7. W.R. Hamilton. Dilemma of Direct-Fixation Fastening Systems. In Transportation Research Record 744, TRB, National Research Council, Washington, D.C., 1980, pp. 37-40.
8. T.P. Brown. The Development of Rail Fastening Systems to Meet Changing Requirements. Presented at AIT Symposium, Madrid, Spain, 1981.
9. F.L. Dean. Investigation of Rail Fastener Performance Requirements. Battelle Columbus Laboratories, Columbus, Ohio, June 1981.
10. F.E. Dean et al. Effect of Tie Pad Stiffness on the Impact Loading of Concrete Ties. Presented at 2nd Heavy Haul Conference, Colorado Springs, Colo., 1982.
11. H.G. Moody. Some Aspects of Concrete Tie Performance in FAST and in Revenue Service. Battelle Columbus Laboratories, Columbus, Ohio, 1979.
12. R.J. Davern. Insulation for Track Circuitry. Presented at 4th International Rail Track and Sleeper Conference, Adelaide, Australia, 1981.
13. G.J. Berg. Electrical Resistance of Concrete and Wood Tie Assemblies. University of Calgary, Calgary, Alberta, Canada, May 1979.
14. R.K. Steel and R.P. Reiff. Rail: Its Behavior and Relationship to Total System Wear. Presented at 2nd Heavy Haul Conference, Colorado Springs, Colo., 1982.
15. C.T. Collins et al. Optimization of CVRD Track Structure. Presented at 1st Heavy Haul Conference, Perth, Australia, 1978.
16. A. Worth. Rail Corrugation on the British Columbia South Line of CN Rail. Presented at American Association of Railroads/British Rail Conference, United Kingdon, 1981.
17. B.H. Langson and S.T. Lawson. Development of Rail Profile Grinding at Hammersley Iron. Presented at 2nd Heavy Haul Conference, Colorado Springs, Colo., 1982.
18. L. Borup. Railway Engineering at Swedish State Railways. Presented at 4th International Rail Track and Sleeper Conference, Adelaide, Australia, 1981.
19. H.H. Jenkins et al. The Effect of Track and Vehicle Parameters on Wheel/Rail Vertical Dynamic Forces. Railway Engineering Journal, Vol. 3, No. 1, 1974.
20. D.F. Sullivan. Concrete Ties on the Northeast Corridor--An Update. Presented at Concrete Tie Systems Workshop, Chicago, 1983.
21. G.A. Van de Water. Use of Concrete Ties on CN Rail. Presented at American Railway Engineering Association Regional Meeting, Los Angeles, 1980.
22. C.O. Frederick. The Effect of Wheel and Rail Irregularities on the Track. Presented at 1st Heavy Haul Conference, Perth, Australia, 1978.
23. J.C. Lucas. The Total Track Structure and Its Response to Its Environment. Presented at 3rd International Rail Sleeper Conference, Brisbane, Australia, 1979.
24. J.M. Tuten. Analysis of Dynamic Loads and Concrete Tie Strain Data from the Northeast Corridor Track. Battelle Columbus Laboratories, Columbus, Ohio, 1981.
25. L.E. Daniels and N. Blume. Rail Corrugation Growth Performance. Presented at 2nd Heavy Haul Conference, Colorado Springs, Colo., 1982.

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

Timber Crossties in Relation to Track Structure System Design

J. FRANK SCOTT

ABSTRACT

The timber crosstie and cut spike rail fastening system has performed admirably for many years on North American railroads. With the introduction of six-axle locomotives, 100-ton freight cars equipped with roller bearing trucks, and concentrated unit train operations, problems with track maintenance arose on sharp curves. Simple logic dictated that the first course of action was to measure the forces that were being applied to the track structure. If the forces could not readily be alleviated through modifications in equipment or operations, then the strength of the track structure system would have to be increased to cope with the situation. In this paper a brief review of conclusions derived from track measurements taken in the early 1970s is presented. Results from measurements taken in 1982 and laboratory fatigue tests run in early 1983 on various tie and rail fastening systems were combined with engineering judgment in an economic analysis to select an upgraded tie and rail fastening system for the sharp curves of a branch line that handles 4 to 5 million gross tons of unit train 100-ton car traffic.

The timber crosstie has been the vertebra in the backbone of the North American railroad track structure since railroading began on this continent. There were no tough decisions made in choosing the timber tie; it was cheap and abundant. The simplest method of fastening the rail to the tie was to nail it down, and over the course of years there evolved the current style: the cut spike and tie plate rail fastening system. This system cannot actually be called design, but it can be called system optimization; that is, it delivered the most benefit from the least expenditure. But what was optimum track construction in the 1950s is not necessarily optimum track construction in the 1980s. Railroading has changed. Powerful four- and six-axle diesel locomotives now haul 12,000- and 14,000-ton unit trains comprised of uniformly loaded 100-ton cars. The effects on weak track structure can be devastating.

