to the year 2000, the price index is expected to remain stable and favorable relative to 1967 prices. But with a decreasing inventory and increasing demand for timber after the year 2000, the price index is expected to rise (2).

CONCLUSIONS

In the near future and up to the year 2000, the outlook for timber availability for crossties is favorable. After 2000, increased demand for hardwood pulpwood, pallets, and miscellaneous hardwood products may affect timber availability for crossties, especially in regions where these products compete most for hardwood timber.

The opportunity exists for greater increases in growing stock inventories. This opportunity lies in more intensive, improved forest management. However, such a management level would require larger investments in timber stand improvement, reforestation, and research (9).

REFERENCES

1. A.H. Ulrich. U.S. Timber Production, Trade, Consumption, and Price Statistics, 1950-81. Miscellaneous Publ. 1424. Forest Service, U.S. Department of Agriculture, 1983, pp. 10-12, 46.
2. America's Renewable Resources: A Supplement to the 1979 Assessment of the Forest and Range Land Situation in the United States. Forest Service Report FS386. Forest Service, U.S. Department of Agriculture, 1984, pp. 12-19.
3. Yearbook of Railroad Facts. Economics and Finance Department, Association of American Railroads, Washington, D.C., 1977, p. 54.
4. Yearbook of Railroad Facts. Economics and Finance Department, Association of American Railroads, Washington, D.C., 1982, pp. 43, 53.
5. An Analysis of the Timber Situation in the United States, 1952-2030. Forest Res. Report 23. Forest Service, U.S. Department of Agriculture, 1982, pp. 30-41, 75-78, 116-141, 153-161.
6. Proceedings, 78th Annual Meeting of the American Wood Preservers' Association. American Wood Preservers' Association, Bethesda, Md., Vol. 78, 1982, pp. 217, 222, 227.
7. D.B. McKeever and C.A. Hatfield. Trends in the Production and Consumption of Major Forest Products in the United States. Res. Bull. FPL14. Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Madison, Wis., 1984, p.42.
8. K.E. Skog and I.A. Watterson. Residential Fuelwood Use in the United States: 1980-81. Available National Technical Information Service, Springfield, Va., No. ADA 131724, 1983.
9. D. Hair. The Hardwood Timber Situation in the United States, 1952-2030. Crossties, Vol. 64, July 1983, pp. 7-10.

Publication of this paper sponsored by Committee on Track Structure System Design.

Steel Ties: A Viable Alternative

ANGELO M. D'ATTOMA

ABSTRACT

Steel crossties are a viable, cost-effective alternative to wood and concrete, but they are not new to the railway industry. Steel ties have been used in Europe since the early 1800s. A recent report indicated that the life of steel ties is much greater than wood ties in the same track under identical conditions. Although the traffic density, matrix, and other conditions in Europe do not apply to the United States, there is no reason that the modern steel crosstie design would not apply in the United States. In addition, an extensive research program was recently conducted to develop and test a range of steel ties, which covered the spectrum of operating requirements from iron ore operations to secondary lines. The analyses included ballast depth and tie spacing requirements. All track system components were tested, including insulating pads and fasteners. Finally, Omark Industries developed a computer program to compare costs of different types of ties, including wood, concrete, and steel.

A recent study published by the University of Lausanne on the life of steel ties in the Swiss Railway (68 percent steel and 22 percent wood) stated the following conclusions [note that these data are from a collection of research reports on steel sleepers by l'Ecole Polytechnique de l'Universite de Lausanne, Lausanne, Switzerland (Number 1, undated)].

> The investigation carried out has shown that the steel sleeper has very considerable advantages over the other

> types of sleepers for the renewal and maintenance of tracks. Modern means and techniques have been developed which permit this work to be carried out with steel sleepers at least at equal cost, if not more cheaply than with any other type of sleeper. The homogeneous life of steel sleepers considerably facilitates their renewal.

Consequently, steel sleepers maintain a constant life. Wood failures occur intermittently and sporadically. This is an important economic consideration.

> Of special importance is that by choosing suitable lighter steel sleeper types with direct fastenings, the purchase price for the sleeper and the fastenings is lower, as a rule, than that of wooden or concrete sleepers.
>
> It must be added that, because of the high scrap value of the spent sleeper, the net investment cost of steel sleepers is considerably lower than that of other types. From this results, for the steel sleeper, lower interest cost and, because of the very long life...considerably lower depreciation costs.
>
> Particularly important is the fact that the economic advantages of the steel sleeper do not depend on specific conditions in individual countries.

The estimated scrap value of steel sleepers is 25 percent of the initial cost.

STEEL TIES

There are two different types of steel trough-shaped ties: those with uniform wall thickness and those with a shaped cross section comprising a thick top, thin legs, and bulbous edge. The first type is manufactured by pressing a flat plate; the other type is manufactured by either pressing a profiled section or by hot rolling the final shape. The latter method allows better use of materials by varying the thickness of the steel to fit design needs. A cross section of both types is shown in Figure 1. The bottom drawing shows the uniform-wall tie used for light-tonnage railways. The top drawing shows a steel tie with a thicker top to accommodate heavy-tonnage railways.

STEEL TIE DESIGN

The design method consists of three phases:

1. Prevention of fatigue in the fastening area at the rail seat;
2. Prevention of failure in the tie at the base of the rail from exceeded tensile strength, primarily caused by center binding; and
3. Assessment of bearing pressure criteria to ensure that track maintenance costs are controlled.

However, testing is an integral part of each phase in the design of a tie. Testing was performed at the Melbourne Research Laboratory (MRL) in Melbourne, Australia. Testing facilities will be described later in this paper (after a description of tie design phases).

