method, we stand to improve design and performance rather than hinder it.

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Comparison of Performance of Wood-Tie Fasteners at FAST

Howard G. Moody

The results of experiments with wood-tie fasteners at the Facility for Accelerated Service Testing are reported. Since the beginning of the use of 91-Mg (100-ton) freight cars, there has been an increasing problem with wood-tie fasteners. The resulting high axle loads have caused an increase in the deterioration of wood ties from spike killing and tie-plate cutting and have taxed the cut-spike fastener to the limit in preventing rail rollover and wide gage. The objective of the wood-tie fastener tests at the Facility for Accelerated Service Testing is to find an alternative to the cut spike that would alleviate some of the problems that have occurred in revenue service. Two test cycles have been completed, and a third is currently being run. In the first test, an excessive amount of rail wear, attributed to high flanging forces and a lack of effective lubrication, resulted in two rail transpositions. The rail was regaged each time, which eventually "spike killed" the ties. In the second test, in the elastic-clip segments, a large number of the hold-down fasteners failed, which resulted in wide gage. This led to a redesign for the current test to incorporate four hold-down fasteners, twice as many as in the second test. The results have not yet demonstrated that there is a wood-tie fastening system that will perform better than the cut spike. The results of the third test, however, may change this conclusion.

For the past 10-15 years, the increasing dynamic forces imposed on track by the 91-Mg (100-ton) cars on North American railroads have, in many instances, created conditions in which the traditional cut-spike fastener has not performed well. In particular, the heavy wheel loads in curved track have resulted in rapid rail wear, which has led to frequent transposition, relay, and replacement of rail. These maintenance activities and heavy axle loads have resulted in wide gage from spike-killed ties. In addition, it is apparent that on sharp curves the cut-spike fastener is less than optimal in preventing rail rollover and the looseness of the fastening system that can lead to tie-plate cutting.

Many railroads, including the Atchison, Topeka, and Santa Fe Railway Company, the Bessemer and Lake Erie Railroad Company, and the Canadian National Railway, have recently been testing alternative fastening systems in main-line track in curves that would resist gage widening and rail rollover, eliminate respiking, and restrain the rail longitudinally without the use of rail anchors. The systems that are being tested include a variety of elastic fasteners and compression clips that are designed to alleviate the problems associated with the cut spike.

At the Facility for Accelerated Service Testing (FAST), similar fastening systems and others that are not currently being used in revenue service are being tested to find the elusive alternative to the cut spike as a wood-tie fastener.

BACKGROUND ON FAST

A general description of the FAST track, the consist used, and the test conditions is given in the paper by Steele and others elsewhere in this Record. The diagram of the FAST track shown in Figure 1 pinpoints section 7, where wood-tie-fastener testing is being conducted.

A record of the traffic load accumulated to July 1979, before a major summer rebuilding, is shown in Figure 2. The traffic load to that date was 381 million gross Mg (419 million gross tons) (traffic loadings throughout this paper are in gross megagrams and gross tonnage). This rapid accumulation of load greatly accelerates the wear and fatigue life of the track components. Track components that might normally experience 27 million Mg (30 million tons) in revenue service in one year will accumulate 136 million-182 million Mg (150 million-200 million tons) at FAST.

In addition to the heavy traffic loads at FAST, other factors should be taken into consideration in evaluating FAST results in relation to revenue service. These factors are

1. The lack of flat wheels in the consist;
2. The speed range of 64-72 km/h (40-45 miles/h);
3. The 5- to 7.6-cm (2- to 3-in) underbalanced conditions in the curves;
4. The short test duration and relatively mild, dry climate, which tend to reduce environmental effects; and
5. The grade and track configuration of each test section with which comparisons are being made.

TEST DESCRIPTION

The wood-tie-fastener tests are conducted in section 7 of the FAST track, which consists of a 303-m (1000-ft) long, 5° reverse curve with a 0.07 percent grade that has been divided into test segments. Since the test section is a reverse curve and, as shown in Figure 3, the train speed through the curve is generally between 68 and 72 km/h (42 and 45 miles/h), the curve is one of the most severe environments at FAST. Histograms of the vertical and lateral forces produced by the consist operation are shown in Figures 4 and 5. These data were taken on the high rail. In this curve, with a 5- to 7.6-cm (2- to 3-in) underbalanced condition, the high rail has higher dynamic loads than the low rail. The mean lateral forces are greater for the lead axles, which is almost always the case in curved track.

