure to be costly, and may prove to be disastrous, whether the replacements are too few or too many.

The total number of ties required to maintain satisfactory track in one year is rarely the same as the number renewed during the previous year or the average renewals over any period. Therefore, careful inspection of the ties in track will provide more dependable information than any assumptions based on statistics.

Whatever method is used in the inspection and selection of the ties to be renewed, the procedure should be so planned as to provide a record of the system requirements as distinguished from those of a section or division. Training and experience for those making inspections of ties in track are necessary to assure uniformity in their procedure and consistency in their conclusions.

Each tie to be removed is generally identified by a mark on the tie or on the rail above it. Absolute adherence to this marking is required in some instances. More often the foreman is allowed to leave some marked ties and to remove some unmarked ties. Ordinarily, only ties which are useless where they are should be removed; but when track is given a general out-of-face overhauling, all ties, which appear to be nearing the end of their service life, may be removed.

Records of inspections of ties in track, detailed as to location by telegraph poles or other short stretches having easily recognized landmarks, aid in the unloading of ties where needed and thus avoid expensive extra handling.

7.3 AREMA - SECTION 5.14 Salvage (1985)

Ties still serviceable enough for economical reuse become available when lines are abandoned and tracks are taken up; when the renewal of all ties in tunnels, in road crossings, or at station platforms releases them; and when ties under heavy traffic have to be removed because their service in such track is no longer satisfactory.

While the reclamation or salvage of ties is sound in principle and highly desirable, it can easily be overdone. To guard against any tendency toward false economy resulting from loyalty to reclamation as such, all costs must be considered. Complete records of all expenses connected with picking up, stacking, preparing, and shipping ties for reuse should be kept for comparison with the prices of other materials for a given purpose, together with the respective costs of installation. Expenditures for handling and hauling may confine their reuse to locations close to where they are removed from track.

The most economical use of ties is to leave them in their original locations until they are so decayed or mechanically worn that they cannot serve their purposes any longer. However, in connection with general track reconditioning, it is usually economical to replace ties near the end of their serviceability, in order that the track need not be disturbed again for several years. This procedure is desirable in heavy-traffic, high-speed lines where spot tie renewals are expensive and the disturbance of refined track surface is especially inadvisable.

Ties removed from track should be carefully inspected and sorted into those fit for reuse in tracks, those suitable for other uses and "culls".

Generally, secondhand usable ties have had their original quality lowered, and in consequence their reuse should be confined to tracks of lesser importance, such as those in light-traffic branch lines, sidings and yards. These ties should be reinserted in track quickly to avoid accelerated deterioration.

Ties reusable in track should be re-inserted with the same surface up as in original location. Only when light adzing of that surface will not provide satisfactory seats for the tie plates should ties to be turned over.

All spike holes in reused ties should be filled with tight-fitting treated plugs.

Treated tie plugs can be inserted and a preservative paste or a preservative treated pad applied to the plate bearing areas advantageously as the removal of the rail progresses during the recovery of serviceable ties.

The following are visual characteristics a tie should possess to be considered salvageable:

(1) Rail seats sound, no evidence of decay.
(2) Limited mechanical wear under the tie plates.
(3) Spike holes sound.
(4) No splits from end of tie to a point beyond the outside edge of tie plate.
(5) No center-bound break.
(6) No evidence of internal decay.
(7) Tie should have evidence of treatment.
(8) Tie could have surface checks but no checks half way or more through the tie.

Salvaged ties must be reinstalled or re-treated as soon as possible after being removed from ballast. If a used tie is allowed to dry out it tends to be subject to excessive checking and/or splitting.

Ties unfit for reuse in standard gage track have possible uses as follows:

(1) Fence posts. Some ties removed from track will make satisfactory fence posts.

(2) Narrow gage ties. Cutting off the useless ends of ties will shorten them for reuse in tracks of material, repair, or seasoning yards.

(3) Current retards. Set on end and properly spaced, ties useless in track will divert water and thus control erosion for a period justifying their use for that purpose.

(4) Crib walls. Rectangular ties are more suitable than slab ties for such construction.

(5) Mud sills. Unusable ties serve satisfactorily to support stacks of ties or other material off the ground.

(6) Paving. Where more elaborate paving is not justified on motor car set-offs or in stockyards, unusable ties may provide a durable, serviceable pavement.

(7) Scrap bins. At section house and elsewhere, ties no longer useful in track can be cribbed to provide receptacles for material to be reclaimed or discarded.

(8) Sale. Local demands for old ties to be used for landscaping, charcoal, fuel, wood chips, blocking and other uses may provide markets, which will absorb ties no longer desired by the railroad company.

Where no other method of disposal can be found, the ties may be disposed of in a smokeless, EPA approved burner. Ties may not be burned in the open air nor buried due to strict EPA rulings. Care must be taken when stock piling new or used ties not to allow creosote to enter potable water supplies, streams or rivers where they may present an environmental problem.

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION EIGHT

ALTERNATE TIE SYSTEMS

8. Alternate Tie Systems

Approximately 93% of all the crossties in the tracks of North American railroads are made of wood. About 90% of all new ties installed by the major railroads are wood. Wood, as it has been for the past 150 years, remains the primary choice for crossties for the American railroads.

Since 1831, when the Camden and Amboy Railroad first started using wooden crossties as an effective substitute for stone blocks, railroads have been employing wood as the material of choice for crossties. It continues to be an essential material for many railways for transverse ties and longitudinal ties, and in its use for switches and crossings it remains paramount.

In the past few years, however, railroads have been researching, testing and employing various alternate crosstie materials. Concrete ties are being use extensively on heavy haul segments of the major freight railroads, on urban transit systems, and in third word countries where wood is a premium. Steel ties, widely used in Australia and other parts of the world, are being applied in small but growing numbers, mainly at special locations such as tunnels, ballast deck bridges and yards. Research and testing continues on ties made of reconstituted wood and recycled plastics. Direct fixation track is often used on transit lines and at special locations such as passenger stations.

With the railway mergers and line reductions taking place over the last 20 years, the number of crossties installed annually has been decreasing from over 27 million in 1977 to about half that figure in recent years. The total reason for the decrease in crosstie installation however, is not based solely on reductions in track mileage; it also includes a great improvement in tie life. Since the major US railroads spend $500 million to $1 billion dollars annually on crossties, even small improvements in tie performance can result in very impressive cost benefits. It is for this reason that a great deal of interest, research and development money is being expended on improving the performance of the crosstie.