The first phase in the design method involves determining procedures for design that will prevent fatigue in the tie. The procedure for designing a steel tie is given in the following list [the initial aim (number 3) is to establish the section properties of the tie]:

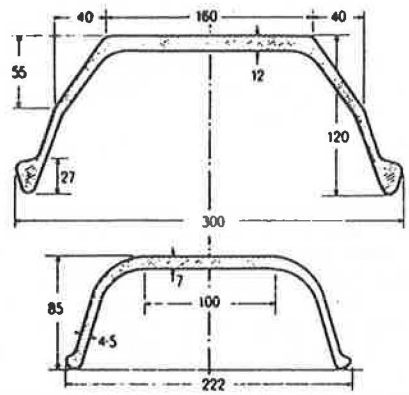

FIGURE 1 Steel tie cross sections.

1. Compute the permissible maximum stress by using loading history;
2. Establish maximum permissible working stress by considering the tie as a welded beam;
3. Use beam on elastic foundation (BOEF) analysis to establish moment of inertia;
4. Establish cross-sectional shape;
5. Compare results with other ties of known performance; and
6. Finalize rail fastener, mode of cant, and insulation.

(Note that procedures 1-4 require testing or computation or both. These procedures are described in the following paragraphs.)

To compute the permissible maximum stress, failure criteria must be established. Failure criteria in steel ties are usually caused by fatigue (the tendency of material to break under repeated stress). The number of fatigue cycles the tie must withstand equals the number of passing axles expected over the design life, which is usually 40 years. In assessing the cumulative fatigue damage of the tie (1), the loading history must be considered because the load range exerted by the passing axles depends on the spacing of the axles, bogies, and ties.

The number of damaging fatigue cycles is used to establish the maximum range of stress that is permitted at the detail that attaches the fastener. Figure 2 shows a typical load spectrum. Note that one-quarter of the fatigue cycles are at maximum-load range, one-quarter are at half-load range, and one-half are at quarter-load range. (The range of load is fatigue damaging, not the absolute value.)

The tie may be analyzed as a BOEF. The theory for BOEF analysis has been thoroughly documented by Hetenyi (2). This analysis is used to calculate moment of inertia in a tie section. The equation for computing the bending moment in a beam with two symmetrically placed loads is documented by Hetenyi (2).

Cross-section shape is established by using the moment of inertia determined in the BOEF analysis. The following requirements must be considered when determining the shape:

1. Mass (cost should be minimized but consistent with strength),
2. Width should be maximized to reduce ballast pressure and consequent degradation and track deformation (3), and
3. Height should not exceed a level that would impede tamping of the tie.

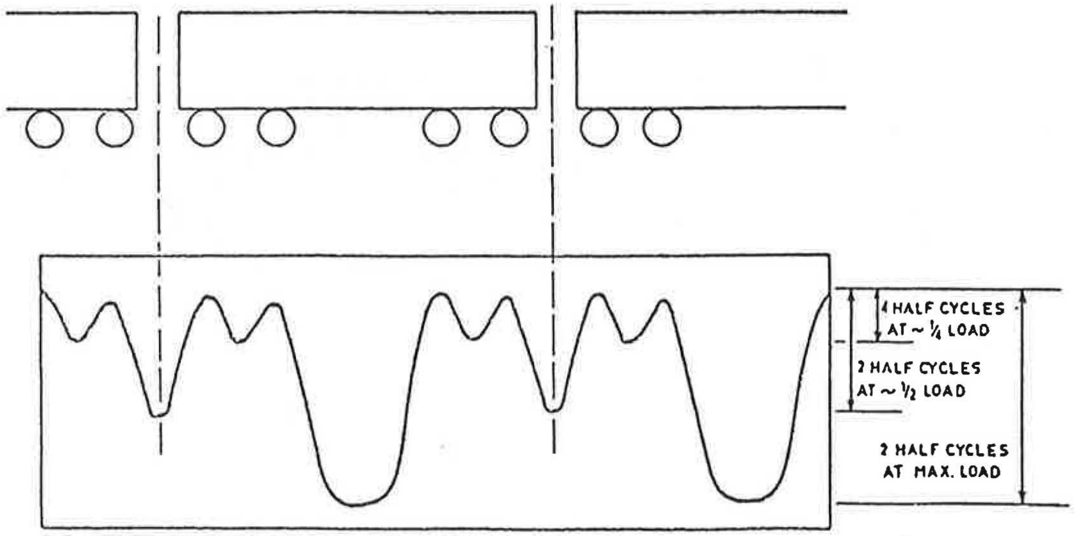

FIGURE 2 The load spectrum.

The second phase in the design method involves prevention of failure from exceeded tensile strength, which is usually caused by center binding. Several design procedures are available for prevention of center binding, a condition that can cause distortion of the tie. One method--the uniform pressure method--uses the BOEF analysis. In addition, the effect of center binding can be calculated by assuming that, under such conditions, the tie is supported and cantilevered. Consequently, trough-shaped ties should be less susceptible to center binding than flat-bottomed ties, such as wood or concrete, because the central portion of the trough is left unpacked during tamping.

By the nature of their design, trough ties should circumvent center binding unless considerable subsidence into the ballast occurs. Furthermore, trough-shaped ties should require less tamping and maintenance than other ties. Figure 3 shows ballast support under ties. The top diagram shows a flat-bottomed tie and the bottom diagram shows a trough-shaped tie with a gap in the middle where center binding might occur in the flat tie.

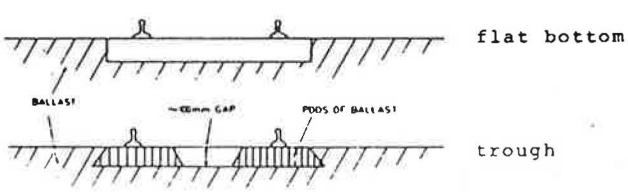

FIGURE 3 Ballast support under ties.