There is a strong belief that research can play a significant role in guiding the evolution of optimum track systems. The traditional method of trial-and-error field installation followed by "observe and debate" must be complemented, but note that this does not mean replace this method by the more expedient method of "measure and conclude". Tough decisions must be made when there is a lack of information, and there is always a lack of information. Much of the information that is available is subjective and a matter of opinion. If tests are conducted and measurements are taken, some objective technical information can be provided, which can then be included with experience and economic analyses in arriving at decisions concerning track structure.

There is not much point in talking about design of timber ties, which are squared-off logs; or design of cut spikes, which are squared-off nails; or design of tie plates, which are configured plates with holes punched in them. Instead, system design should be discussed, and the system must be designed to carry the fatigue loadings over some projected economic life, be it 10 or 50 years. An optimum system cannot be designed without a knowledge of the loadings which that system must endure. These loads must be measured and defined, and the system must be evaluated accordingly.

In this paper some of the track measurement information that Canadian National (CN) Rail Research has accumulated over the past dozen years is presented. This information is by no means comprehensive, but it does provide satisfactory insight into how the technique of "measure and conclude" can be used to indicate appropriate courses of action.

BACKGROUND

During the winter of 1970-1971, track forces on certain subdivisions in Quebec observed an increased frequency of occurrence of wide gauge and loss of superelevation on the high rail of virtually all curves greater than 4 degrees. On several curves rail spikes were lifted by as much as 1 in. on the inside of the high rail, gauge was as much as 1.25 in. wide, and loss of superelevation was as much as 1.25 in. In some instances track spikes were bent into S-curves, and there was evidence of tie crushing around spikes. It was clear that track damage was primarily caused by the application of excessive lateral loading. Six-axle locomotives had been introduced on the territory in 1968, and a second series of six-axle units had been added in November 1970. Although evidence against the six-axle diesels was circumstantial in nature, steps were taken early in 1971 to phase these units out of operation in the Quebec area.

CN Research was asked to take track measurements in the fall of 1971. An 8.5-degree curve with superelevation of 3.5 to 4 in. and gradient of 2 to 3 percent was selected as the measurement site. Track construction was 100-lb rail, 7 x 9 in. No. 1 hardwood ties in excellent condition, double shoulder 11-in. tie plates, and four cut spikes per plate. Four instrumented base plates, such as the one shown in Figure 1, were used to measure vertical and lateral loads imposed on four consecutive ties under the high rail of the curve. Displacement transducers were used to measure railhead lateral displacements or dynamic gauge widening. A work train of two six-axle and two four-axle locomotives was run back and forth across the site, and 32 regular freight trains were also recorded.

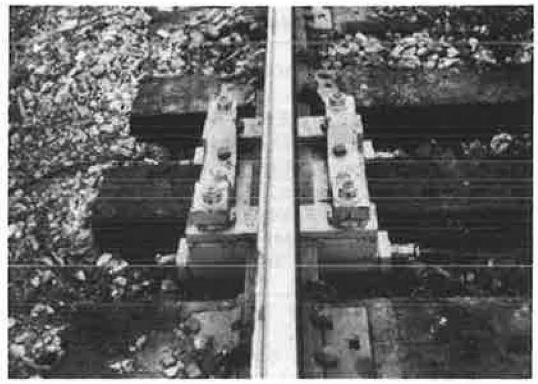

FIGURE 1 Instrumented base plate for measuring vertical and lateral tie loads.

A number of conclusions were drawn from this research.

1. The cause of the wide gauge development could not be determined because of data scatter, and the case against the six-axle units could not be proven or disproven.
2. Some freight cars developed lateral loads as high as those of the locomotives, and there was considerable overlap in forces from four- and six-axle units.
3. Running overspeed on the curve led to significantly higher vertical and lateral loads on the high rail.
4. Dynamic gauge widening ranged from 0.08 in. at 20 mph to 0.2 in. at 36 mph (curve balanced for 25 mph).
5. Depending on compaction under tie, vertical tie plate loads ranged from 2,000 to 38,000 lb.
6. Lateral tie plate loads were as high as 16,000 lb.
7. Future test measurements would have to be geared for the collection of statistical data.

A second set of measurements was taken on the same curve in March 1972. Base plates were spread out around the curve, and more than 150 runs were made with locomotive work trains. The average peak lateral tie plate loads developed by four- and six-axle locomotives are shown in Figure 2, where each plotted point represents the average of 120 readings. Two strong conclusions were drawn:

1. Six-axle locomotives developed high rail lateral tie plate loads ranging from 3,000 to 4,000 lb higher than those developed by four-axle locomotives, and
2. Lateral forces increased significantly with increasing train speed on the sharp curve.