8.1 Wood Tie Research

The basic wood crosstie in service today is solid-sawn, creosote-treated, 7"X 9" X 9' long (mainline) or 6" X 8" X 8' 6" long (number 2). With a 35-year life estimation, the wood tie doesn't appear to need improving, however; the Research and Development Committee of the RTA has several projects currently underway to try and improve the technology of the wood tie.

A number of research and testing programs are at work, trying to lengthen tie life and improve performance, thus enhancing the economics of the treated wood tie. Various organizations-the RTA, the AAR, universities, government agencies, tie producers and the railroads sponsor these R&D programs. Research in this field has had a significant effect on the life of the tie. Even though traffic loads have increased, tie change-outs have dropped from 150 ties per mile in 1977 to less than 120 ties per mile in recent years.

In particular, The Association of American Railroads conducts a wide range of research and development programs on crossties. Tests such as the accelerated aging/performance tests aimed at defining current tie performance and developing rapid techniques for evaluating new tie products have assisted in reducing improved crosstie research. Alternative and supplemental treatments to stem off existing and reduce the onset of new biological decay are proving to be highly effective in reducing premature tie failure as well as addressing concerns about environment regulations.

Testing and evaluation of under-utilized wood species, dowel-laminated and glue-laminated wood, as well as parallel-oriented wood fiber or parallel-strand lumber are all under test.

Parallam, a product of TrusJoist MacMillan is one example of parallel-strand laminated material. The process allows use of wood species never before thought sufficiently dense or heavy to meet the performance demands of crossties. Parallam also has a shorter treating cycle and requires less creosote to treat than solid-sawn ties. Both dowel and glue-laminated ties have been around for decades. The laminated tie offers the benefit of being able to be constructed to any dimension without the need to have large diameter trees available. This can results in the laminated tie, having a wider bearing area, having a service performance comparable to the 7X9 solid crosstie. Using a larger tie plate to take advantage of the larger bearing area of the tie, the service performance can be further enhanced.

The committee also has southern pine glue-laminated crossties being tested at the Transportation Technology Center at Pueblo Colorado. These ties have more than 150 MGT of service with no failures.

Fiberglass is another innovation for wood crossties. Discarded or relay ties can be reused to handle relatively heavy traffic. The ties are cleaned throughout the tie plate area, and then wrapped with a fiberglass resin combination. This reinforces against wear and damage like tie-plate cutting, checking, and spike kill, and should add another 10-15 years to the tie's service life.

8.2 Concrete Ties

Concrete ties follow wood crossties with a 5-6 % market share. Concrete ties are now in use on every transit system in the West. In the East, Amtrak uses concrete for crossties, turnout ties, bridges, station platforms, catenary foundations, and retaining walls on the Northeast Corridor.

The main trend continues to be to use concrete ties in new, heavy haul track construction, as well as in new Transit construction. Class 1 Roads such as Union Pacific, BNSF and Canadian National install hundreds of thousands of them annually in their heaviest use trackage with great success.

Concrete ties appear to have their greatest economic advantage for the freight railroads in heavy-traffic, heavy-haul routes such as the UP and BN coal lines.

Still, several of the large North American freight rail systems continue to not use concrete ties extensively. Norfolk Southern, Conrail and CP Rail System all have relatively small concrete tie installations and no present plans to use concrete on a large scale.

One of the reasons given for not using concrete is the problem of rail seat abrasion. Although the cause in all cases is not totally understood, it has been found on all the North American heavy freight haulers (and reportedly on at least one Australian heavy-haul line); but has not seemed to have affected Amtrak, urban transit or lighter-load railways in other parts of the world (although the Indian Railroad is believed to have been affected). (It should be noted, however; even though Amtrak and other urban transit railroads have not experienced rail seat abrasion, they have had their share of other concrete tie problems included alkali aggregate disintegration.)

Once rail seat abrasion was determined, methods of repairing already damaged ties were developed, as were methods of keeping abrasive material away from the rail seat area. Several of them work well, but at present the sandwich-type pad, which actually consists of two pads with a steel plate between them, appears to be the most effective device for preventing abrasion. The lower pad, of soft polyethylene foam, seals off the rail seat area to keep out abrasive material, while isolating any movement of the upper, hard polyethylene pad and the steel plate from the tie itself.

The sandwich pads, originally developed by Hartley Young of Safelok, have been in service for more than six years on the Burlington Northern and so far seem to be doing their job of preventing abrasion of the ties, while holding up well. But they are a costly and complex approach. Research by railroads and suppliers continues in an effort to find equally effective but more economical solutions. "We continue to do research on the concrete tie material itself but so far, there has been no real break through. We can get perhaps 8 to 10% improvement in rail seat abrasion reduction only," say Derek Firth.

According to BNSF, the Safelok solution is the way to go. Their analysis appears to be correct as the standard now for BNSF is the "Sandwich" pad after 6 years in track. This is now the standard as well on the UP where with the BNSF, over 3/4 million ties complete with the new pads, will be installed this year.

Meanwhile, Pandrol is introducing a new fastening system called "Fastclip" which is meant to replace the e-clip. According to Pandrol Inc., "The Fastclip is on test at present on the BN, CSX and Metro North and seems to be working well". The new clip has a low profile, attaches perpendicular to the rail and develops 2750 lb. of toe load. The system uses a dual insulator concept and is expected to have a very long insulator life.

8.3 Steel Ties

Steel ties have been around since the early 1900 but have never been able to make a large impact on the railway industry. The three main problems associated with the steel tie:

- shoulder and weld cracking and failure
- lateral stability
- clip failure due to vertical flexure

have been addressed with possible solutions proposed by steel tie producers of North America. The cracking problem has been addressed by the use of hook in shoulders and paying close attention to the quality of manufacture of the product is believed that the lateral stability problems have to a large extent been solved by the use of proper installation techniques. Installation techniques are also at the core of the vertical flexure and hence the clip failure problem. According to one major US railroad, "we are waiting to see the results of the AAR tests being carried out at the TTC in Pueblo before committing ourselves on the acceptability of the steel tie products."

At the present, CP Rail is devoting considerable attention to steel ties in turnouts. Like other railroads, it is using them at special locations to solve specific problems. Both the Connaught and Spiral tunnels have been changed over to steel tie after a test installation in an

11-degree curve on a 2% ruling grade in one of its spiral tunnels. The track carries 45 MGT steel ties were installed primarily to increase clearance and thereby allow the track to be raised for surfacing in the future. CP is also trying steel ties and turnouts in yard leads as a solution to the characteristic gauge widening experienced at those locations. Another application for steel ties is around fueling facilities, where there is contamination from petroleum distillates.