The third phase in the design method involves ballast depth and bearing pressure. For a specified shoulder width, the following major factors affect the volume of ballast (track level): tie type and ballast depth. Ballast depths are usually dependent on allowable subgrade pressure, the average pressure exerted on the ballast surface, and tie dimension. Typical empirical equations are given in Table 1. These equations are used to calculate pressure as a function of ballast depth.

Measurements of pressure beneath ties indicate that significant nonuniformities of pressure exist under steel, wood, and concrete ties. The pressure distribution beneath a steel tie is shown in Figure 4.

TABLE 1 Variation of Pressure with Ballast Depth

Source	Equation
Clark[a]	$\sigma_h/q = 25.4/h$
Okabe–gravel[b,c]	$\sigma_h/q = 125/(50 + h^{1.5})$
Okabe–broken stone[b,c]	$\sigma_h/q = 350/(240 + h^{1.6})$
Horikoski, Japan National Railway[b,c]	$\sigma_h/q = 58/(10 + h^{1.35})$
Talbot[c,d]	$\sigma_h/q = 54/h^{1.25}$
India	$\sigma_h/q = 2b/\pi h$
German[e] (DB)	$\sigma_h/q = 1.5(L-g')b/[3(L-g')+b]\ h \tan\theta$

Note: b, L = sleeper width (length), g′ = distance between rails, and σ_h = pressure at depth h below sleeper (cm).

[a] Approximate to equation by Talbot.
[b] Narrow gauge (1.067 m).
[c] Assume a contact pressure distribution along total tie length to determine q.
[d] For depths between 10 and 72 cm; derived for 20-cm-wide ties.
[e] Assumes contact pressure distribution beneath each rail seat.

Figure 5, which was taken from measurements by the American Railway Engineering Association (AREA) and ASCE Special Committee on Stresses in Railroad Track that operated from 1918 through 1934 in the United States, shows that stresses across the width of a wood tie vary from 110 kPa to 0 and that spreading of pressure does not commence until approximately 100 mm below the surface of the tie. (Note that some of these data are from A.N. Talbot, Special Committee on Stresses in Railroad Track, AREA, 1919.)

Figure 6 (4), based on measurements of concrete ties from the Research and Testing Office (ORE) of the Union Internationale des Chemins de Fer [(UIC) International Union of Railways], shows significant variation in contact pressure along the tie design. The centroid of the pressure distribution for ballast depth calculations can be conservatively calculated by assuming a uniform contact pressure distribution on the interior surface of the tie. By using the dimensions of the steel tie shown in Figure 7, the centroid of the pressure distribution ($\bar{h}$) for ballast depth can be calculated.

The following equations are used to determine the centroid of the pressure distribution for ballast depth:

$$\bar{h} = \{[135 \times (116 - 8.5)] + 2\,[(41 \times 90) + (77 \times 36)]\}$$
$$\div [135 + 2\,(41 + 77 + 7)]$$
$$= [14{,}512.5 + 2\,(3{,}690 + 2{,}772)]/385$$
$$= 71.3 \text{ mm (from base of tie)}$$

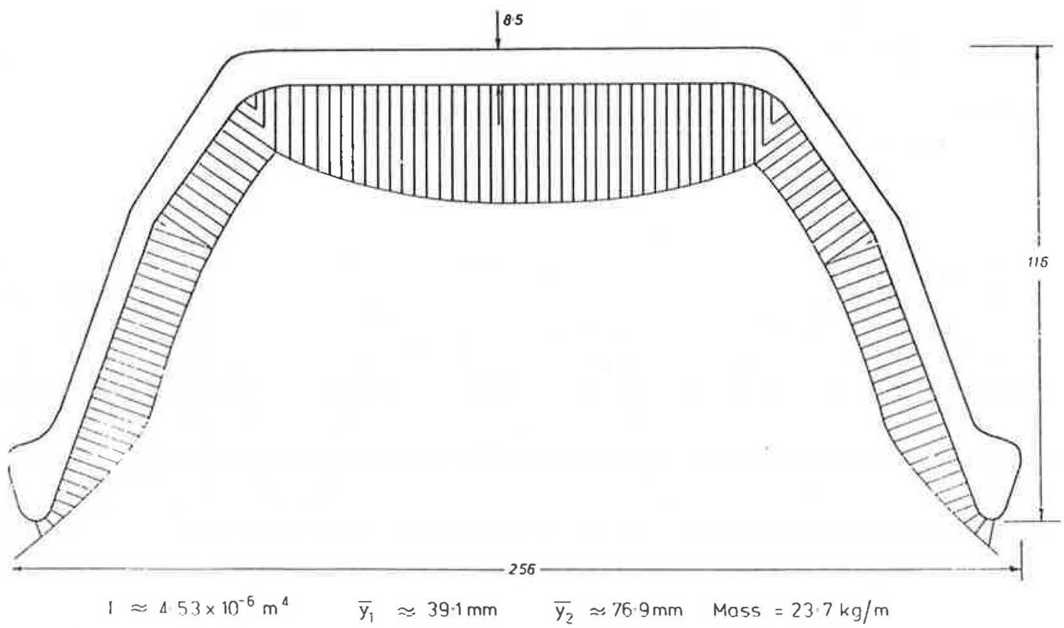

FIGURE 4 Pressure distribution beneath a steel tie.