The means and standard deviations for vertical wheel load (Figure 4) are as follows (1 kN = 224.8 lbf):

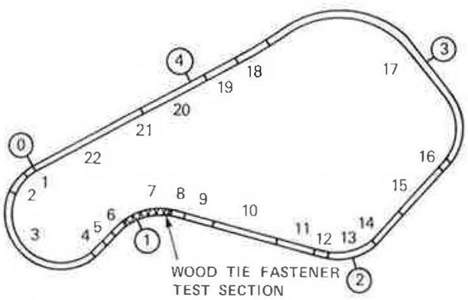
Rail	Mean (kN)	Standard Deviation (kN)
High	145.19	33.89
Low	122.73	27.09

The means and standard deviations for lateral wheel load (Figure 5) are as follows:

Axle	Mean (kN)	Standard Deviation (kN)
Lead axle, lead truck	40.57	14.72
Trail axle, lead truck	23.26	6.58
Lead axle, trail truck	46.44	14.01
Trail axle, trail truck	21.13	7.03

The primary intent of the wood-tie-fastener tests is to determine qualitatively and quantitatively the ability of different fastening systems to restrain the rail laterally and to prevent rail rollover. A secondary objective is to determine what types of fastener systems minimize tie-plate cutting and "spike killing" of ties in the test section. Each test sequence—and there have been three to date—is expected to last until there are component failures that cause wide gage throughout the test section or until there is a deterioration of the ties that results in a substantial number of ties being replaced.

Figure 1. FAST track.



One of the overall objectives of the FAST experiments is to permit comparison and evaluation of as many different components as possible while adhering to and maintaining statistically sound practices. In the wood-tie-fastener experiment in section 7, everything except the fasteners has remained the same from one test to another, with few exceptions. The ballast, curvature, grade, and continuously welded rail (CWR) have remained constant. Except for one case in the third test, the ties have also stayed the same.

Two sequences of tests have already been performed, and a third sequence is in progress. The past tests were used partly to establish which fastener components warranted further investigation and under what conditions further testing was required. The first test ran from September 1976 to September 1977 and accumulated a traffic load of 0-122.347 million Mg (0-134.582 million tons). The second test ran from November 1977 to November 1978, accumulating 122.434-326.007 million Mg (134.678-358.608 million tons). [In reality, the second test was effectively terminated in July 1978 at 249 million Mg (274 million tons).] The third test began in January 1979 at 326.55 million Mg (359.21 million tons).

All fastener types have been and will be compared with the performance of 35.5x20-cm (14x7.75-in) 1:40 American Railway Engineering Association (AREA) tie plates with 15x1.6-cm (6x0.625-in) cut spikes and conventional rail anchors.

In the first test, there were five 61-m (200-ft) segments. The second and third tests had (have) ten 30.5-m (100-ft) segments. The location of a particular test component within the curve may change, but there will always be at least a single test control segment that has the standard AREA plates and cut spikes. In general,

Figure 2. Accumulated traffic load.