A number of other freight railroads are using steel ties. BC Rail, BN, and IC are users. (BN installed about 8000 steel ties in 1996, mostly in yards, branch lines and at locations like fueling stations.) BC Rail's pioneering mainline steel tie installations continue to perform well, using larger, improved ties that replaced the initially installed steel ties that proved inadequate.

Although the steel turnout tie is not as yet produced for insulated track, several railways have installed them in yards and dark territories. BC Rail has 100 turnouts, BNSF have 130, the New Orleans Public Belt Railroad has ordered 38 sets, with IC at 10 and CP, CN, NS and CSX having a few. NARSCO forecasts a conservative sales estimate for steel turnout tie sets over the next few years to grow from the present 100/year, and steel crosstie sales to increase from the present 80,000/ year.

NARSTCO (Figure 8-1), which is the new company that sprung like a phoenix from the ashes of the BHP steel tie plant in Squamish BC is not the only new comer to the steel tie industry. Applied Rail Research Technologies Inc. has developed a T-section steel tie (Figure 8-2), which is described by President Jude Igwemezie as stronger than any existing steel tie, with pads that are wedge-shaped, thus incorporating the cant into the pad. In addition, with improved clip designs, better load distribution and unique side baffles for lateral stability, "on a per tie basis, UniP also delivers considerable savings," says Dr. Igwemezie.

Alan Briggs, President of Tie & Track Systems, Inc., describes TTS's entry into the steel cross tie race as a tie with a similar cross-section to BHP'S, but with differences including stress-point benefits.

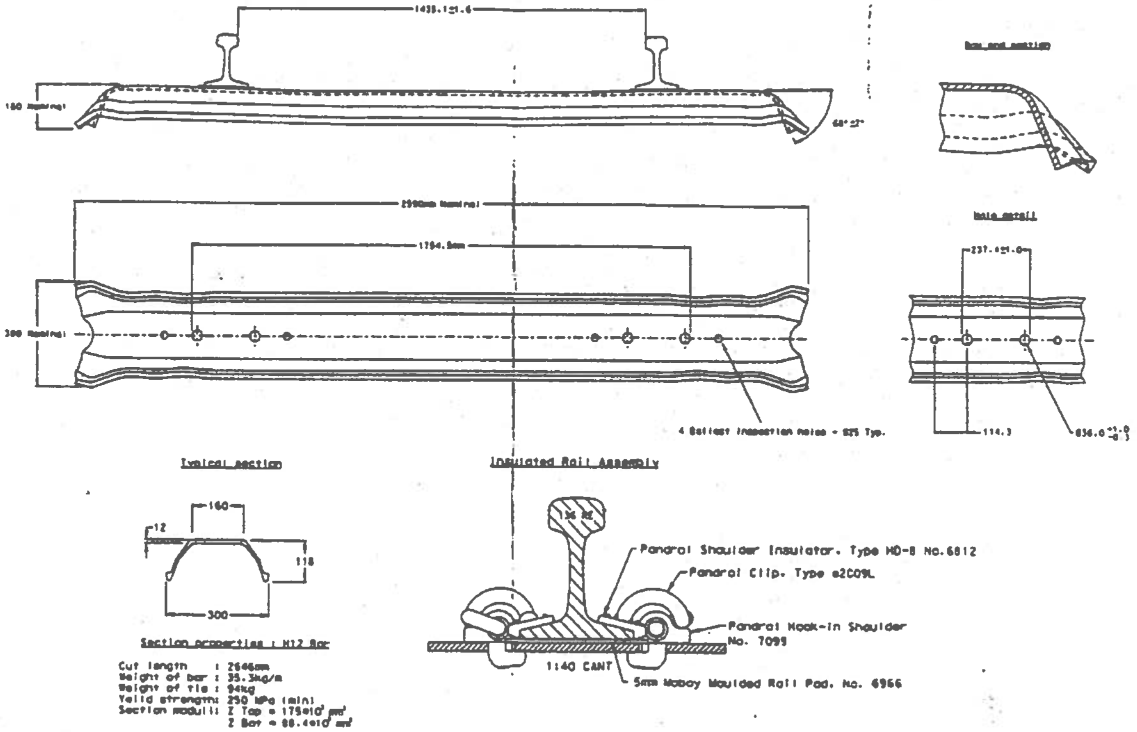

Figure 8-1: BHP Standard Steel Tie

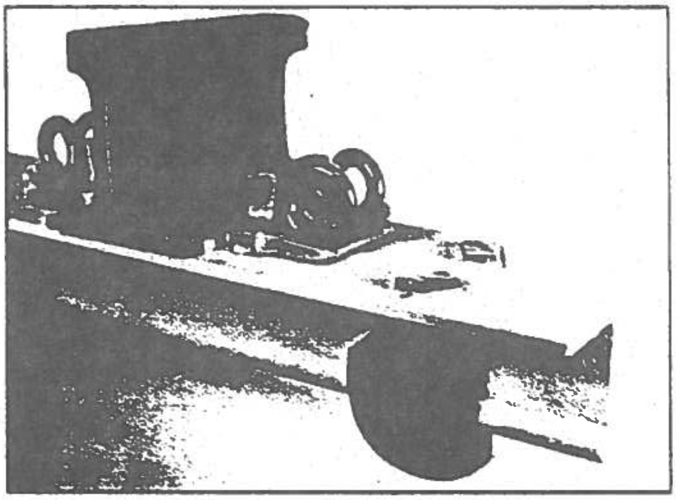

Figure 8-2: UniP Tie with Baffle

8.4 Plastic Ties

In the search to develop alternate tie material, several companies have been experimenting with the use of recycled plastics. Norfolk Southern, in conjunction with Conrail, The Army Corps of Engineers, and Rutgers University Center for Plastic Recycling and Research, have enlisted Earth Care Products to manufacture several prototype plastic ties for testing in track and laboratory.