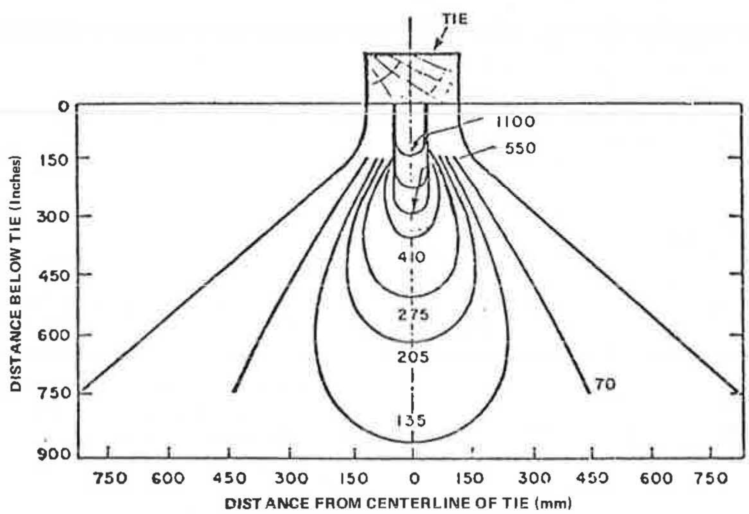

FIGURE 5 Lines of equal vertical pressure (kPa) in the ballast for a single loaded wood tie (from Talbot).

The total surface width in contact with the ballast (385 mm, as shown in Figure 7) is greater than that obtained with comparable wooden or concrete ties. But nonuniformities in the pressure distribution beneath the tie (in all ties) should be accounted for. To correct for nonconformities and to obtain maximum allowable ballast pressure beneath the steel tie, an effective bearing width can be calculated by assuming that contact pressures on the surface of the legs are half those obtained on the web section. Effective bearing width ($\bar{b}$) for the tie in Figure 7 is as follows:

$$\bar{b} = 135 + 2[(7 + 41 + 77)/2]$$
$$= 260 \text{ mm}$$

Examples of calculated total ballast depth requirements for different types of ties are given in Table 2. The major difference between tie types is the reduced, total ballast depth required for steel ties. Although the data in Table 2 indicate that the steel Trak-Lok™ tie requires greater ballast depth from its centroid than a comparable concrete tie from its base, the overall ballast depth is reduced.

Ballast volume reductions can be calculated by using the equations in Figure 8 with the appropriate inputs. Also, Figure 8 shows the reduced formation width requirement for steel ties (compared to wood and concrete) that may, in some cases, lead to considerable cost savings.

TESTING FACILITIES

Full-scale laboratory tests have been conducted at MRL on a number of steel ties, which cover the heavy-haul, main-line, and secondary track ties.

Steel Tie Testing

Initially, full-scale tests were performed on pairs

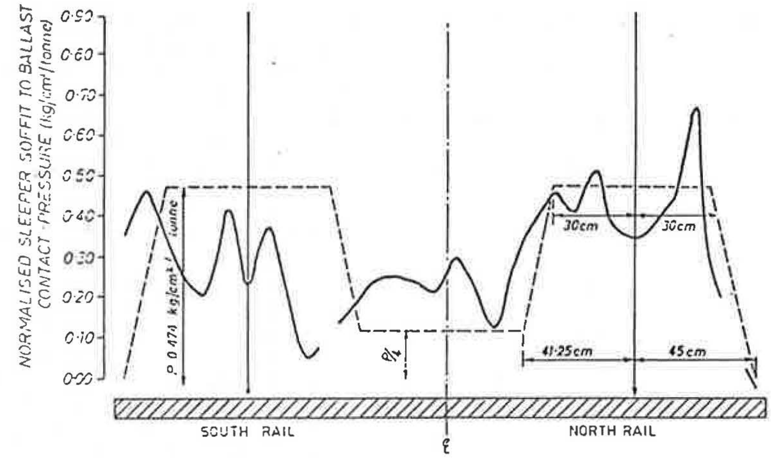

FIGURE 6 Thickness of construction 7.0 + 15 cm, concrete ties at 79 cm, portable electric hammer packing, mean of two passes of two axles, force balance error = 9 percent *(4)*.

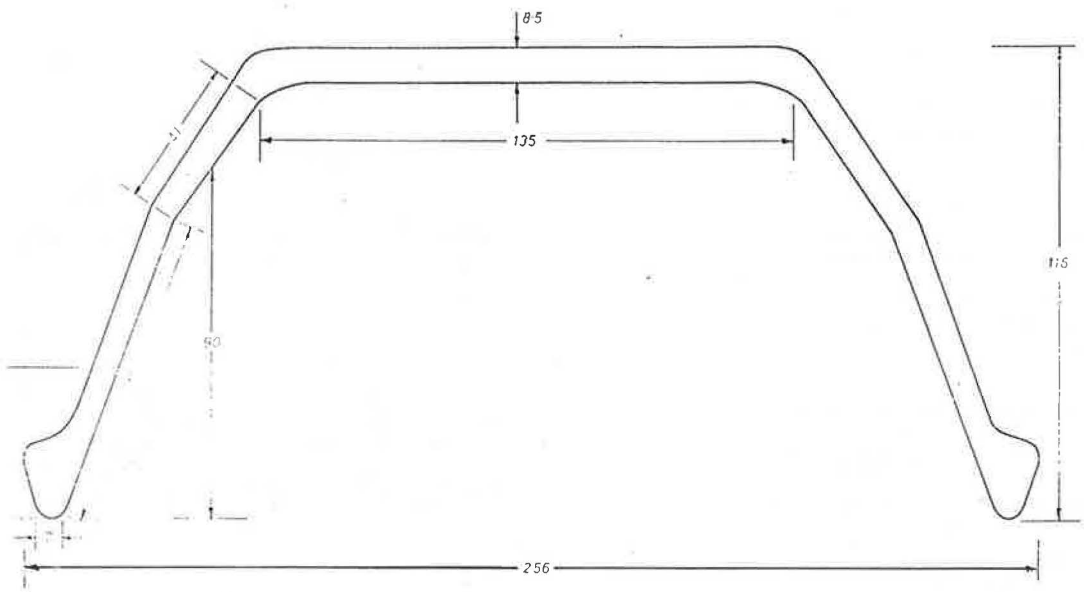

FIGURE 7 Steel tie dimensions (mm) used for calculating centroid of the pressure distribution for ballast depth and effective bearing width.

of ties placed on ballast about 0.5 m deep in a box about 5 x 2 m. Loading was provided by slow-acting hydraulic rams capable of operating at only 0.4 Hz. Accelerated testing was achieved by loading the ties with a series of exaggerated loads, such as 0.5 million cycles (MC) at a nomimal axle load, 0.5 MC at 1.5 nominal loads, 0.75 MC at 2 nominal loads, and 0.25 at 2.5 nominal loads. A modified version of Miner's rule (1) was used to compute the effective number of cycles at the nominal axle load.