The significance of the locomotive track loading

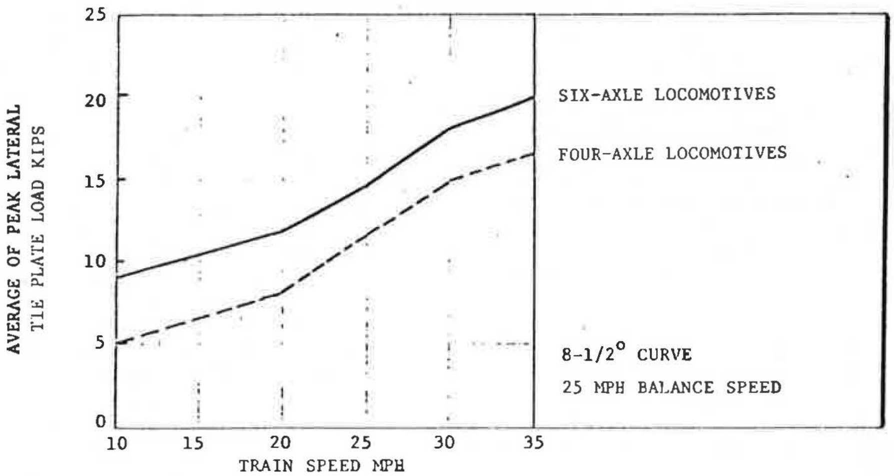

FIGURE 2 Lateral tie plate loads developed by locomotives.

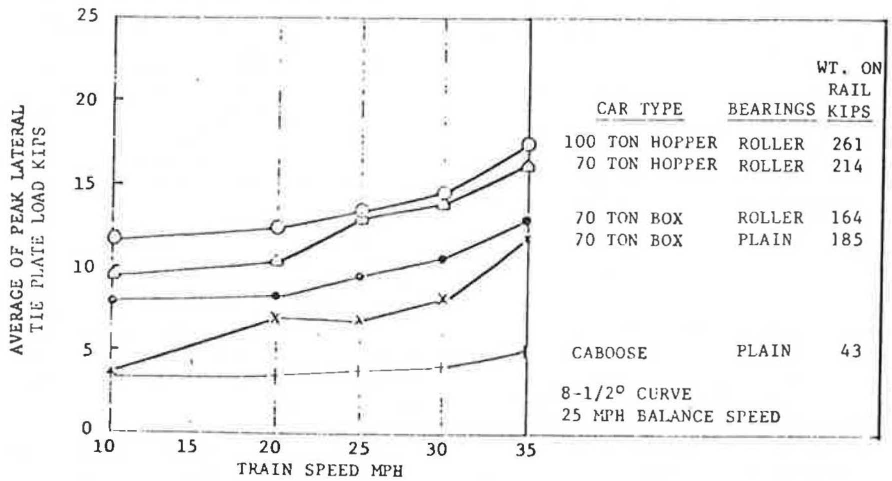

FIGURE 3 Lateral tie plate loads developed by freight vehicles.

comes into focus when compared with the lateral loading developed by various freight vehicles, as shown in Figure 3. Again, some strong conclusions were drawn:

1. Lateral forces developed by loaded 70- and 100-ton cars on roller bearings were comparable with those developed by four-axle locomotives,
2. A loaded car on plain bearings developed significantly lower lateral forces than a lighter car on roller bearings,
3. Increases in lateral force with increasing train speed were not as substantial for freight cars as they were for locomotives, and
4. The case against the six-axle locomotives was no longer circumstantial.

There was no quick and easy solution to the track strength problem. A track structure that had performed satisfactorily for years had become a maintenance problem within a few months. The structure was no longer optimum for the service. The six-axle units were kept off the territory. The Engineering Department at CN Rail was not particularly pleased because they recognized the increased severity of loading. The Transportation Department was not particularly pleased because of restrictions on their assignment of power. The locomotive manufacturers were not particularly pleased because of effects on sales. When enough people become displeased, changes occur.

RESEARCH TESTS, 1972

During 1972 CN Rail made a major test installation of 10,000 concrete ties west of Jasper, Alberta. The life of softwood ties with the conventional cut spike rail fastening system had become less than satisfactory for the high tonnages carried on the sharp curves. In the fall of 1972 CN Research, in conjunction with the Engineering and Equipment Departments, embarked on a comprehensive program to measure the curving performance of railway vehicles. It was recognized that there were four basic options available to the railways in dealing with problems concerning track maintenance on curves:

1. Run existing newer equipment at desired speeds on existing track and pay the penalty on track maintenance or higher risk of derailment; this was not a satisfactory solution;
2. Pay the penalty in train speed and vehicle weight reductions to affect savings in track maintenance and lowered derailment risk; this also was not a satisfactory solution;
3. Redesign trucks and wheels of vehicles to re-

duce lateral curving forces; and

4. Redesign and upgrade the track structure to cope with an increased severity of loading.

It was known that option 4 was unavoidable in the longer term, but that option 3 could provide some significant benefits in the shorter term. By using the instrumented base plates and the statistical measurement approach developed during the Quebec area tests, a large number of work train test runs were made over an 11-degree test curve in the Montreal Yard. Many conclusions were drawn from these tests.

1. Six-axle locomotives statistically developed significantly higher lateral forces on the high rail of the curve than did four-axle locomotives.
2. Six-axle locomotives with Heumann wheel profiles developed lower curving forces than those with standard new wheel profiles.
3. Increased lateral clearance in the center axle of three-axle trucks led to a significant reduction of curving forces in six-axle locomotives.
4. There was considerable scatter in curving force levels developed by a random selection of six-axle units within the fleet.
5. Lateral forces on 70-ton cars equipped with plain bearing trucks averaged 20 percent lower than they did on cars equipped with roller bearing trucks.
6. Lateral curving forces were directly proportional to vehicle weight on rail for any given car.
7. All vehicles equipped with average worn wheels generated lateral curving forces that were 25 to 30 percent lower than identical vehicles equipped with new wheels of the current standard profile.
8. Lateral curving forces of all vehicles were reduced by as much as 40 percent by a light rain, which reduced rail adhesion.