The first plastic tie prototype produced by Eaglebrook Products Inc. of Chicago is being tested by three switching/terminal railroads in Chicago owned by OmniTRAX, Inc. With the help of a grant from the State of Illinois, OmniTRAX acquired about 900 eight-foot, six-inch, six-by-eight inch ties made of high-density polyethylene. The ties have been installed on the Chicago Rail Link, Chicago, West Pullman & Southern and Manufacturers Junction railroads. Although the ties have been installed in yard or industrial track sites, they have been subjected to 100-ton carloads. The ties use a standard cut spike fastener and so far exhibit good holding capability with the only a couple of problems being reported so far. Bill Turk of MJ advises; "On one of our tracks leading into a warehouse facility, 500 consecutive ties were installed in Nov. 1994. With speeds of 5-6 mph, cuts of 9 loaded 100 ton cars are brought in on an average of 5 times a week. We have seen on curves, 78 ties crack through the spike hole area and 15 - 20 ties have a tendency to bend, center down, under load1. Other than those failings, the ties are holding up well and we certainly appreciate the 60 - 70 pound weight of the tie when it comes to installation."

Another plastic tie produced by U.S. Plastic Lumber is the same plastic tie as the Eagle Brook tie but modified with a ribbed side to improve the lateral holding capabilities. It was recently installed in the FAST track and seems to be holding line better but no information on other problem areas.

The Black River & Western Railroad, a tourist railroad in New Jersey, installed what is believed to be the world's first polystyrene/polyethylene polymer/polymer composite on its main line in June of 1999. The ties are the result of a cooperative project involving Rutgers University, Innovative Railroad Services, and Polywood, Inc. a plastic lumber manufacturer. Polywood says its ties are the first to be manufactured with 100% recycled plastic materials, including milk jugs, detergent bottles, plastic utensils, and Styrofoam coffee cups. It also says that the plastic ties are expected to last 50-100 years and may be especially suited for areas where there is poor drainage and in locations where ongoing maintenance is impossible, like under road crossings.

The Polysum Tie is a tie proposed to be manufactured from plastic and gypsum. This tie has been proposed by the University of Louisiana and funded by Kerr McGee. At present there are few of these ties produced and they are looking for funding to continue the research.

Primix Corp. offers a composite tie that includes a steel W-beam filled with concrete and wrapped in a one-inch, rubber-filled plastic composite outer shell. Based on spike-pull tests in an industrial park in Indiana, tie-plate cutting, weather ability, and lab tests, Primix believes these ties will give railroads 60-plus years of service. Once again, there are few produced and its sponsors require research funding. The Primix Company has stated that the tie will sell for $67 once it is in production, but there is no information as to when that will be.

Seaward International is at present producing marine piling made with plastic and fiber glass and has stated that they are interested in producing a plastic tie but that the tie will not go into production until at least the year 2005.

The latest entry into the plastic tie market is "TIETEK". This company has produced several thousand ties that have been tested by Pu Chow and are being field tested by Union Pacific under heavy haul conditions (in a recent publication of Railway Age, UP noted that they have installed 1500 TieTek ties in both storage yards as well as heavy haul mainline track). The TieTek tie has been tested in the Transportation Systems Center in Pueblo Colorado for in excess of 150

1 This was the first plastic tie manufactured and patented by Rutgers University in conjunction with the Earth Care Company. A few of these ties were installed in the FAST Track in Pueblo Colorado to test their capability and were found to have poor single tie push capability (lateral restraint). In addition, they could not be spiked and they were found to take on a permanent deformation under load.

MGT with no indication of problems. Although this tie also uses recycled plastic, in addition, it also uses other additives including fiberglass and rubber (from old tires). The consistent problem associated with plastic based ties is initial costs. Costs ranging from $55-$125 are reported. While some ties show some level of performance adaquecy this initial cost disadvantage will limit the railroad usage significantly. In April of 1999, the Houston Corporate Recycling Council presented UP and TieTek the Environmental Excellence Award for 1998. The demand for the TieTek tie has increased beyond the capability of the pilot plant to supply and has caused the TieTek Company to start construction of a high production manufacturing facility near Huston to be open in the summer of 2000.

8.5 Reconstituted Ties

The search continues for the perfect reconstituted tie. Michael McGuire, President and CEO of Reconstituted Technologies Inc. is presently looking into the development of a new entry into the alternate tie race. "This is not the Cedrite tie, but a new concept that will allow the salvage of old wood ties to be used in the construction of new ties with equal or superior qualities." At present the reconstituted tie is again on the drawing board and may be a competitor worth watching.

For the moment, however, the wood crosstie seems certain to remain the choice for 90 to 95% of North American freight railroad trackage in the foreseeable future. But concrete ties, currently the favorite for newly-built trackage, are slowly increasing their presence in the total picture, possibly to as much as 7% some years down the road, assuming projected life-cycle costs are viable. Other alternatives to the wood tie, especially steel or perhaps plastics, or the reconstituted tie, could also become more significant, especially if they can be perfected to the point where they can be competitive in terms of initial and life-cycle costs. At present, the main problem with all wood tie competitors is the initial purchase price. Most alternative tie products run anywhere from 2 to 3 times that of the wood tie. Many producers claim that their product will last 50 or more years. With a wood tie lasting 35-40 years in track, their claim must be indeed realized in order to be cost effective.

WOOD CROSSTIES

An Engineering Perspective

STUDENT HANDBOOK

SECTION NINE

ECONOMICS

9. Economics of Wood vs. Alternate Ties

When faced with the decision of whether to use wood ties or any of the alternates, the final analysis is generally one of economics. The economic evaluation of various tie systems is not as simple as one may think at first blush. Certainly the capital cost of the material involved must be factored into the decision and that must be balanced with the life of the system, however that is just the tip of the iceberg.

In order to assist the engineer in making the economic decision of what tie system to use, RTA has commissioned a computer model from ZETA-TECH Associates, Inc. called SelecTie™ that can be used to evaluate each project for the best tie system to be used.

This model is designed to compare and investigate the relative economics of the wood tie track system and the alternate tie track system, taking into account the different track and maintenance characteristics of the systems. The model assumes that the wood tie track is the existing system and examines the economics of replacing that track with the alternate tie track.

The economic analysis presents the track characteristics defined by the segment of track, followed by the operating and maintenance parameters.