The machine operates at between 10 and 20 Hz, which is approximately equivalent to a train moving at 60 mph; it has a maximum load capacity of 90,000 lb and may be used to test a section of track comprising up to 5 ties. The ballast bed is 5 x 5 x 1 m deep and simulates in-track conditions and provides valuable information on performance of the track structure. The output force of the machine is developed by rotating fly wheels with out-of-balance masses. This machine is operated at appropriate nominal axle load; hence the use of exaggerated loads and Miner's rule (as previously described) was not necessary. (Note that for the convenience of the readers certain measurements of weight and speed were converted to customary units in the text.)

Insulation Pad

The insulation of the two rails that form the track is achieved by using a pad that encloses the rail base. The life of the pad is required to be at least the life of the rail (approximately 10 years in typical high-axle-load conditions). Also, the pad should be adequately stiff so that deflection of the rail during passage of a train in not excessive, and it should be sufficiently resilient to recover its shape and dimensions. Furthermore, the pad must be stable under environmental conditions such as heat, cold, and ultraviolet radiation.

Electrical impedance tests performed in rainfall and under contamination with iron ore dust revealed that early, flat pads lacked sufficiently long elec-

TABLE 2 Tabulated Input Data and Calculated Ballast Depths for Different Types of Ties

Tie Type	Timber	Concrete	Steel[a] (other fastening systems)	Steel (Trak-LokTM)
Length (m)	2.44	2.514	2.50	2.50
Width (mm)	229	264	256	256
Depth (mm)	150	204	116	116
Depth of centroid (mm)	150	204	45	40
Rail seat load (kN)	60	60	60	60
Effective bearing width (mm)	229	264	260	256
Effective bearing length[b]	2.44	4.514	2.50	2.50
Bearing pressure (kPa)	215	181	185	188
Allowable subgrade pressure (kPa)	100	100	100	100
Ballast depth[c] (mm)	449	391	398	403
Total ballast	599	595	443	443

[a]Exact calculation.
[b]In practice the effective bearing length is less than the actual length of the tie.
[c]See equation for Talbot in Table 1.

high-density polyethylene (HDPE) (5). The data in Figure 10 indicate that neoprene was unsatisfactory, but HDPE and polyurethane were satisfactory under the most severe conditions anticipated in service. Although these tests aided material choice for pads, the fact that the impedance of the pads fell below AREA specifications (6) of 10 x 10³ Ω per rail tie joint during the rainfall tests demonstrated the unsatisfactory geometry of the early pads that permitted short electrical leakage paths between the rail and clip.

In addition, these pad materials were subjected to cyclic loading tests. Rail, tie, and load assemblies received the equivalent of more than 50 years of in-track loading. The cyclic loading tests agreed with the impedance tests. Only HDPE and polyurethanes remained intact, with no significant visual sign of wear or distortion (7).

The long-term effect of ultraviolet (UV) radiation on a large range of pads and tensile specimens is being studied at MRL. These pads and specimens contain various amount of carbon black, the additive used to inhibit degradation. Currently, the HDPE pads have received the equivalent of 10 years of in-track radiation. In addition, specimens containing 2.5 percent carbon black (the standard amount used for UV protection) are performing satisfactorily, with barely perceptible signs of surface damage. Because HDPE passed all tests and is less expensive than polyurethane, MRL chose HDPE as the preferred insulating material.