It was exceedingly clear that what was optimum track construction for four-axle units hauling mixed freight trains of 70-ton partly loaded cars on plain bearing trucks and worn-in wheels was no longer optimum track construction for six-axle units hauling new unit trains of 100-ton fully loaded cars on roller bearing trucks and new wheel profiles. In 1973 CN placed its first major order for concrete ties.

RESEARCH TESTS, 1982

In 1982 CN suffered wide gauge and track maintenance problems on sharp curves on the Mountain Park and Foothills Subdivisions in Alberta. The branch line carries rock and coal unit trains of 100-ton cars hauled by six-axle locomotives. Annual traffic was 4 to 5 million gross tons (MGT). To assess the severity of loading, measurements on 10- and 12-degree curves were taken in October 1982 with base plates on the high rail, instrumented gauge rods between rails, and displacement transducers to record dynamic gauge widening. For comparative purposes, similar measurements were also taken on a 6-degree curve on the main line.

Track construction on the 12-degree curve consisted of jointed 115-lb rail, 7 x 9-in. No. 1 softwood ties, 14-in. double shoulder tie plates, five cut spikes per plate, and gauge rods nominally spaced every fourth tie. Every second tie was box-anchored on the 2.5 percent grade. On the 10-degree curve rail was 100-lb jointed, ties were No. 1 and No. 2 softwood, and gauge rods were spaced every three to six ties. On the 6-degree reference main-line curve rail was 132-lb jointed, ties were 7 x 9-in. No. 1 softwood, tie plates were 14-in. double shoulder, two to three cut spikes per plate were used, and there were no gauge rods. There was moderate tie plate cutting, and static gauge was nominally 0.375 in. wide on the main-line track.

From the track measurements, several conclusions were drawn.

1. Gauge spreading forces measured under 100-ton freight cars on the 10- and 12-degree curves of the branch line were 2 to 5 times greater than those measured on the 6-degree main-line curve.
2. Gauge spreading forces on the sharp curves were consistently high under loaded unit trains running upgrade and downgrade, at speeds from 7 to 23 mph and under power or dynamic brake. It was concluded that the sharp curves in conjunction with the heavy freight vehicles were the primary cause of the high gauge-spreading forces.
3. In spite of five spikes per tie plate and gauge rods every fourth tie, dynamic gauge widening on the 12-degree curve was 0.5 in.
4. Although there were differences in force levels developed by loaded cars with different truck characteristics, the differences were not significant enough to pinpoint any particular vehicle characteristic as the cause of gauge maintenance problems.
5. The gauge-spreading forces developed by the six-axle locomotives on the 10- and 12-degree curves were consistently lower than those developed by the loaded 100-ton cars. This was directly attributable to the truck center axle clearance modification that had been implemented following the 1972 tests.
6. Measured gauge rod forces ranging up to 12,000 lb were sufficient to explain the gauge rod fatigue failures that had been occurring. The magnitude and repetitive nature of the track loading and rail lateral displacement signals generated by the uniformly loaded 100-ton cars in the unit trains pointed to fatigue stresses that were greater than the endurance limit of the softwood tie rail fastening system.

Recommendations were made that the gauge-retaining strength of track on curves of 6 degrees and greater on the two subdivisions should be increased, and that a series of laboratory fatigue tests to determine the relative strengths of various tie and rail fastening systems should be conducted. Both recommendations were accepted, and laboratory tests commenced immediately.

LABORATORY TESTS

Dating back to 1974 CN Rail Research had become heavily involved in concrete tie inspection, and over the intervening years it had conducted a myriad of tests to define the static and fatigue characteristics of the concrete tie and its rail fastening systems. One of the tests developed was an inclined loading fatigue test on the rail fastening system. The test setups are shown in Figures 4 and 5. Angles of loading ranged from 25 degrees where accumulated fatigue damage was too slow to 30 degrees where risk of rail tipping was too great to 27.5 degrees where a happy medium was finally struck. To accelerate destruction of components, the equivalent of a 100-ton car wheel load was applied to one rail seat. Vertical load was 32.5 kips, lateral load was 16.9 kips, and the lateral to vertical force (L/V) ratio was 0.52. Damage to concrete tie pads and insulators still did not resemble that observed in the field, and a 1,000-lb spring return force was added to the setup to more closely simulate actual rail movements. With this rather severe rail loading, it was now possible to generate component failures in hours and days compared with years in the field. Although pads and insulators could be destroyed, the