The track characteristics studied in this model are:

- Type of Construction (New/Old)
- Wood Tie Fastener Type (Cut Spike/Elastic)
- Curvature of Track
- Grade
- Superelevation
- Rail Section
- Rail Type
- Tie Spacing
- Number of Ties per Mile
- Depth of Ballast Section Below The Bottom of The Tie
- The Use of Premium Rail
- Third Rail Support (Long Tie or Plate)

Operating Parameters Studied are:
- Operating Speed
- Balance Speed
- Annual Tonnage
- Car Weight/Wheel Load
- Braking Acceleration effect

Maintenance Parameters
- Level of Lubrication
- Presence and effectiveness of guard rail
- Profile grinding
- Undercutting for conversion to alternate
- Undercutting as maintenance operation
- Ballast Condition
- Environmental Conditions (Wet, Dry)

The above variables govern the component life cycles used in this model. These component lives are based on the studies carried out by ZETA-TECH and results from studies carried out by the industry. Direct input was also obtained from several transit properties and the results were then formulated in a closed form mathematical equation.

Note; if the calculated values of the component life cycles do not match what is currently experienced by the individual transit property, a user input "Override" section has been provided. Any non zero entry will be used by the model to carry out the analysis. Caution: the values input in the user input section do not change with the change in the track segment characteristics and as such the user has to exercise caution when making use of this option.

The component life cycles used in this model are:

1) Rail Replacement Cycle
2) Rail Transposition Cycle
3) Tie Life
4) Tie Gang Cycle
5) Rail Grinding Cycle

6) Gauging Cycle
7) Anchor Adjustment Cycle
8) Undercutting

Due to the differences in the activity cycles, all the comparisons were carried out on a "present worth" basis using an infinite series presentation. The cost of money is introduced as a variable in the economic characteristics of this model.

Next the Labor costs per day (fully allocated) are utilized in the calculation of the total labor cost for each individual activity. Note: in the transit environment the maintenance activities are labor intensive and the equipment used is minimal. The equipment costs per day are similarly presented. These costs are utilized in the calculation of the total cost of equipment per maintenance activity.

The tie dimensions are presented next. These dimensions are used for the sole purpose of defining the ballast section for the wood and alternate tie track system.

The Material costs are presented next. In this area, the component costs are presented for both the wood track system and the alternate track system, to include the price of ties, fastenings and the third rail support.

Since this model has the ability to examine both new and existing systems, a section depicting the salvage values of wood tie track system in the case of existing track system is provided. In an existing track system the model compares the economics of continuing the present wood tie maintenance practice against the conversion to an alternate track system, there exists an inherent salvage value for the wood tie track.. The salvage value for key track components such as ties, tie plates, spikes, and anchors are also presented. This salvage value is used in the calculation of the premium cost of alternate ties over wood ties. Note; in a new track construction all the numbers in this section are zeroed out and not used in the calculations.

The labor, equipment and material costs are presented at the beginning of the model to facilitate any change in the prices or costs. Changing any of these costs will result in changes being carried out throughout the model.

For each maintenance activity, the corresponding productivity rates (for both the alternate tie track and the wood tie track) are presented. These productivity rates are used throughout the model to calculate the cost of the individual activity per mile.

In order to allow for comparison of costs over different lengths of track, all costs are converted and presented as per mile costs.

The maintenance activities and associated costs examined in this model are as follows:

1) Conversion to Alternate Track / New Track Construction
2) Basic Force
3) Alternate Tie Maintenance
4) Rail Change out
5) Grinding
6) Rail Transposition
7) Gauging (for cut spikes only)
8) Tie Installation
9) Anchor Adjustment (cut spikes only)
10) Surfacing
11) Undercutting
12) Fuel Consumption

A short discussion of the individual activities are presented along with any assumptions made.

Conversion to Alternate Track

The cost of converting the present wood cross-tie track system into an alternate tie track system is presented at the beginning of the model. This cost includes the cost of increasing the ballast section, as specified by the track characteristics at the beginning of the model.

Next, the equipment required to carry out this conversion is listed and the total cost accumulated. The labor cost required to carry out this activity is presented based on the labor designation as presented previously in the model. Based on the labor and equipment costs per day, a cost per mile is calculated using the productivity rate for this activity.

As a part of this activity the undercutting cost of the track is introduced for the locations where clearance problems may arise as well as the location where ballast conditions are very poor. In the undercutting operation the ballast recovery rate is addressed and the cost of the undercutting is accounted for in terms of contractor cost, labor and equipment.

This is a one time cost occurring at the onset and as such is already a present dollar value.

Note, a key assumption made is that new rail is installed at the time of conversion for a wood tie to alternate ties. The cost of this new rail is presented in the rail change out activity section.

New Track Construction

In this section the cost of constructing a new track is introduced for both wood and alternate tie track systems, The cost includes the labor, equipment and material costs. These costs are used in the model only if the option of new track is activated in the beginning, otherwise all numbers are set to zero and drop out of the economic analysis,

Basic Force

Basic forces are the personnel permanently assigned to inspect and maintain the track. The number of workers that make up this basic force are dependent on the railroad property and the type of track and fastening system. Due to the nature of the alternate track system, it has been found that fewer personnel are required for basic maintenance. The final present worth cost calculation is based on an annual cost difference.

Alternate Tie Maintenance

The costs for repairing concrete ties due to rail seat abrasions are added in this latest version. The analysis is based off the probability that a tie will develop an abrasion, which is then modified by the climactic conditions of the segment, and the time to deterioration in MGT (which the user can override by putting any positive number other than zero in the cell next to the "Override" cell). With these assessments the costs of repairing the abrasion can be determined with the values for Materials, Labor and Equipment.

Rail Change out

The analysis for this activity is presented in two parts, one calculating the cost of the activity for wood tie track and the other for alternate tie track.

The variables considered in each analysis are:

1) Equipment cost
2) Labor costs
3) Productivity rates
4) Material cost, to include rail and fastening components
5) The cycles at which the rail is replaced

The total cost of the rail replacement gang is based on the cost of equipment and labor per day. This in turn is divided by the production rate to get the cost per mile.

Due to the variability in the rail cycles between the wood track and the alternate track, the costs have been converted to present worth values to facilitate the comparison between the two systems.

Grinding

This activity is governed by the following variables:

1) Curvature
2) Tonnage

3) Track Stiffness

Again the present worth cost is calculated and the difference between the wood and the alternate values obtained.

Rail Transposition

This activity is identical to the rail change out presented earlier; however, this cycle is a half cycle out of phase with the rail change out, i.e. it is staggered.

