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CROSSTIE AND FASTENER TESTS AT FAST: 1988-1999

REPORT NO. R-937

RAFAEL JIMÉNEZ
DAVID DAVIS
M. CARMEN TREVIZO
SATYA SINGH

Transportation Technology Center, Inc.,
a subsidiary of the Association of American Railroads
Pueblo, Colorado

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13. Abstract

The Heavy Axle Load (HAL) implementation program began in 1988 with the objective of developing economically optimal and safe axle loads for North American railroads. This research is currently being conducted by the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), to examine the effects of increased axle loads on track and track components, subgrade, and structures, and to ensure that safe operations are not compromised as axle loads increase. The Tie and Fastener Test has been an integral part of the HAL program since its inception in 1988. This report compiles the results of tests that characterize the performance of cross ties under heavy axle loads. The program is sponsored by the AAR in partnership with the Federal Railroad Administration.

14. Subject Terms	15. Availability Statement
Wood Tie, Cross Tie, Rail Fasteners, Heavy Axle Loads	Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads P.O. Box 79780 Baltimore, Maryland 21279

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EXECUTIVE SUMMARY

The Heavy Axle Load (HAL) implementation program began in 1988 with the objective of developing economically optimal and safe axle loads for North American railroads. This research is conducted by the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), to examine the effects of increased axle loads on track and track components, subgrade, and structures, and to ensure that safe operations are not compromised as axle loads increase. The Tie and Fastener Test has been an integral part of the HAL program since its inception in 1988. This report compiles the results of tests that characterize the performance of cross ties under heavy axle loads. The program is sponsored by the AAR in partnership with the Federal Railroad Administration.

The effects of heavy axle loads are being examined at the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center (TTC) in Pueblo, Colorado. A FAST/HAL train is being operated on the FAST High Tonnage Loop (HTL), a 2.7-mile test loop. The HTL has three 5-degree curves with four inches of superelevation, one 6-degree curve with five inches of superelevation, and tangent sections. The train normally consists of 70 to 80 mostly 315,000-pound on the rail gondola cars and operates four days-per-week generating 3 to 5 million gross tons (MGT) per week. The Tie and Fastener Test zones are located in Sections 7 and 31, both of which are 5-degree curves, and in the 6-degree curve of Section 25. At a steady 40 mph, the train runs at 1.7 inches over balance speed in Sections 7 and 31, and at 1.6 inches over balance speed in Section 25.

The main objective of the Tie and Fastener Test is to quantify the performance of numerous tie types and fastening systems under 39-ton axle load traffic. An additional objective is to compare the results gathered during the 460 MGT logged in Phases I and II of FAST/HAL operations under standard three-piece trucks, to the results of Phase III testing using vehicles equipped with improved suspension trucks. These trucks provide the benefit of improved curving response with enhanced wheelset steering and resistance to truck warp.

Major Findings

The findings listed below have been grouped into these categories: Effect of Truck Suspension, Failure Modes, Effect of Species and Materials, Effect of Fasteners, FAST Test Section Effects.

Effect of Truck Suspension:

Truck suspension has been the largest single factor in tie performance during the HAL experiment. The use of premium suspension trucks with better steering capabilities has greatly improved the performance of all ties tested under 39-kip wheel loads.

- Improved-suspension trucks provided a reduction of about 50 percent in the average lateral loads as compared with standard three-piece trucks.
- The gage-widening rate over ties in the 5-degree curve was affected more by the reduced lateral load environment under the improved-suspension trucks during Phase III than by tie species type or fastening system.
- In the 6-degree curve, during standard-truck operations in Phase II, two hem-fir and two southern yellow pine subzones reached 1 inch over standard gage after 200 MGT. Two Douglas fir subzones reached the same limit after 360 MGT. These subzones were fastened with cut spikes.
- The gage-spreading strength degradation of softwood ties with e-clip and SAFELOK® fasteners under standard trucks was comparable to that of softwood ties with cut spikes under improved suspension trucks in Section 7 at 0.5 L/V static loads.

Failure Modes:

Gage widening is the largest cause of wood tie maintenance at FAST. Lateral loading resulting in gage widening, tie splitting, and spike killing are all seen. Vertical loading problems have been minimal, except at abrupt test section stiffness changes. The dry climate of southeastern Colorado prevents wood decay from being a significant factor.

- Tie-plate cutting has not been significant at FAST under improved trucks. Although cracks in ties have not been a major problem, most occur on the field side of high rails.

- The cracks originating at the high-side gage hold-down spikes on the majority of the Oak dowel-laminated ties have not affected track strength while in service for 470 MGT.

Effect of Species/Materials:

Under the more severe load environment of standard trucks, Oak hardwood tie performance, in gage widening, was superior to the performance of softwood ties. Under the more benign load environment of premium trucks, the performance of hardwoods and softwoods was equally good. Both achieved markedly improved gage widening performance. In addition, azobe and various laminated wood ties performed well, resisting gage widening under premium trucks.