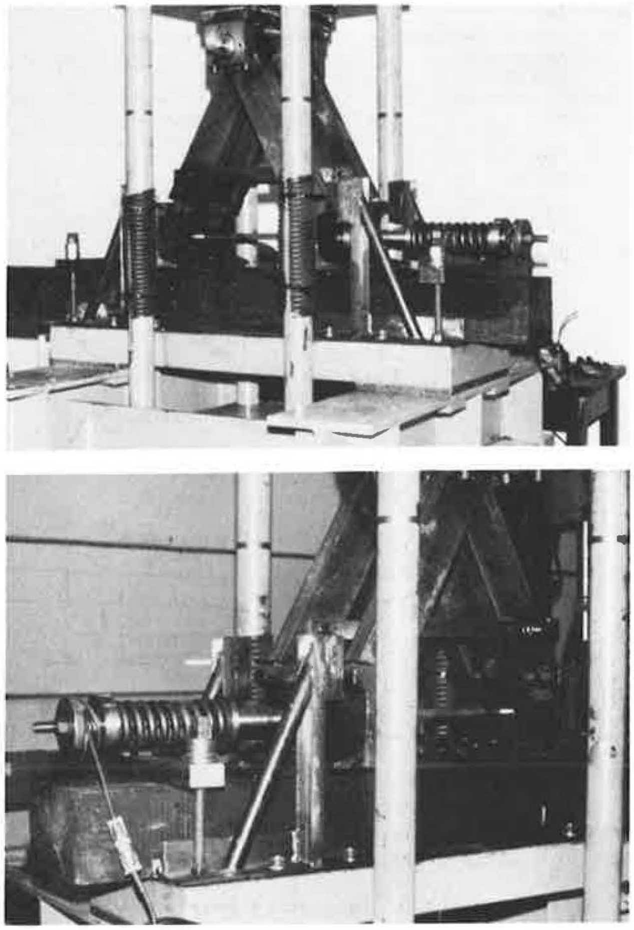

FIGURE 4 Fatigue test setup for loading two rails (loading 27.5 degrees, V = 32.5 kips, L = 16.9 kips, L/V = 0.52).

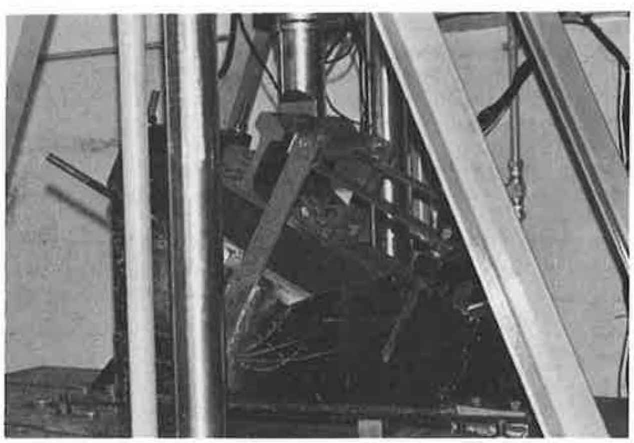

FIGURE 5 Fatigue test setup for loading single rail (loading 27.5 degrees, V = 32.5 kips, L = 16.9 kips, L/V = 0.52).

concrete tie with its cast-in shoulder showed only minor distress after 4 million cycles in one test, and no distress after 7.5 million cycles in a second test.

It should be noted that the laboratory test provides information on the relative fatigue performance of various rail fastening systems. The number of cycles to failure cannot be directly correlated with service track tonnage because many factors, such as climatic conditions, degree of curvature, traffic wheel load distribution, and train speed, affect the life expectancy of the tie and rail fastening system on any particular territory.

For the new series of tests on wood tie rail fastening systems, an arbitrary limit of 1-in. gauge widening was defined as failure. A summary of these tests is given in Table 1. On test 1, with a new No. 1 softwood tie, 14-in. tie plate, and five cut spikes per plate, failure was reached after 78,000 cycles. Gauge-side spikes had wiggled up from 0.5 to 2 in., and the field side of one of the plates had cut 0.75 in. into the tie. Initial rate of damage was slow, but as the system loosened the damage accelerated, with the result that the final devastating gauge widening occurred within the last few thousand loading cycles.

On test 2, with hardwood tie, 16-in. tie plate, double elastic spikes, and two cut hold-down spikes per plate, permanent gauge widening of only 0.09 in. was experienced after 543,000 cycles of loading. The test was terminated with no failure, and the apparent fatigue life as at least 7 times better than that of test 1.

On test 3, with hardwood tie, 14-in. tie plate, Pandrol weld-on shoulders, and four lag bolts per tie plate, gauge widening was less than 0.02 in. after 540,000 cycles, when the test was terminated.

On test 4, with hardwood tie, 14-in. tie plate, and five cut spikes per plate, permanent gauge widening of 0.52 in. developed after 4.02 million cycles of loading. The apparent life was 50 times greater than that obtained with similar rail fastening on softwood tie. Although this appears to be unbelievable, remember that with fatigue, being above or below the endurance limit or permanent damage threshold can make the significant difference between finite and infinite life.

To expedite testing, the second machine loading on only one rail fastening system was also used. It was run without the return spring. On test 5, with hardwood tie, 14-in. tie plate with weld-on Pandrol shoulders, and four lag bolts per plate, the tie plate fatigue failed under the field side of the rail after 60,000 cycles. This plate had 540,000 loading cycles from previous test 3.