Gauging

This activity is carried out only on wood tie tracks with cut spikes, Thus, it represents a specific savings for alternate tie track. The variables governing this activity are:

1) Cost of Equipment Used
2) Labor Cost
3) Amount of Material Replaced
4) Gauging Cycle

Note, the gauging cycle is also a staggered cycle occurring out of phase with the tie gang cycle. The total cost is calculated based on the sum of the labor and equipment cost divided by the productivity rates. The cost of material replaced is then calculated and the total for labor, equipment and material is calculated. Finally, the present worth value of the total cost is calculated.

Tie Installation

This activity is one of the major cost item in this economic analysis, and has the potential of driving the outcome of the analysis. The variables governing this analysis are:

1) Tie Replacement Cycle
2) Number Of Ties Replaced Per Cycle
3) Percentage Of Fasteners Replaced

4) Equipment Cost
5) Labor Costs
6) Productivity Rate

Again, the economic analysis is carried out separately for both the wood tie track system and the alternate tie track system, for ease of comparison.

Due to the nature of this economic analysis and the long life cycle for alternate ties (which may vary from 15 to 50 years, though any value can be used in the model) it is assumed at this point that complete track renewal is carried out every time the alternate ties are replaced.

Anchor Adjustment

This activity may not be needed for some alternate tie tracks and therefore generally translates into savings for the alternate tie track system when compared to wood tie track. The variables governing this activity are:

1) Labor Cost
2) Equipment Cost
3) Productivity Rate
4) The Anchor Adjustment Cycle

Surfacing

The same gang composition is used for both the alternate and wood tie track system. In addition, the same equipment is used. The only difference between the cost of surfacing on wood vs. alternate is the length of the surfacing cycle and the productivity rate. The general trend for the length of cycle is that the surfacing cycle is longer on alternate tie track than on wood tie track. Also, due to the uniform spacing of the alternate ties and lower number of ties per mile compared to wood tie track, the productivity rate for the surfacing on alternate tie track is usually longer than its counterpart wood tie track. Again, one of the cost items considered in the analysis is the cost of ballast required for surfacing.

Undercutting

This activity is introduced in the model to account for the cost of track undercutting and the implied maintenance results of this activity in terms of better track performance and increase in the length of the surfacing cycle. In this activity the labor, equipment and material costs are introduced in the same manner as the previous maintenance operations and are present worth based, on the cycle presented at the beginning of the model.

Note, this activity will not be accounted for in the ROI unless the option of undercutting is initiated at the beginning of the model.

Fuel

Fuel savings are achieved on concrete tie track due to the increase in track stiffness and thus decrease in rolling resistance. Results of studies performed seem to indicate that fuel savings of the order of 1.5% to 2.5% are realized over concrete tie track, and as such these savings are introduced in the model. Tests still need to be conducted in order to determine the effect that steel ties and other tie alternatives would have on fuel savings.

Model Output

Figure 9-1 graphically displays the relative costs (wood versus concrete ties) for each of the categories used in the model. Using the relationships developed for each of the categories discussed, an evaluation of the benefits of using the alternate tie can be produced. For example, the Return of Investment (ROI) (for using the alternate tie type versus wood) when graphed against curvature can be used to determine the economic "break even" point for using the alternate tie type. Figure 9-2 shows an example of this type of analysis in which the break even point for using concrete ties is determined to be a 7.5° curves. For curves greater than 7.5° concrete is economically viable but not so for curves of lesser degree. Caution: This result is for a particular situation and cannot be used universally. On another road with differing category outputs, the result will be different.

This also applies to the other ROI comparisons shown in Figures 9-3 to 9-8.