- Ties in the 5-degree curve of Section 7 that have not required re-gaging during 920 MGT of service include:

  - Oak with cut spike, e-clip, and double elastic fasteners

  - Douglas Fir ties with cut spike and e-clip fasteners

- In the 6-degree curve, during standard truck operations in Phase II, two hem-fir and two southern yellow pine subzones reached 1 inch over standard gage after 200 MGT. Two Douglas fir subzones reached the same limit after 360 MGT. These subzones were fastened with cut spikes.

- Although higher than over solid hardwood tie track, the gage-widening rate over the mixed-specie subzone in the 6-degree curve, where three southern yellow pine ties were installed for every oak tie, was a low 0.07 inch per 100 MGT under improved-suspension trucks.

- There has been no significant gage degradation in the azobe cut-spike (520 MGT) and elastic-fastener subzones of the 5-degree curve in Section 31.

- During Phase III improved-truck operations, the average measured gage widening rate over the parallel-strand lumber ties with e-clips, the dowel-laminated oak ties with cut spikes, and both the vertical and the horizontal glue-laminated ties with cut spikes was comparable at about 0.02 inch per 100 MGT.

- Cedrite ties, spaced at 19.5 inches and held down with four screw spikes, were removed after 178 MGT during standard-truck operations due to rail-seat cracks in 90 percent of the 6-degree curve installation. The installation in the tangent test zone, spaced at 24 inches and held down with four screw spikes, remains in service after more than 400 MGT.

- Spruce ties, pre-drilled at 3/4 inch for screw-spike hold-downs, were removed from service after 3 MGT due to the number of screw spikes working out.

- The USPL plastic composite ties developed cracks originating at hold down screw spike holes due to the small size of the pre-drilled hole (5/8 inch). The cracks have not propagated during the past 100 MGT. The condition is not affecting track strength.

- The rough-sided USPL plastic composite ties, consolidated by over 10 MGT of traffic, provided 60 percent more lateral resistance in the Single Tie Push Test than wood ties under similar conditions.

Effect of Fasteners:

Under standard truck operations, use of elastic fasteners generally improved the gage-spreading performance of most ties tested. The effect is larger for low-density species and ties. Under the premium suspension truck operations, many more ties provide acceptable gage-spreading performance.

- The type of fastening system and the lateral load environment plays a greater role in determining the long-term degradation of gage-spreading strength than tie type or specie. The gage-spreading degradation rate of both Oak and Douglas Fir ties fastened with cut spikes was nearly five times greater than that of track fastened with e-clips during standard-truck operations in Section 7.

- The gage-spreading strength performance of softwood ties with e-clip and SAFELOK fasteners under standard trucks was comparable to that of softwood ties with cut spikes under improved suspensions trucks in Section 7 at 0.5 L/V static loads.
- Under improved-suspension truck operations, the number of hold-down cut spikes in three southern yellow pine subzones, where all the ties were 7″×9″x8′5″ and all had three rail spikes, did not affect the rate of gage widening.
- During standard truck operations, fastening system problems included loss of toe load, fractures of elastic fasteners and hold-down screw spikes working out, and fracturing below the tie surface.
- During improved truck operations, screw spikes in softwood ties continued to work out and some fractured below the tie surface. One elastic fastener type fractured regularly at two rail joint locations.
- With the cut-spike fastening system, increasing gage-spreading loads resulted in further weakening of gage-spreading strength. On the other hand, the elastic fastening systems tested provided increasing gage-spreading strength as gage-spreading loads were increased.
- Refitting the softwood ties in Section 25 with e-clips (originally installed with cut spikes) improved gage retention after re-gaging. Maintenance of the badly split ties increased, however, due to screw spikes working up. The splits were caused by the numerous rail changes; that is, rail defects that were removed and replaced in that test zone.
- Although the condition did not significantly affect track geometry or stability, tie skewing occurred in 19.5-inch tie-spaced track and in 24-inch tie-spaced track where double elastic fasteners were used in both cases.

FAST Test Section Effects:

The limited space available in curves for testing rail materials, rail maintenance policies, and crossties leads to an undesirable overlapping of component tests. The small size of the test sections in FAST and the lack of stiffness transition zones leave the tests vulnerable to the effects of uncontrolled variables such as rail breaks, bad joints, or other test section end effects.

- In the 5-degree test zone of Section 7, and the 6-degree test zone of Section 25, as much as 70 percent of the measured gage widening was attributed to rail wear.
- Numerous rail changes, due to rail defects in the 6-degree curve, was the cause of spike-killed ties during Phase II standard truck operation.
- Out-of-face surfacing and alignment of the Wood Tie and Fastener test zones at FAST is generally required at 100 MGT+ intervals.