On test 6, with hardwood tie, 14-in. tie plate with weld-on Pandrol shoulders, and four lag bolts per plate, the plate fatigue cracked under the field side of the rail after 310,000 cycles. This plate also had 540,000 cycles from previous test 3. The crack did not run through the weld.

On test 7, with hardwood tie, 14-in. tie plate, and five cut spikes per plate, the plate fatigue cracked under the field side of rail after 204,000 cycles.

On test 8, with hardwood tie, 14-in. tie plate, and five cut spikes per plate, the plate fatigue cracked under the field side of rail after 142,000 cycles.

On test 9, with hardwood tie, American Railway Engineering Association (AREA) 14.75-in. tie plate with Trak-Lok spring clips, and four cut spikes per plate, the plate fatigue failed under the field side of rail after 456,000 cycles.

On test 10, with hardwood tie, 14-in. tie plate with Pandrol hook-in shoulders, and two cut spikes per plate, the plate cracked under the field side of rail after 168,000 cycles.

On six tests in a row the tie plates fatigue cracked, and there was minimal gauge widening and plate cutting. The results were not satisfactory because tie plate fatigue failures are not common in the field. It is believed that softness in the jig may have permitted tie bending, which led to the plate cracking. The plate failures had nothing to

TABLE 1 Summary of Fatigue Test Results on Rail Fastening Systems

Test No.	Tie	Fastening	No. of Cycles (000,000s)	Comments
—	Concrete	Pandrol	4.5	Slight cracking of concrete around shoulders
—	Concrete	Pandrol	7.48	Concrete tie all right
1	Softwood	14-in. tie plate, 5 cut spikes	0.078	0.75-in. plate cutting on one tie, 0.97-in. permanent gauge widening
2	Hardwood	16-in. tie plate, elastic spikes, 2 cut spikes hold-down	0.543	Negligible plate cutting, 0.019-in. permanent gauge widening
3	Hardwood	14-in. tie plate, Pandrol weld-on shoulders, four 3/4 x 6 lag bolts	0.541	Negligible plate cutting, minimal gauge widening
4	Hardwood	14-in. tie plate, 5 cut spikes	4.02	Roughly 0.0625-in. plate cutting, 0.52-in. permanent gauge widening
5	Hardwood	14-in. tie plate, Pandrol weld-on shoulders, four 3/4 x 6 lag bolts	0.06	Tie plate cracked under field side of rail (had been used in test 3)
6	Hardwood	14-in. tie plate, Pandrol weld-on shoulders, four 3/4 x 6 lag bolts	0.31	Tie plate cracked under field side of rail (had been used in test 3)
7	Hardwood	14-in. tie plate, 5 cut spikes	0.204	Tie plate cracked under field side of rail
8	Hardwood	14-in. tie plate, 5 cut spikes	0.142	Tie plate cracked under field side of rail
9	Hardwood	14.75-in. tie plate, Trak-Lok clips, 4 cut spikes hold-down	0.456	Tie plate cracked under field side of rail
10	Hardwood	14-in. tie plate, Pandrol hook-in shoulders, 2 cut spikes hold-down	0.167	Tie plate cracked under field side of rail
11	Softwood	14-in. tie plate, 5 cut spikes	1.249	0.38-in. permanent gauge widening, tie plate cracked under field side of rail
12	Hardwood	14-in. tie plate, Pandrol weld-on shoulders, 4 drive spikes	1.463	Tie plate cracked near plate center, fatigue failed one spike 2 in. below head
13	Hardwood	14-in. tie plate, Pandrol weld-on shoulders, 4 drive spikes	1.722	Tie plate cracked under field side of rail

Note: Tests 1-4 were run on setup loading two rails, and tests 5-13 were run on setup loading single rail.

do with welding on the plate, the type of rail fastening, the CN 14-in. tie plate, or the AREA 14.75-in. tie plate. The plate-bending stresses were simply greater than the endurance limit of the steel, and failure resulted.

On test 11, with softwood tie, return spring now added, CN standard 14-in. tie plate, and five cut spikes per plate, the test was terminated after 1.25 million cycles. Railhead movement had increased from an initial 0.20 in. to a final 0.58 in., an increase of 0.38 in. The tie plate had small fatigue cracks running through the field-side spike holes and also some adjacent to the field-side rib. Tie plate cutting was on the order of 0.0625 in. Although spikes could be observed moving on each loading cycle, they had not wiggled up out of the tie to any extent.

This test 11 was actually a repeat of test 1, which had failed with 0.75-in. plate cutting after 78,000 cycles. There was a factor of 16 in the number of cycles to failure, and failure modes were not even similar. It is believed that this difference in results reflects some of the variables involved in wood quality and fatigue testing in general. Similar types of results are generated in the field, which is why it has been so difficult to categorically state that one tie rail fastening system is x times better than the next system.

On test 12, with hardwood tie, 14-in. CN tie plate with weld-on Pandrol shoulder, and four drive spikes per plate, the test was terminated after 1.46 million cycles when the tie plate cracked at the plate center. One of the gauge-side drive spikes had fatigued off about 2 in. below the head. Plate cutting was barely discernible, and there was virtually no permanent gauge widening.