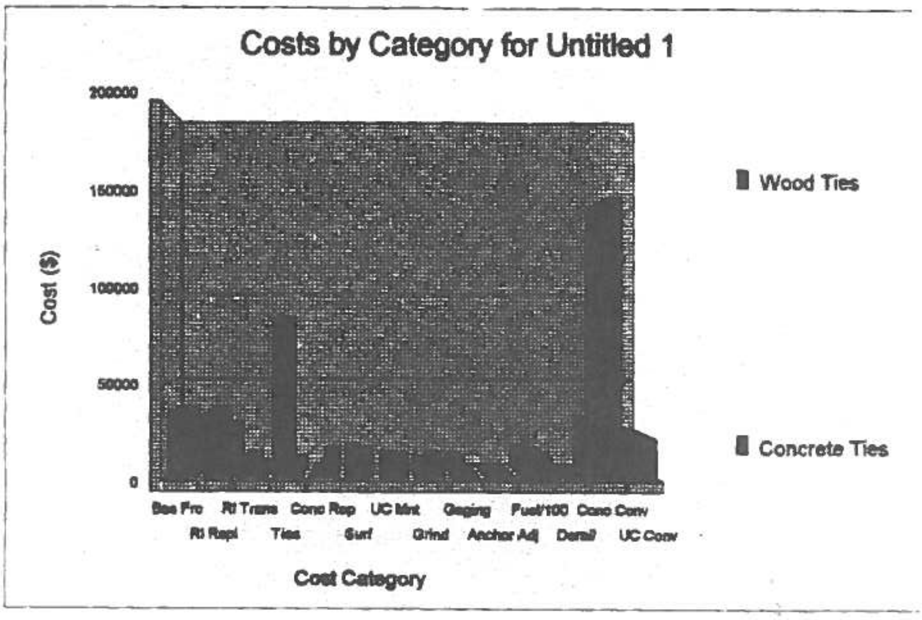

Figure 9-1

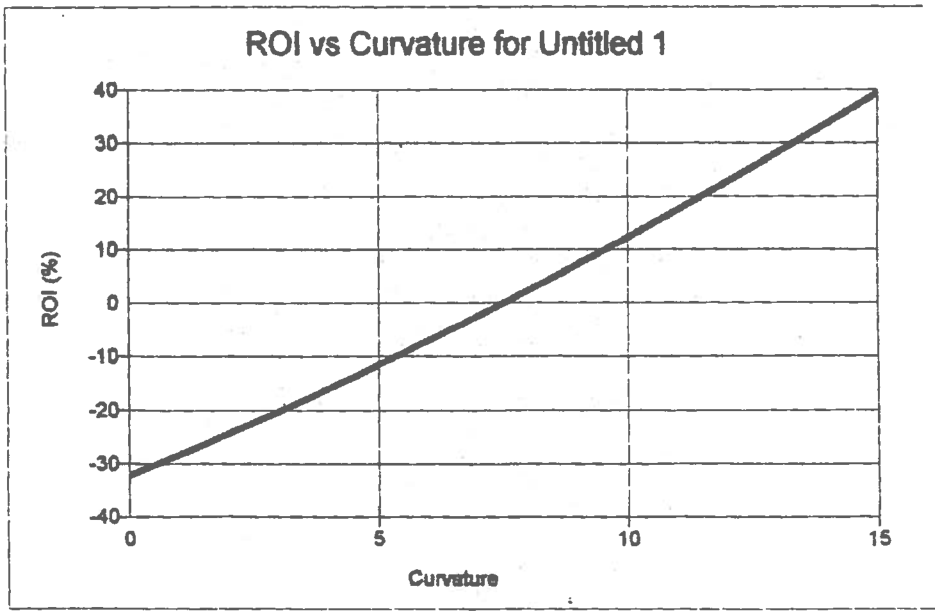

Figure 9-2

ECONOMIC BENEFIT ANALYSIS
Wood vs Concrete Ties

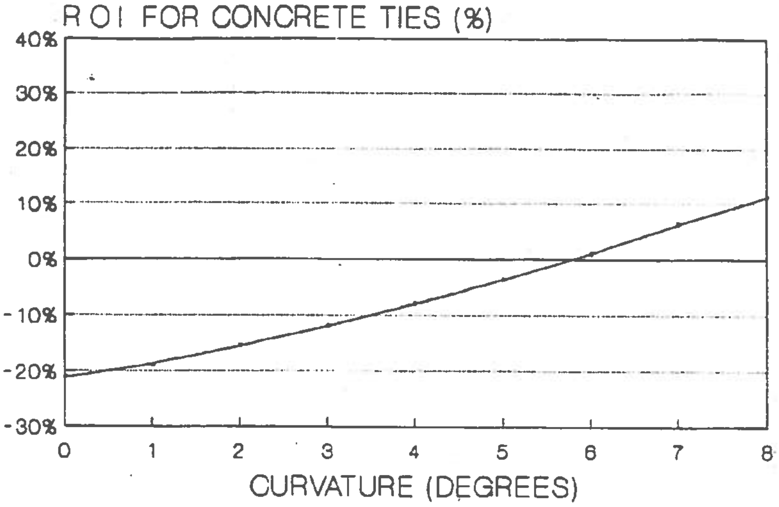

Figure 9-3 ROI for Concrete over Wood Tie (with cut spike fasteners) versus Curvature (Degrees)

ECONOMIC BENEFIT ANALYSIS
CONCRETE VS WOOD TIES/ELASTIC FASTENERS

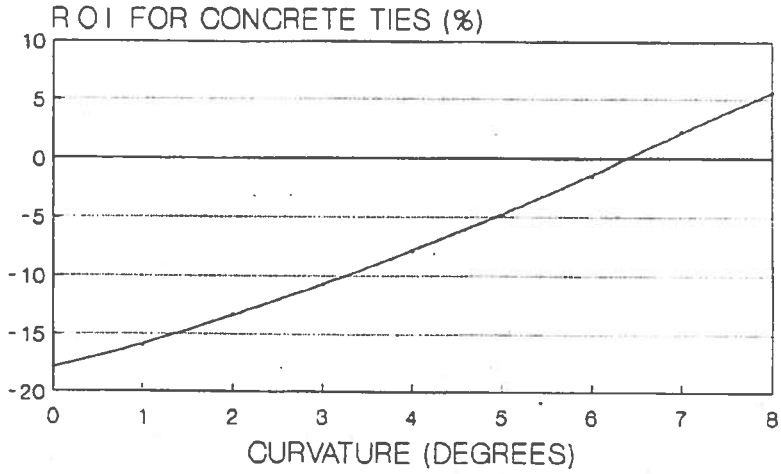

Figure 9-4 ROI for Concrete over Wood Tie (with elastic fasteners) versus Curvature (degrees)

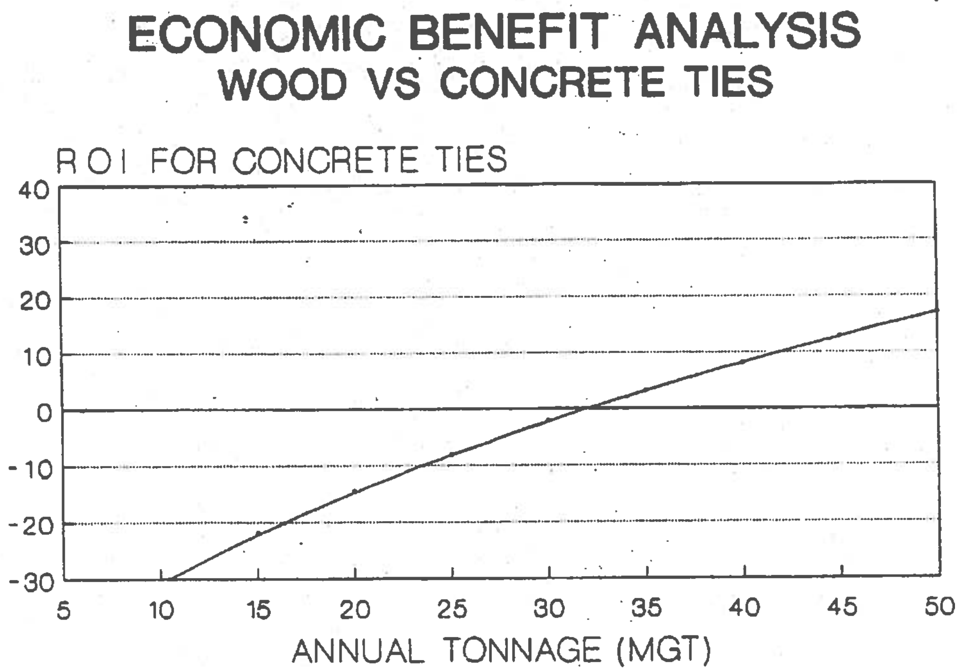

Figure 9-5 ROI for Concrete over Wood Tie (with cut spike fasteners) versus Annual Tonnage (MGT)