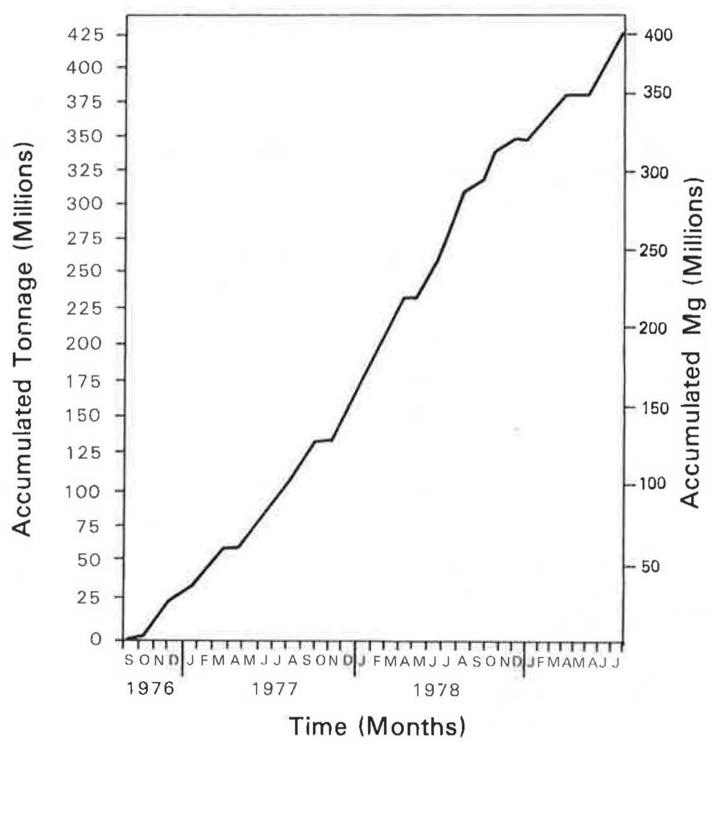


Figure 3. Track and locomotive-speed profiles.

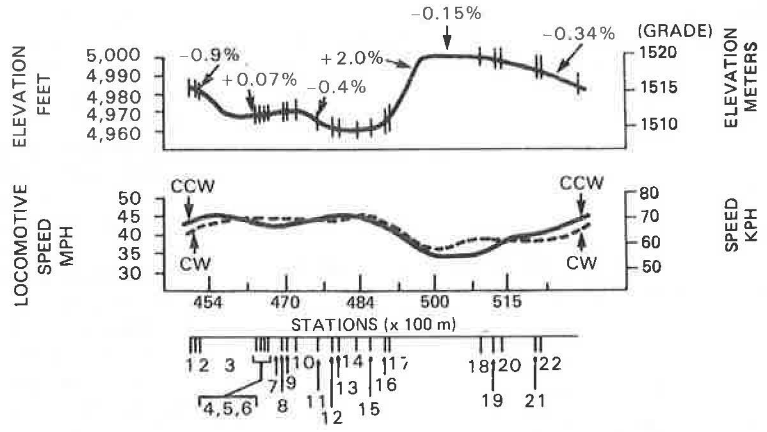


Figure 4. Vertical wheel loads.

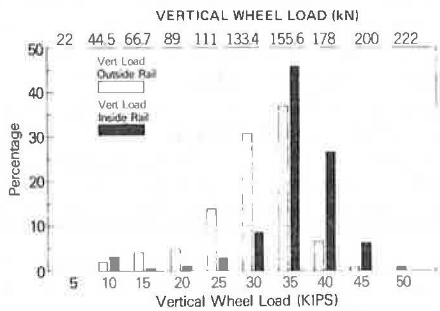
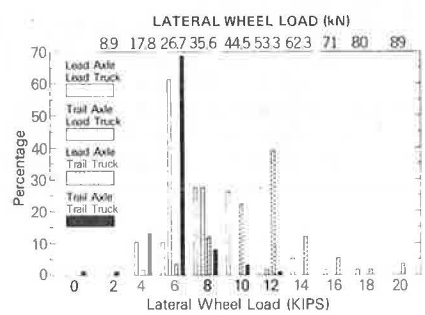


Figure 5. Peak value for lateral wheel loads.



all new test components are installed at one time to prevent differentiating effects caused by changes in operating variables. Failed components are replaced in kind from the same lot of components.

The experiment design is intended to limit the number of controlled variables that affect fastener performance. Ties are selected for the test from the same species and if possible from the same treatment lot. All of these ties are new. The ballast cross section is constant throughout the test section. As a result, there should be uniform track support conditions throughout the test section. To achieve this, a high degree of track maintenance is performed in section 7 so that anomalies of track geometry that could affect fastener performance will not occur.

A 30.5-m (100-ft) test segment contains 61 or 62 ties on 49.5-cm (19.5-in) centers. Each segment can be considered to consist of a central test zone isolated from the adjacent segments by transition zones. If a sample of 30 ties in the central zone is accepted as statistically big enough to permit the drawing of valid inferences about a large population, and if each transition zone contains 6 ties, then the 30.5-m test-segment length is more than adequate. No measurements are taken in the transition zones.

Table 1 gives the layout for each of the three test sequences. The ballast is slag, and in the past two tests the rail has been 69.5-kg/m (140-lb/yd) RE CWR.

The properties of the test components that help to determine fastener performance are spring rate or resiliency, toe load, and fatigue strength. Because of the short test segments, toe load or fastener longitudinal restraint was not measured.