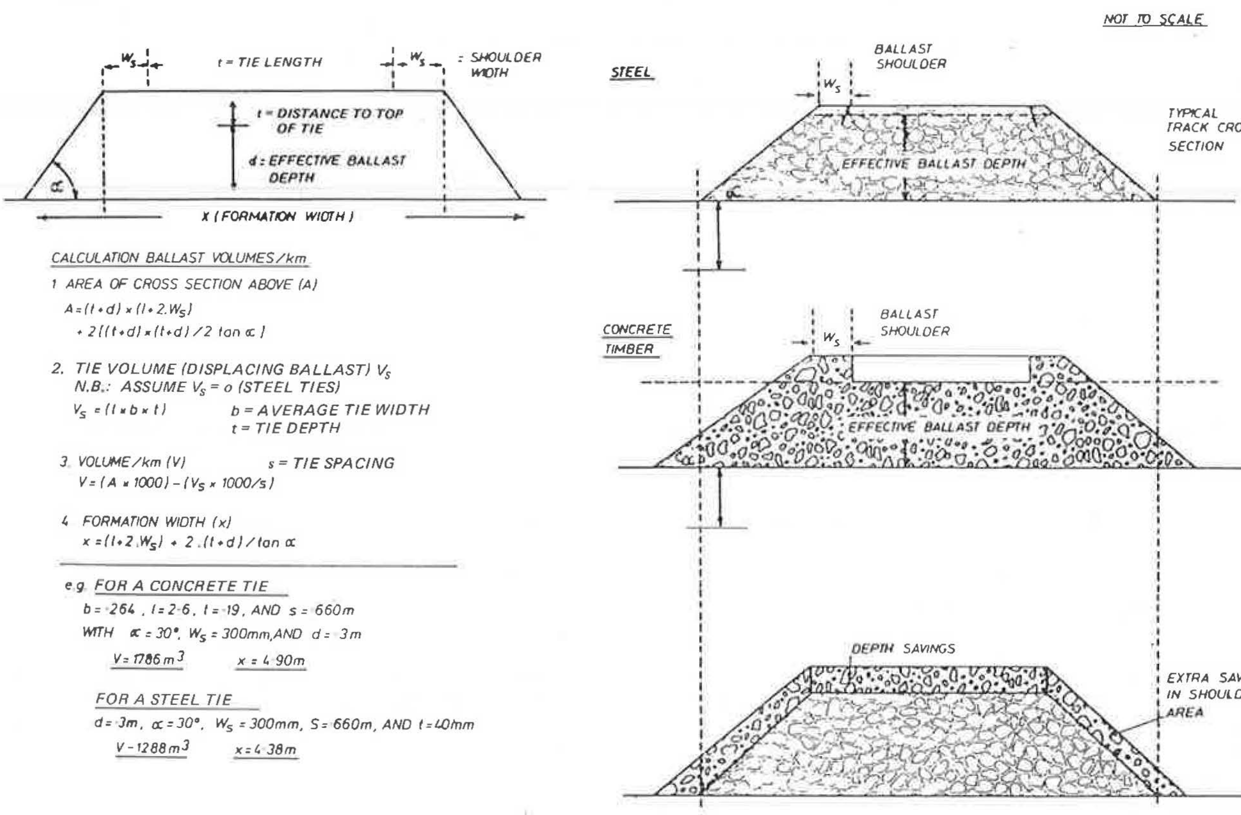

FIGURE 8 Reduced formation and ballast requirements for steel ties.

trical leakage paths between the rail and tie and lacked proper drainage to facilitate removal of contaminants. Consequently, the pad shape was altered to include relatively high upstanding ridges along the periphery of the top side of the pad. In addition, use of the one-piece pad (rather than two piece) simplified manufacture, storage, distribution, and installation (see Figure 9).

Results of the early impedance tests under varied environmental conditions (dry and wet) that used different pad materials are shown in Figure 10. These materials included neoprene, polyurethane, and

Fasteners

MRL tested tie and fastening systems at their Melbourne facility. Two 10-mm and one 9-mm (top thick-

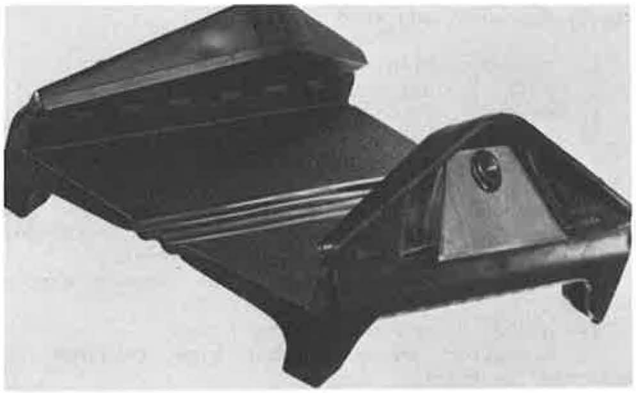

FIGURE 9 Wrap-around insulator pad.

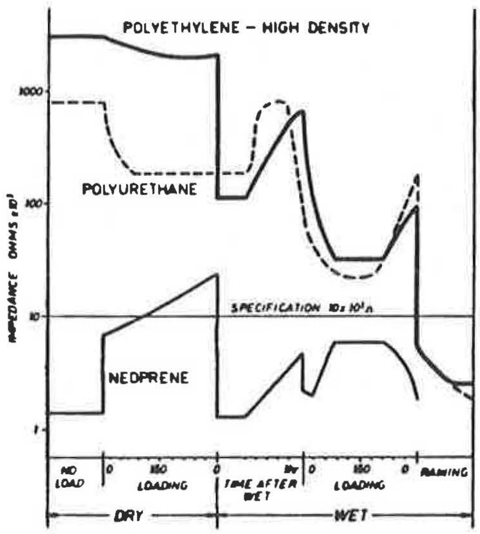

FIGURE 10 Summary of results of electrical leakage measurements on early half pads.

ness) ties with Omark Trak-Lok™ I fastenings were used. A load cycle of approximately 20,250 lb per rail seat was imposed, starting with a minimum of 9,000 lb per rail seat and finishing with a maximum of 29,250 lb per rail seat. The tie and fastener assemblies were examined after 3.0 x 10^6 load cycles, and no cracking was evident in the ties or clips, and the insulation pads remained in good condition.

The forces that affect tie and fastener systems are different on curved railroad track than on straight track. On curved track lateral forces are applied to the rail. These forces depend on curve radius, wheel and rail profiles, and vehicle dimensions, and they can be established theoretically by modeling the curving behavior. The MRL vehicle curving model for a variety of axle load levels is shown in Figure 11. The data in this figure reveal that the lateral to vertical force (L/V) ratio is generally less than 0.4.

To test fastening behavior under these conditions an apparatus similar to one developed by Eisenmann at the Institute for Eisenbahnbau in Munich was used. A tie, reduced in length, was placed in a ballast bed enclosed in a containing box. The ties used in the test were the same as those previously tested in the full-scale test, but they were cut and welded to appropriate length. Then a combination of vertical and lateral loads was applied through inclined loading arms. An L/V ratio of 0.4 was

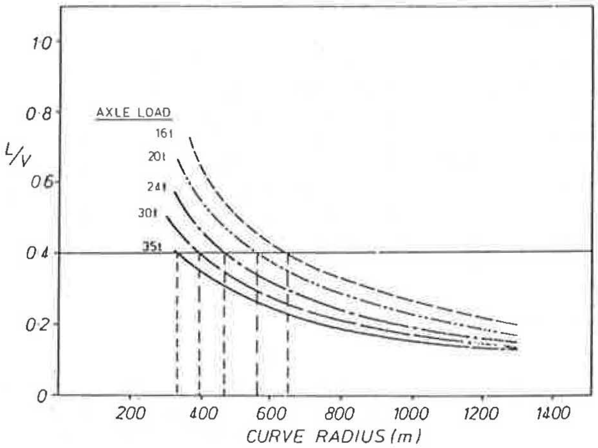

FIGURE 11 Approximate L/V ratio versus curve radius (predicted by curving model calibrated for 30-t axle load).

selected. The applied vertical load range was 40,500 lb (20,250 lb per rail section), with an applied maximum vertical load of 41,625 lb. After 3.0 x 10^6 cycles no cracking was evident in the tie, no failure occurred in the clips, and a small amount of crushing was apparent in the insulation pad.