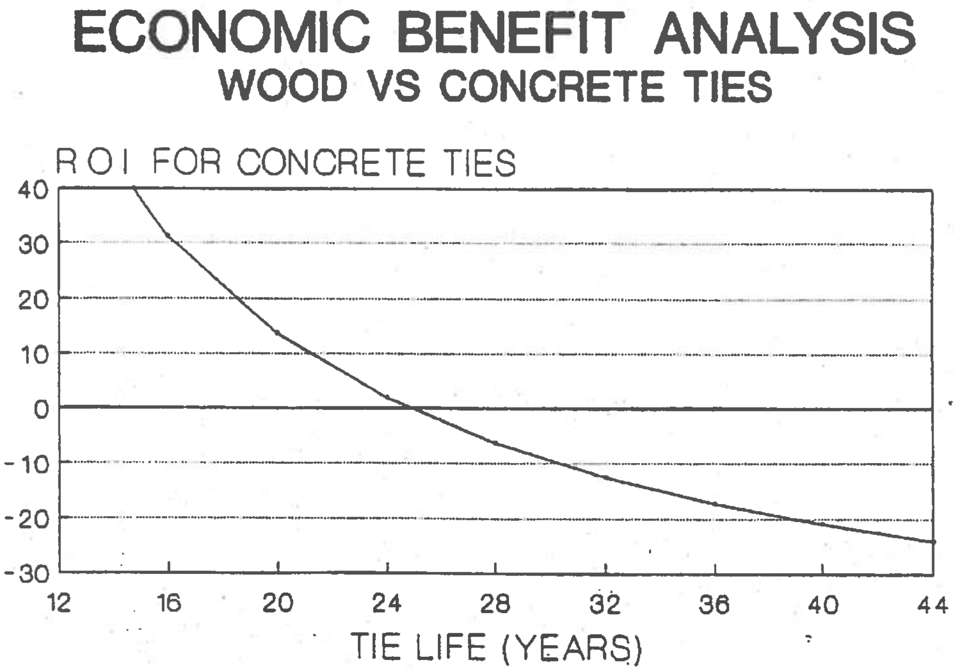

Figure 9-6 ROI for Concrete over Wood Tie (with cut spike fasteners) versus Tie Life (years)

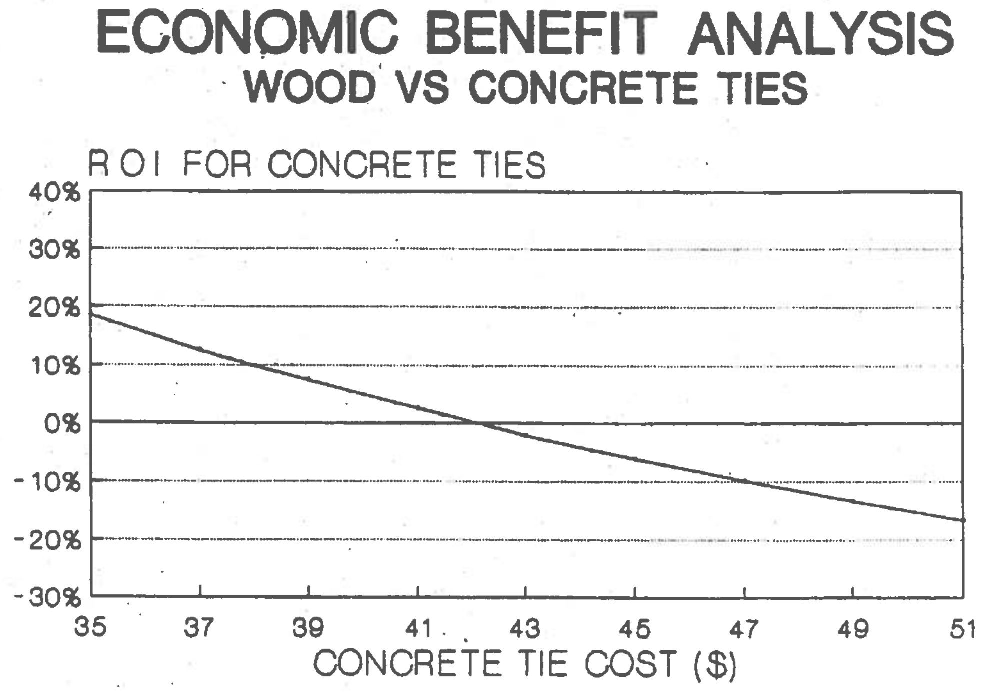

Figure 9-7 ROI for Concrete over Wood Tie (with cut spike fasteners) versus Concrete Tie Costs ($)

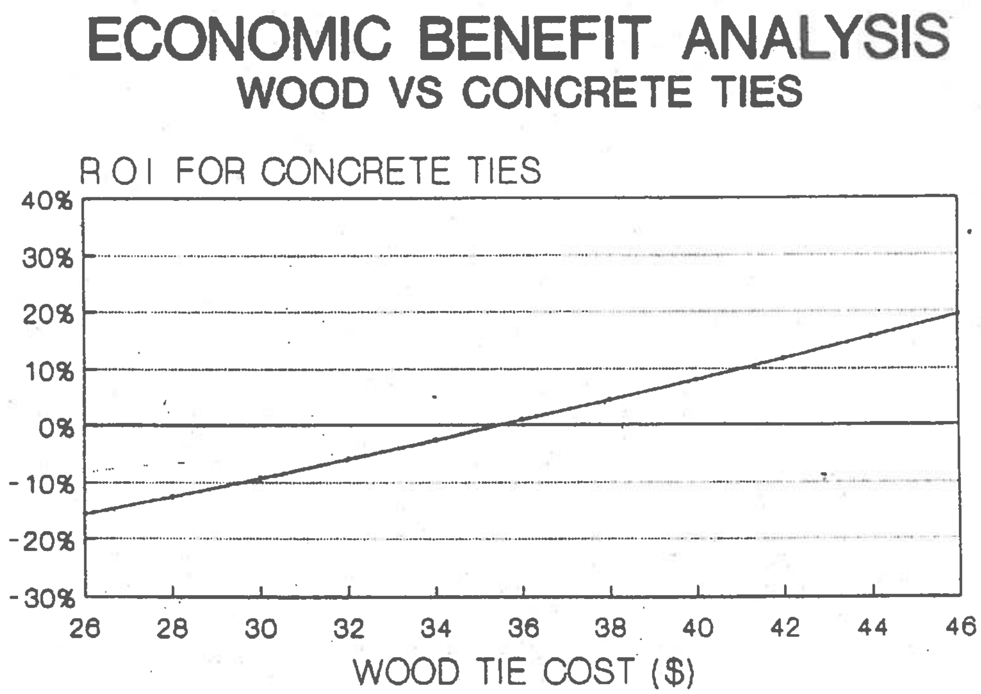

Figure 9-8 ROI for Concrete over Wood Tie (with cut spike fasteners) versus Wood