Several static and dynamic measurements have been taken in section 7 to meet the stated objective. These measurements are (a) static gage and gage point wear, (b) track geometry (gage only), (c) tie-plate cutting, and (d) vertical track modulus.

The static gage and track-geometry-gage measurements are similar in that they both measure the net gage widening under little or no load. The measurement of static gage and gage point wear is taken by using a standard gage bar to measure the gage and a snap gage device to measure the wear on the gage corner of the high rail. By subtracting the wear on the rail from the standard gage, a true value of track gage is obtained. These measurements are made at specified intervals in five locations in each segment. The measurement of track geometry gage is taken from the track geometry data as measured daily by the EM-80 track geometry car. It is a continuous measurement and serves as a check on the static gage measurement.

The measurement of vertical track modulus is used to define track support conditions by using the beam-on-elastic-foundation theory (because the equation is formulated in U.S. customary units, no SI equivalents are given), in which

$$k = \sqrt[3]{P^4/64EIY^4} \qquad (1)$$

where

k = track modulus (lbf/in^2),
P = applied load (lbf),
EI = stiffness of the rail (lbf/in^2), and
Y = deflection of the rail under load (in).

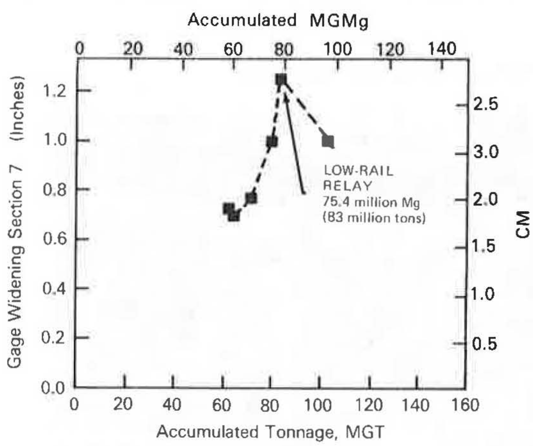
The dynamic measurements are (a) wheel-rail loads, including rail vertical load V and rail lateral load L; (b) dynamic gage widening; (c) lateral railhead deflection H; and (d) lateral rail-base deflection B. The dynamic measurements are used to characterize the dynamic load environment in each track segment. At one location in each segment, wheel-rail loads and lateral

Table 1. Layout of FAST section 7 for three wood-tie-fastener tests.

Segment	Tie No.	Type of Fastener
Test 1[a]		
1	001-123	35.5x20-cm 1:40 AREA A plate, four 15x1.6-cm cut spikes, box anchored every other tie
2	124-246	35.5x20-cm 1:40 AREA A plate, 15x1.6-cm cut spikes (two line) and lock spikes (two hold-down), box anchored every other tie
3	247-370	35.5x20-cm 1:40 AREA B plate, two compression clips, two 15x1.6-cm cut spikes
4	371-492	Plate and elastic clip, two lock spikes
5	493-616	35.5x20-cm 1:40 AREA A punch plate, 15x1.6-cm cut spikes (two line), screw spikes (two hold-down), box anchored every other tie
Test 2[b]		
1, 10	001-061, 553-616	35.5x20-cm 1:40 AREA B plate, three 15x1.6-cm cut spikes, box anchored every other tie
2, 6	062-122, 308-368	35.5x20-cm 1:40 AREA A plate, two compression clips[c], two 15x1.6-cm cut spikes
3, 7	123-184, 396-428	1:40 elastic-clip plate, two 2.7-cm screw spikes
4, 8	185-245, 429-490	1:40 elastic-clip plate, two 15x1.6-cm cut spikes
5, 9	246-307, 491-552	1:40 elastic-clip plate, two 1.9-cm cone-necked drive spikes
Test 3[c]		
1	001-060	Standard 35.5x20-cm 1:40 A punch plates; five 15x1.6-cm cut spikes; on gage side, one plate holding and two line; on field side, one plate holding and one line; every other tie box anchored
2	061-121	1:40 elastic-clip plates; four 0.8-cm screw spikes, one each corner of plate; one elastic clip each side of rail, diagonally opposite
3	122-182	1:40 elastic-clip plates; four 0.8-cm screw spikes, one each corner of plate; one elastic clip each side of rail, diagonally opposite
4	183-243	1:40 elastic-clip plates; four 1.9-cm cone-necked drive spikes, one each corner of plate; one elastic clip each side of rail, diagonally opposite
5	244-304	1:40 elastic-clip plates; four 1.6-cm lock spikes, one each corner of plate; one elastic clip each side of rail, diagonally opposite