On final test 13, with hardwood tie, 14-in. CN tie plate with Pandrol weld-on shoulders, and four drive spikes per plate, the test was terminated after 1.72 million cycles. The tie plate was cracked 0.5 in. from the field-side rib but toward the plate center, and one of the gauge-side drive spikes had fatigued off roughly 1.5 in. below the head. There was no visible plate cutting or permanent gauge widening.

After 6 months of laboratory work and an accumulation of roughly 11 million loading cycles spread over the 13 tests, the following conclusions were reached.

1. Failure of the wood tie and rail fastening systems was as a result of fatigue.
2. Discounting the tie plate fatigue cracking failures as an anomaly of the test and not representative of field experience, the following lives have been indicated: softwood ties--0.1 to 1.25 million cycles, hardwood ties--1.5 to >4 million cycles, and concrete ties--4 to >7.5 million cycles.
3. Clamping the rail to the tie plate with spring clips prevented the rail from banging back and forth between plate shoulders and reduced plate scuffing.
4. Clamping the tie plate to the tie with driven-solid spikes reduced plate movement and cutting. Spikes should be reseated following bedding-in of ribbed tie plates.

It would be unwise to draw solid conclusions from these few tests because hundreds of tests would have to be conducted before any confidence limits could be established. The results, however, can be added into accumulated engineering experience and used to help formulate judgments. Therefore, in the light of track measurements, laboratory measurements, and field experience, what would be the optimum track structure to install on the sharp curves of the 5 MGT per year coal branch line?

ECONOMIC ANALYSIS

It was at this point that the Research Department bowed out and the Engineering Department took over. An outline of some of the factors included in the economic analysis is given. Five tie proposals were evaluated:

1. Softwood tie, 14-in. tie plate with five cut spikes;
2. Hardwood tie, 14-in. tie plate with five cut spikes;
3. Hardwood tie, 14-in. tie plate with elastic spikes;
4. Concrete ties; and
5. Hardwood ties, 14-in. tie plate, weld-on Pandrol shoulders, and four drive spikes per plate.

Tie and hardware costs were determined based on 3,100 wood ties per mile and 2,640 concrete ties per mile. Installation costs, ballast costs, and surface operation costs were added to determine a total cost per mile for each proposal. For wood tie proposals, costs of rail anchors were included, as were transportation costs in moving hardwood ties from eastern to western Canada. For concrete ties, the cost of providing transition wood ties was included. Service lives were assigned to the proposals as follows: (a) concrete ties = 50 years; (b) hardwood ties, spring clips, drive spikes = 25 years; (c) hardwood ties, cut spikes = 12 years; and (d) softwood ties, cut spikes = 6 years.

Maintenance costs and cycles were included, with the track lined and surfaced every 3 years on wood tie proposals and every 5 years for the concrete tie proposal. Rail relay and transposing costs were determined for a 4-year rail life. It was assumed that concrete ties would not require renewal during the economic life of the study, and that 100 wood ties per mile would have be renewed each year.

A study period of 50 years was used in the economic analysis. Proposals were rated according to the net present value of each proposal at various costs of capital. A hurdle rate of 25 percent was used for economic decision making. Salvage values for various proposals at the end of the study were not included.

The most economical system was the hardwood tie with 14-in. tie plates and cut spikes. The next most economical system was the concrete tie. This was followed in order by the hardwood tie with elastic spike, the softwood tie with cut spike, and finally the hardwood tie with 14-in. tie plate, weld-on shoulder, Pandrol clip, and drive spike.

As a result, the hardwood tie with 14-in. plates and cut spikes now is standard in curves 4 degrees and greater wherever substantial numbers of 100-ton capacity cars are handled. Four degrees was chosen because there did not appear to be any derailments from spread gauge on curves easier than that.

But one exception was made. In curves 7 degrees and sharper on the Alberta coal branch line, hardwood ties with 14-in. plates, weld-on shoulders, Pandrol clips, and drive screws were installed.

CONCLUSIONS

Why, after all the work, was the most expensive system chosen? Call it engineering judgment. The rail on the sharpest curves of the Alberta line had a history of wearing out much more rapidly than is normal for curves elsewhere of the same degree carrying the same tonnage. No doubt wide gauge on the softwood ties did not help, but still everyone wanted to be sure that a system whose strength would not suffer from repeated pulling and redriving of spikes when changing rail would be chosen.

Concrete ties were out of the question because the normal high-production installation equipment could not work in the sharpest curves and because many of the sharp curves were quite short. It was discovered that short stretches of concrete ties inserted in wood tie territory exhibited unsatisfactory performance because of differences in dynamic track response. Thus the highest-cost alternative was the only alternative.

It cannot be stated that the optimum system has been selected. It can be stated that the new system has significantly greater fatigue resistance than the system that posed maintenance problems.

In February 1983 the engineer standards issued a general policy paper on timber ties for curves under heavy axle loads. Some of the conclusions and recommendations follow.