To test lateral resistance, MRL performed creep resistance tests on a new section of rail attached to two ties fixed by clamps and fully clipped. A load was applied at 101 foot pounds per second² (fib/sec²) longitudinally. A vibrator that fluctuated at 50 Hz was attached to the top of the rail. This vibrator produced a 2,700-lb peak-to-peak oscillation. Lateral resistance ranged from 0.6 to 0.8 at the rail seat load. Figure 12 shows clip load deflection characteristics and a clip diagram. (Note that Figure 12 refers to toe load in kilonewtons. For the convenience of the reader, in the text kilonewtons were converted to fib/sec².)

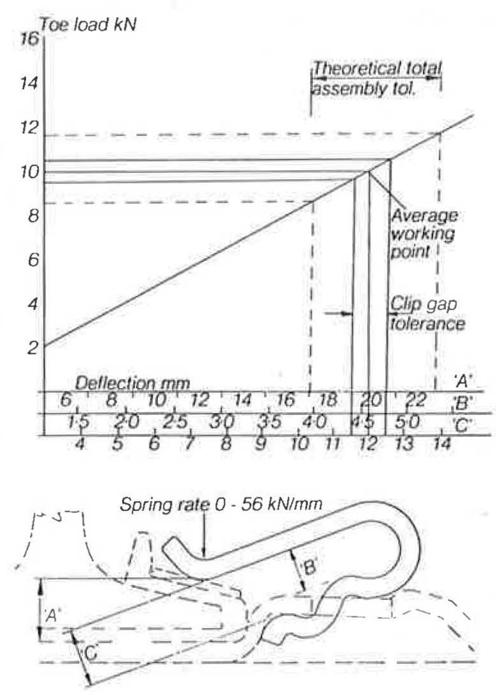

FIGURE 12 S 193 clip-load deflection characteristics.

Tie Spacings

The allowable number of cycles that may be imposed on a tie is inversely proportional to tie spacing. As tie spacing increases, the allowable number of cycles imposed on that tie decreases. For 20 million gross ton (MGT) traffic, the steel tie recommended by MRL for main-line tracks may be spaced at intervals greater than 600 mm. Ballast depth required at 600-mm spacings is approximately 335 mm from the tie neutral axis.

Minimum Capital Cost Track

Several factors influence the minimum capital cost track, including construction costs, which vary with tie type; actual tie costs (material); ballast volumes; and formation width required. The trade-off between tie, spacings, and ballast depth is important because increases in tie spacing (a) decrease the number of ties and the component costs, (b) may increase the ballast depth requirement, and (c) may increase cyclic maintenance costs.

ALTERNATIVE TIE ANALYSIS PROGRAM

Many other factors must be considered in determining costs in an alternative tie analysis. The following calculated steps form the basis of a computer program from Omark Industries that compares cost in steel, concrete, and wood ties:

1. Transportation cost and routing;
2. Rail life extension, if any;
3. Value of second-hand wood tie;
4. First year expenditure or investment;
5. Rate of return as incremental investment to install concrete or steel ties (note that if rate of return is not greater than 5 percent, rail and tie lives are decreased as annual tonnage is increased, based on a ratio dictated by the TOP formula);
6. Present worth of future maintenance expenditures;
7. Annual maintenance savings; and
8. Reduction in possession time required to maintain the track.

The following basic assumptions are used in the analysis:

1. Constant 1982 dollars;
2. Labor costs include full fringe benefits and overhead;
3. All labor and material costs are current as of December 1981;
4. Equipment costs include maintenance, fuel, and capital recovery;
5. The 132-lb rail is replaced with similar rail that requires the replacement of 5 percent plates, 46 percent anchors, and 50 percent spikes;
6. Ballast cost is $5/yd^3$;

OMARK INDUSTRIES

TRAK-LOK RAILWAY FASTENERS

The potential benefits of installing STEEL or CONCRETE TIES On The CONRAIL in the area of PHILADELPHIA

Base Data Supplied by the Railroad :

Length of Installation :	1.0 MILES	Rail Type :	CWR
Present Life of Ties :	20.0 YEARS	Rail Metalurgy :	STD CARBON RAIL
Present Life of Rail :	20.0 YEARS		
Ties Presently Req Replacement/Mile :	925 TIES		
Annual Traffic Density :	20.0 MGT		
Ballast Transportation Distance :	25.0 MILES		
On Line Wood Tie Cost :	$22.50		
Average Track Curvature :	4.0 DEGREES		