Note: 1 cm = 0.39 in; 1 m = 3.3 ft; 1 Mg = 1.1 tons.
[a] All ties were 18-cm x 23-cm x 2.7-m southern yellow pine.
[b] Terminated May 8, 1978, at 198 million Mg.
[c] Ties for segments 1, 3, 4, and 5 are 18-cm x 23-cm x 2.6-m southern yellow pine; segment 2 ties are 18-cm x 23-cm x 2.6-m mixed hardwoods.

Figure 6. Static gage widening.



railhead and rail-base deflections are measured simultaneously at frequent intervals of approximately 23 million Mg (25 million tons). By using the lateral load and the deflection measurements, which are referenced to the tie, the rail and fastener spring rate or stiffness and the fastener's ability to resist rail rollover and gage widening are defined. The dynamic gage-widening measurement determines the widest gage that occurs during one passage of the consist at both the railhead and the rail base. Since it only measures the greatest excursion or spread of the two rails, it reflects a "worst-case" condition. These measurements are taken at five locations in each segment.

With the exception of the dynamic gage-widening measurement, none of the dynamic measurements were taken in the first two tests in section 7.

RESULTS

The first test was terminated in September 1977 after 122.347 million Mg (134.582 million tons) because of wide gage from spike-killed ties. This condition resulted from constant regaging, between 19 million and 29 million Mg (21 million and 32 million tons), during a period when the rail wear was very rapid, and again at 75 million Mg (83 million tons), when the low rail was relayed.

The high rate of rail wear in the first 29 million Mg was a result of a lack of lubrication. In section 7, almost 1.9 cm (0.75 in) of wear in the high-rail gage corner occurred in this early period. At 29 million Mg, the rail was transposed. After another 45 million Mg (50 million tons), the plastic flow on the railhead in the low rail became excessive and rail from the bypass track was relayed into section 7. In addition, as Figure 6 shows, the track gage at this time was rapidly deteriorating because of the regaging done earlier. Consequently, when the rail was relayed, the track was regaged. After another 36 million Mg (40 million tons), the gage became increasingly difficult to maintain and gage bars were applied, which effectively terminated the test.

There were few component failures during the first test, and there was no tie-plate cutting in any of the test segments. Any comparison of the fastener groups in their ability to hold gage was confounded by the constant regaging.

Section 7 was rebuilt during October 1977, and the second test was begun in November 1977 at 122.434 million Mg (134.678 million tons). In this test, the component segment length was reduced to 30.5 m (100 ft), and replications of each segment were included to determine any position-in-curve effects.

The first component test that had to be terminated was associated with segments 2 and 6. The compression-clip bolt (see Figure 7 for installation) loosened, and the clip backed out of the tie plate and came off the rail. Sixteen clips out of 488 were removed by hand on March 9, 1979. In the next two months, several other clips backed out. Since it was difficult to reapply them, it was decided to terminate the test in segments 2 and 6.

A combination of events led to the termination of the test. Because the ties were not prebored, the surface

Figure 7. Compression-clip assembly.

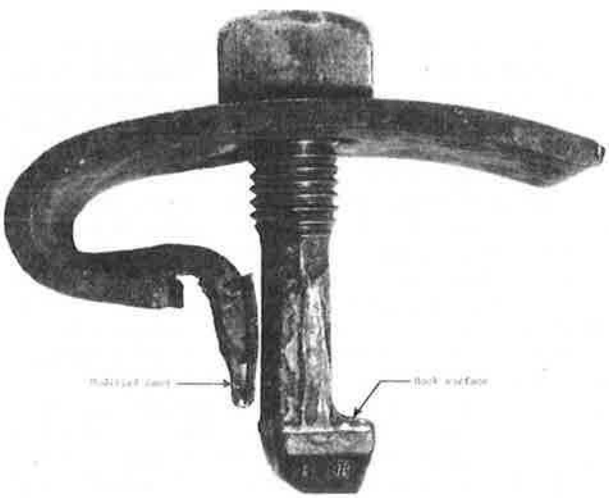


Figure 8. Modified compression clip and tie-plate bolt.