1. The softwood tie, as defined by the species bought in Canada under CN Rail specification, is not strong enough to take vertical and lateral loadings on curves of 4 degrees and greater where substantial tonnages of cars exceeding 220,000 lb gross are operated. This is true regardless of what type of tie plate and fastening are used.
2. The hardwood tie, as defined by species bought in Canada under CN Rail specification, has sufficient strength to take vertical and lateral loadings imposed by any engine or car permitted on CN Rail on tangents and curves, provided rail fastenings at least equal in strength to those specified in standard practice circulars governing spiking are applied.
3. Where existing softwood ties are known to be overloaded and spiked killed, spotting in hardwood ties among the softwood ties will shorten the life of the hardwood ties through excess lateral loading and will not yield the desired long-lasting track.
4. Based on current derailment statistics, there are no grounds for suggesting replacement of softwood ties by hardwood on tangents or curves less than 4 degrees.
5. Attempts at rating the lateral strength of the tie by visual means under current loadings in curves are likely to be incorrect and should no be relied on.
6. Softwood ties should not be used in new construction on curves 4 degrees and greater on any main tracks carrying cars exceeding 220,000 lb gross, or in such curves on any spurs, sidings, or yard tracks on which unit trains of 263,000 lb cars are handled. Any such tracks not qualifying for concrete ties should be built with hardwood ties.
7. A systematic program should be set up to change over existing curves of 4 degrees and greater that carry such traffic until all such curves that do not have concrete ties are equipped with hardwood ties.
8. On lines that demonstrably have a gauge-widening problem, all softwood ties on curves of 4 degrees and greater should be removed out of face and replaced with hardwood ties.
9. On lines that do not have a demonstrable gauge-widening problem, but otherwise meet the criteria for hardwood ties, hardwood ties could be interspersed with softwood ties on a temporary basis. No more than two softwood ties should remain between one or more hardwood ties, but no new softwood ties should be installed, and conversion should be completed within 3 or 4 years.

Optimum track construction is a variable dependent on degree of curvature, traffic density, and axle-load distribution. There are many tie and rail fastening system combinations available on the market that may qualify as optimum for any specific territory and service. The problem is to decide today on a track structure system design that will be providing satisfactory service performance in 20 years.

Therefore, more field measurements are required to statistically define the North American track loading spectra. Also, more laboratory fatigue testing is required to develop relative service lives of various track structure systems.

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

Timber Availability for Crossties

IRENE A. WATTERSON

ABSTRACT

The consumption of wood products in the United States has increased during the past 20 years and is expected to increase further during the next 5 decades. At the same time, the area of commercial timberland has slowly decreased and is expected to decrease even further. In spite of these general trends, available timber resources will meet requirements for current and increased levels of crosstie production in the near future because crosstie production is a relatively small portion of total timber products production. Crossties can be made from lower-quality and smaller-diameter hardwood trees that are not used in the production of other major wood products, and the supply of hardwood timber is increasing and will continue to increase. Following the year 2000, however, hardwood timber inventories are expected to decline and, at the same time, the demand for hardwood timber is expected to increase sharply, which will tend to increase timber prices.

The consumption of wood products in the United States has increased during the past 20 years and is expected to increase further during the next 5 decades. At the same time, the area of commercial timberland has slowly decreased and is expected to decrease even further. With increasing numbers of railroad crossties being installed, the availability of timber for crossties is a concern to the transportation industry. The purpose of this paper is to assess that availability.

GENERAL TRENDS AND PROJECTIONS

In 1980 the total volume of all wood products consumed in the United States was 15.6 billion cubic feet, a 37 percent increase over the 1960 consumption level (1). Between 1950 and 1972 growth in timber product use occurred mainly in softwood species such as pines, firs, and spruces, whereas the use of products made from hardwood species such as oaks, elms, and ashes declined. Since 1972, however, use of hardwoods increased dramatically, mainly as a result of increased demand for hardwood pulpwood and fuelwood. Hardwood products account for 30 percent of the total timber product consumption (1). Crossties are generally made from hardwoods.

The Forest Service, U.S. Department of Agriculture, projects an increase (2) in consumption of timber products during the next 5 decades, reaching a total volume of 25.8 billion cubic feet by the year 2030 (see Figure 1). The demand for hardwood products is expected to double (2), eventually accounting for 40 percent of total consumption.

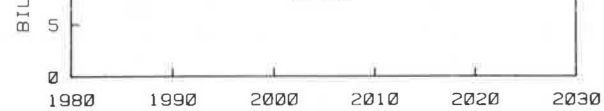

FIGURE 1 Projected demand for timber products to the year 2030.

Part of that increase will be in crossties. Annual crosstie installations by Class I railroads, though currently fewer today than in the 1940s and early 1950s, have also been increasing during the past 2 decades, despite reductions in track mileage (3,4). The number of ties installed annually increased 50 percent between 1960 and 1980. A small portion (3 to 5 percent) of these crossties are recycled ties and concrete ties. Most, however, are new wooden ties, which add to the continuing and increasing demand placed on forest resources.

However, the area of commercial timberland is decreasing. Since the early 1960s extensive forest land areas have been cleared for highways, cities, water reservoirs, and farmland. Between 1962 and 1977 the commercial timberland area decreased by 5 percent (5), although the volume of domestic consumption of timber products increased by 25 percent (1).