INVESTMENT COMPARISON
TYPE OF TIE

	WOOD 19.5 C.C. Selective	CONCRETE 24 C.C. Out Of Face	STEEL 24 C.C. Out Of Face	Comments
Tie Purchase Location		BOSTON	PITTSBURGH	
Transportation Routing		ON LINE	ON LINE	Indicates Gateway City When Originating Off Line
Freight Cost,Per Tie		2.50	0.66	Calculated At $.02 Per Ton Mile On Line & $.06 Per Ton Mile Off Line
TOTAL INVESTMENT - Cost Per Mile ($) -				
Rail Cost	113,713	113,713	113,713	
Tie Cost	18,563	116,160	108,610	Wood Tie Cost Includes Freight
Tie Freight Cost		6,610	1,746	
Fastening Cost	1,625	30,360	29,568	Partial Replacement of Wood Tie Fastening Included
Ballast Cost			7,205-	Steel Ties Require 1048 Cu. Yds Less Ballast Than Other Ties
Tie Installation, Labor And Equipment	4,851	9,592	9,592	Includes Labor Fringe, Machinery Depreciation, Maintenance & Fuel.
Rail Installation, Labor And Equipment	14,972			Steel and Concrete Ties and Rail Installed With Track Renewal Machine
Ballast Cleaning, Labor And Equipment	12,264	10,594	10,594	
SUB TOTAL	165,988	287,029	266,617	
Credit For Wood Ties- Scrap And Reusable	925-	36,160-	36,160-	Includes Cost of Sorting, Plugging and Retreating if Required
Credit For Secondhand Rail	68,228-	68,228-	68,228-	Valued At 60% New
Credit For OTM From Wood Tie Track		27,504-	27,504-	90% Plates And Anchors, 75% Spikes Reusable, rest Scrap
TOTAL	96,935	155,137	134,725	
Incremental Investment Per Mile		58,202	37,790	The Savings Of STEEL Over Concrete Is $20,412

FIGURE 13 Computer printout of investment comparison for different tie types.

	Wood	Concrete	Steel	
MAINTENANCE OPERATION				
Tie Replacement	30,091	3,694	3,242	0.5% Concrete, 0.25% Steel Tie Prematore Failure, And All Future Tie Replacements
Rail Replacement	23,626	18,089	18,089	Used Rail Credited At 60% New. Rail Change Cheaper With Elastic Fastening
Ballast Cleaning	3,852	4,125	4,125	Ballast Cleaning For Wood Justifiable From Reduced Surfacing
Surfacing Including Ballast	7,981	10,621	9,386	11.6% Less Ballast Required When Surfacing Steel Ties
Smoothing	1,829	2,364	2,215	
Gauging	1,354			
Anchor Adjusting	269			Only Required When Rail Life Greater Than 4 Years
Fastener Replacement		3,035	3,219	Approximately 25 Year Average Life
Pad Replacement		8,401	6,377	Pad Life Approximately 10 Years For Concrete And 12 Years For Steel Ties
Present Worth Of Future Maintenance Expenditures ($)	69,002	50,329	46,653	Amount Necessary To Invest At 10% Intrest To Maintain Track Indefinately
Incremental Maintenance Savings Per Mile		18,673	22,348	Present Value Of Reduced Maintenance Cost
Total Initial Investment For 1 Miles Of Track ($)	96,935	155,137	134,725	
Total Incremental Investment ($)		58,202	37,790	
Total Maintenance Expenditure For 1 Miles Of Track ($ Discounted 10%)	69,002	50,329	46,653	
Total Incremental Maintenance Savings ($)		18,673	22,348	
Rate Of Return On Incremental Investment		1.00	6.00	
Annualized Maintenance Savings ($)		1,867	2,235	The Average Annual Tangable Railroad Savings After Offsetting The Incremental Investment
Based On An Investment Of		58,202	37,790	
Percentage Reduction In Track Possession For Maintenance Purposes		39.96	39.96	

Additional Intangable Benefits Include Less Fuel Consumption,

Improve Rolling Stock Utilization From Increased Track Availabilty

FIGURE 14 Computer printout of present worth of future maintenance expenditures.

7. Transportation of ties and ballast are $0.02 per ton mile on line and $0.06 per ton mile off line; and

8. Work gangs are as follows: (a) wood tie gang--10 machines and 20 men plus distribution and tie pick up, and (b) rail relay gang--18 machines and 48 men plus distribution and rail pick up.

Base data for the analysis are supplied by the railroad. This analysis compares the potential benefits of installing different types of ties on Consolidate Rail Corporation (Conrail) rail lines in the Philadelphia area. Figure 13 shows the computer program investment comparison for different tie types. The savings of steel over concrete is $31,175. Although wood ties create the least-expensive initial investment, Figure 14 (the computer program for present worth of future maintenance expenditures) reveals that total maintenance expenditures for 1 mile of track is $69,002 for wood ties, $50,329 for concrete ties, and $45,310 for steel ties. Additional savings for steel accrue from its salvage value.

CONCLUSIONS

1. Steel ties have longer lives than wood ties and, therefore, money is saved on replacement costs.

2. Modern steel ties, fasteners, and insulating pads have been refined to circumvent earlier design inaccuracies.

3. Steel ties are a viable, cost-effective alternative to concrete ties because of low initial cost and ballast savings.

4. Because steel ties weigh less than concrete, savings occur on replacement ties because standard track machinery is required to replace ties. Consequently, money is saved on maintenance.

5. Steel ties have scrap value; wood and concrete ties do not.

REFERENCES

1. N.E. Frost et al. Metal Fatigue. Oxford University Press, Oxford, England, 1975.
2. M. Hetenyi. Beams on Elastic Foundation. University of Michigan Press, Ann Arbor, 1967.
3. M.D. O'Rourke, R.I. Mair, and N.F. Doyle. Towards the Design of Rail Tracks for Heavy Axle Loads. Presented at 1st International Heavy Haul Railways Conference, Perth, Australia, 1978.
4. Stresses in Concrete Sleepers. Question D71, Section 9. Research and Testing Office, Union Internationale des Chemins de Fer, Paris, France, 1969.
5. R. Cornish and M. Toyama. Evaluation of Rail Sleeper Insulation Pads. Report MRL/075/76/003. Melbourne Research Laboratory, Melbourne, Australia, 1976.
6. Manual Recommendation of Special Committee on Concrete Ties. Bull. 655. American Railway Engineering Association, Washington, D.C., 1975.
7. D.H. Skinner. Testing of Rail Insulation Systems. Presented at BHP Seminar on Steel Rail Sleepers, Adelaide, Australia, 1977.

Publication of this paper sponsored by Committee on Track Structure System Design.