of the clip bolt hook (see Figure 8) did not always fit properly under the tie plate. The 1.9-cm (0.75-in) punched hole in the tie plates used in this test usually had a small radius on the edge of the hole that prevented the clip from fully engaging the bottom of the tie plate. This radius is a normal result of the hole-punching operation when the plates are manufactured. In addition, there was enough dimensional tolerance in the bolt and tang of the clip to allow the bolt to back out of the punched hole in the plate when the punched hole was slightly worn.

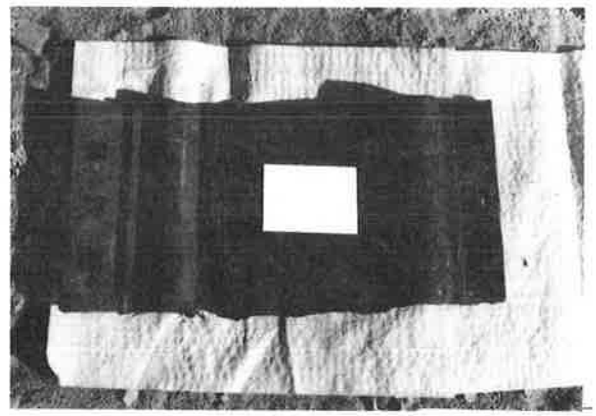


Figure 9. Failure of elastic-clip plate.

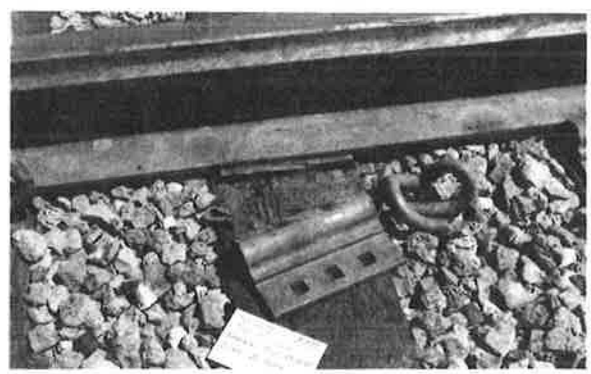


Figure 10. Failure of elastic-clip plate in track.

Table 2. Failures of wood-tie-fastener components in second test.

	Elastic Clip Out or Off				Broken Tie Plate		Spike Out 2.5 cm or More or Failed			
	Gage Side		Field Side				Gage Side		Field Side	
Component	Rail	No.	Rail	No.	Rail	No.	Rail	No.	Rail	No.
35.5x20-cm 1:40 AREA plate, three 15x1.6-cm cut spikes, box anchored every other tie	NA		NA		Inside Outside	0 0	Inside Outside	0 1	Inside Outside	0 0
38x20-cm 1:40 elastic-clip tie plates, two 2.7-cm screw spikes, two elastic clips	Inside Outside	2 1	Inside Outside	5 11	Inside Outside	10 2	Inside Outside	151 8	Inside Outside	10 4
38x20-cm 1:40 elastic-clip tie plates, two 15x1.6-cm cut spikes, two elastic clips	Inside Outside	2 5	Inside Outside	6 2	Inside Outside	22 19	Inside Outside	10 2	Inside Outside	4 0
38x20-cm 1:40 elastic-clip tie plates, two 1.9-cm cone-necked drive spikes, two elastic clips	Inside Outside	4 2	Inside Outside	2 1	Inside Outside	6 6	Inside Outside	9 25	Inside Outside	5 18

Note: 1 cm = 0.39 in.

Compression clips were used in the first test in section 7 without the occurrence of any of these problems. However, the clips used in the first test, as shown in Figure 8, had a 0.152- to 0.228-cm (0.060- to 0.090-in) shim tack welded to the tang on the compression clip. The clips used in the second test did not have the extra shim. It is felt that this modification effectively prevented the clips from backing out unless the nut on the bolt was loose enough for the tang to slip out from behind the bolt.

Early in the second test [the first failure occurred

Figure 11. Failed screw spike.

Figure 12. Screw spike out more than 2.5 cm (1 in).

Figure 13. Cumulative rate of screw-spike failures versus traffic load.

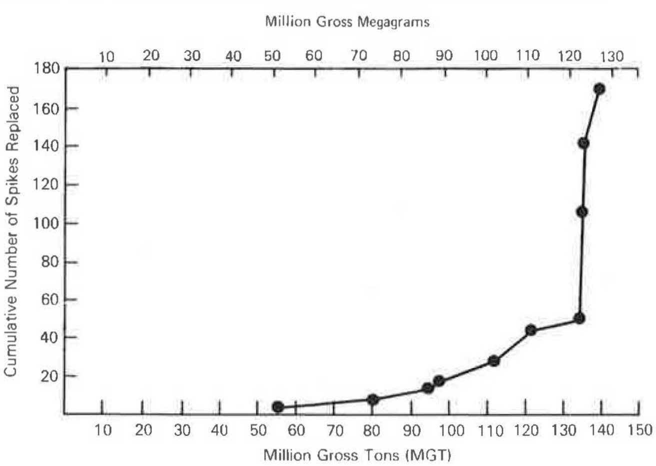


Figure 14. Static gage variation.

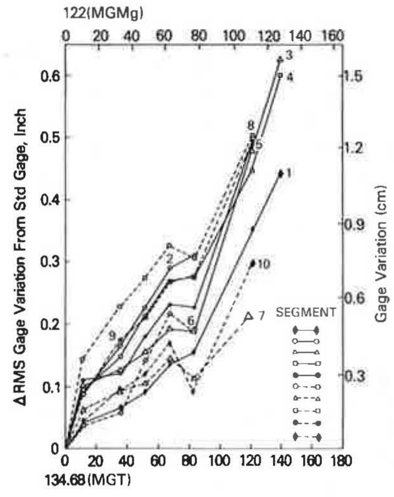


Figure 15. Mean dynamic gage widening.

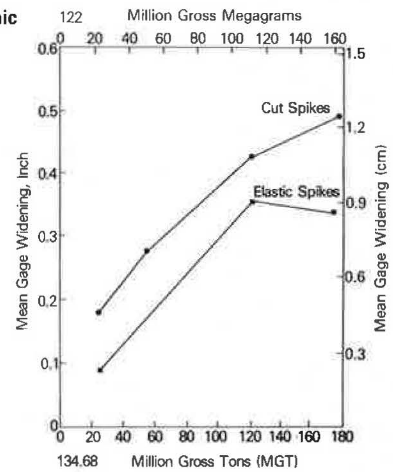


Figure 16. Railhead deflection.

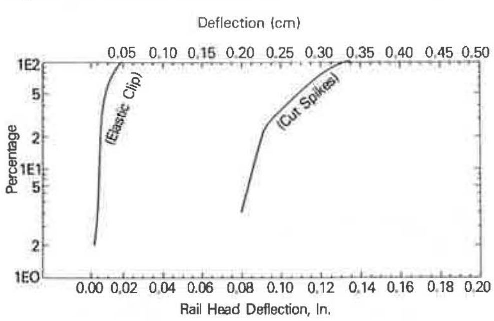
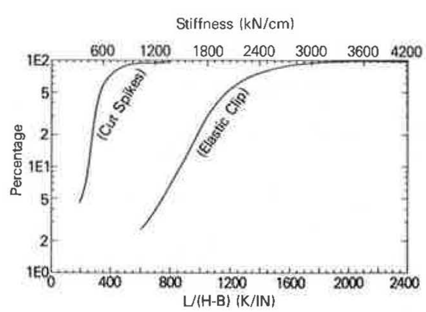


Figure 17. Fastener stiffness.



at 141 million Mg (155 million tons)], a few elastic-clip plates began to fail. These bending failures occurred at the lead edge of the plates where the outside of the rail edge contacted the plate (see Figures 9 and 10). As data given in Table 2 show, 65 of these failures occurred out of a sample population of 732 plates. Forty-one of the failures occurred in cut-spike segments 4 and 8. These were the original plates from the first test. By the time the second test was terminated, they had almost 12 million load cycles on them. There were not enough failures to determine a characteristic curve on the plate but, in contrast, over an accumulation of 213 million Mg (235 million tons), 38 AREA tie plates out of a lot of 22 120 failed.

It is not known whether or not these failures have occurred at all in revenue service and, since the choice of the hold-down fastener may have contributed to the failures, it is difficult to say whether or not this would occur outside of FAST. However, the manufacturer has since redesigned the plate to considerably increase the cross-sectional area in which the fractures occurred. These new plates should perform substantially better.

Beginning at 36 million Mg (40 million tons), the hold-down fasteners in elastic-clip segments 3, 4, 5, 7, 8, and 9 began either to work out of the tie or to fail. A complete tabulation of these problems is given in Table 2. These problems were most pronounced in screw-spike segments 3 and 7. In a period of 127 million Mg (140 million tons), 173 of 484 spikes in these segments either failed (see Figure 11) or came out of the tie more than 2.5 cm (1 in) (see Figure 12). A plot of the failure rate is shown in Figure 13. At about 118 million Mg (130 million tons), the failure rate began to escalate, eventually causing the test to be terminated at 128 million Mg (141.1 million tons).

The majority of the fractured screw spikes, drive spikes, and cut spikes failed in bending about 5-7.6 cm (2-3 in) below the head of the spike. When these failures occurred, the stub end of the spike was driven through the tie and a resin tie filler was used to fill the hole as a new spike.

The result was a deterioration in track gage. Figure 14 clearly shows that, except for segment 7, there was a rapid deterioration in gage after about 73 million Mg (80 million tons) of traffic [200 million Mg (220 million tons) overall]. The dynamic gage widening was also becoming severe, as shown in Figure 15.

The other problem of note in section 7 is elastic-clip fallouts, which are listed in Table 2. These are addressed in another FAST report and will not be discussed here.

It was evident from the results of the second test that the number and type of hold-down fasteners needed to be changed. Consequently, the number of screw and drive spikes was increased to four, and the cut spikes were replaced by lock spikes. In addition, a segment of hardwood ties with screw-spike fasteners was added to duplicate a similar test in revenue service.

Early data taken in section 7 on railhead deflections (see Figure 16) and comparisons of rail fastener stiffness [L/(H-B)] (see Figure 17) indicate a substantial difference in the responses of cut spikes and one kind of elastic clip. Relative railhead movement is much greater with the cut spike, which results in more gage widening, as Figure 15 shows. However, the rigidity of the elastic clip puts a premium on providing adequate hold-down capacity between the tie plate and the tie. In the second test, it was obvious that there were not enough fasteners of this type.

SUMMARY

The results of wood-tie-fastener testing at FAST to date have shown that the alternative elastic clip or compression clip has not performed better than a conventional cut-spike fastener. The dynamic effects of traffic on each system are much different, which indicates that different design considerations must be taken into account. The elastic clip puts a premium on the type and number of hold-down fasteners used to hold the tie plate to the tie, whereas the cut spike allows so much rail movement that there is a greater probability of gage widening and, as has been demonstrated in revenue service, a likelihood of spike-killed ties. Given these basic conditions and the results of the second test, the current test is much more likely than the second test to result in an adequate design alternative to the cut spike.

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Development of an Analytical Approach to Track Maintenance Planning

A. E. Fazio and Robert Prybella

Current research being conducted in a joint effort by the Consolidated Rail Corporation and the Federal Railroad Administration to develop an integrated maintenance-of-way planning model is reported. To develop a rational plan for maintenance-of-way expenditures, it is necessary to predict the effect of increased "basic" track maintenance on the requirement for "discretionary" maintenance. Basic (routine) track maintenance is performed by small, labor-intensive section and subdivision gangs. Discretionary track rehabilitation is performed by large, mechanized track maintenance gangs that move about the track system. Basic-maintenance gangs generally complete a particular task at a higher unit cost than discretionary-maintenance gangs. The frequency of the discretionary-maintenance cycle varies as some function of the level of basic maintenance—i.e., as the level of basic maintenance is reduced, the interval between discretionary-maintenance cycles is shortened. The limiting case, in which basic track maintenance is restricted to complying with safety requirements, requires the most frequent performance of discretionary maintenance. For various reasons, it is generally desirable to fund basic maintenance at a level greater than this minimum.

One of the most serious problems currently facing America's railroads is the deteriorated track structure. For many years, as profit margins decreased, railroads reduced their operating costs by a somewhat subjective program of deferred maintenance. The absence