Full life cycle testing of ties at FAST is often not practical due to the relatively benign climate. Decay is not a significant factor for FAST wood ties. Due to the climatic, subgrade, and operating conditions under which tests are conducted at FAST, including the use of improved-suspension trucks which significantly reduce the lateral load environment, the performance of the ties and fasteners tested may differ in revenue service.

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1.0 BACKGROUND

The Heavy Axle Load (HAL) implementation program began in 1988 with the objective of developing economically optimal and safe axle loads for North American railroads at the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center (TTC) in Pueblo, Colorado. The research is being continued by Transportation Technology Center, Inc. (TTCI) to examine the effects of increased axle loads on track and track components, subgrade, and structures, and to ensure that increasing axle loads do not compromise safe operations. The Tie and Fastener Test has been an integral part of the HAL program since its inception in 1988. This report compiles the results of tests that characterize the performance of cross ties under heavy axle loads.

Exhibit 1 shows the High Tonnage Loop, a 2.7-mile test loop at TTC's Facility for Accelerated Service Testing (FAST). The effects of heavy axle loads are examined at FAST by operating the FAST/HAL train on the HTL. The HTL has three 5-degree curves with 4 inches of superelevation, one 6-degree curve with 5 inches of superelevation, and tangent sections. The FAST/HAL train, which normally consists of 70 to 80 mostly 315,000-pound cars (39-ton axle loads), operates at night starting at 2200 hours and stopping at 0730 hours the following morning. It operates 4 days per week generating 3 to 5 million gross tons (MGT) weekly. The Tie and Fastener Test zones are located in Sections 7 and 31, both of which are 5-degree curves, and in the 6-degree curve of Section 25. At a steady 40 mph, the train runs at 1.7 inches over balance speed in Sections 7 and 31, and at 1.6 inches over balance speed in Section 25.

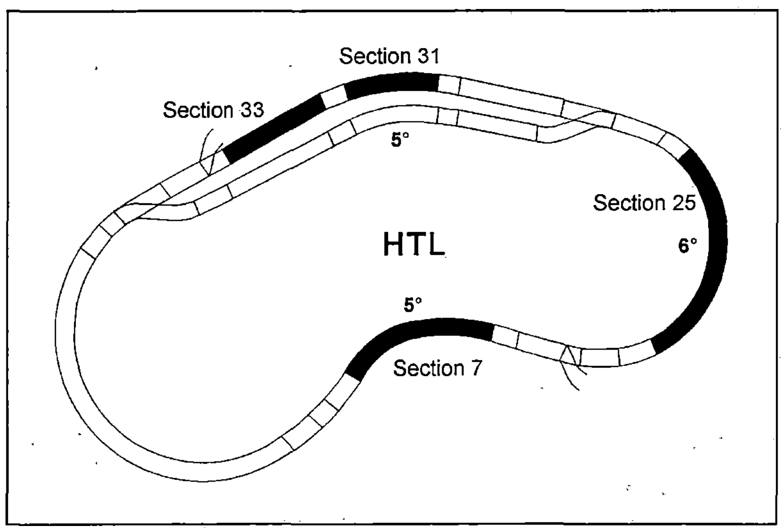


Exhibit 1. Wood Tie and Fastener Test Zone Locations on the High Tonnage Loop (HTL)

2.0 TEST OBJECTIVES

The main objective of the Tie and Fastener Test is to quantify the performance of numerous tie types and fastening systems under 39-ton axle load traffic. An additional objective is to compare the results gathered during the 460 MGT logged in Phases I and II of FAST/HAL operations under standard trucks, to the results of Phase III testing using vehicles equipped with improved suspension trucks.

3.0 FAST/HAL TEST PHASES

Phases I and II of the HAL program investigated track performance under 39-ton axle loads equipped with standard design three-piece freight car trucks. Results of Phase I indicated that 39-ton axle loads could operate on a standard track structure, but with increased track maintenance costs of approximately 30 percent. After 300 MGT of Phase II testing, results indicated that premium materials, especially head-hardened rail, concrete ties with dual durometer tie pads, high integrity frog castings, premium thermite welds, and hardwood ties with elastic fasteners would improve the efficiency and economics of 39-ton axle load operations.

Phase III of the program focused on determining the benefits of operating 39-ton axle loads with improved suspension trucks. An industry-wide truck-performance evaluation program, initiated during Phase II, resulted in the selection of three improved truck designs for Phase III operations. In November 1995, the FAST train was re-equipped with 75 car sets of improved suspension trucks. After more than 400 MGT, logged during Phase III, test results suggest that improved suspension trucks will substantially improve the economics of operating 315,000-pound freight cars. Benefits include a reduction of 20-25 percent in fuel consumption, doubling rail wear life on a 5-degree curve, and a decrease in gage widening in softwood ties of over 50 percent. In addition, lateral forces and wheelset angle of attack have been reduced significantly. Exhibit 2 lists the track component and suspension truck types used during the first three phases of FAST/HAL testing.

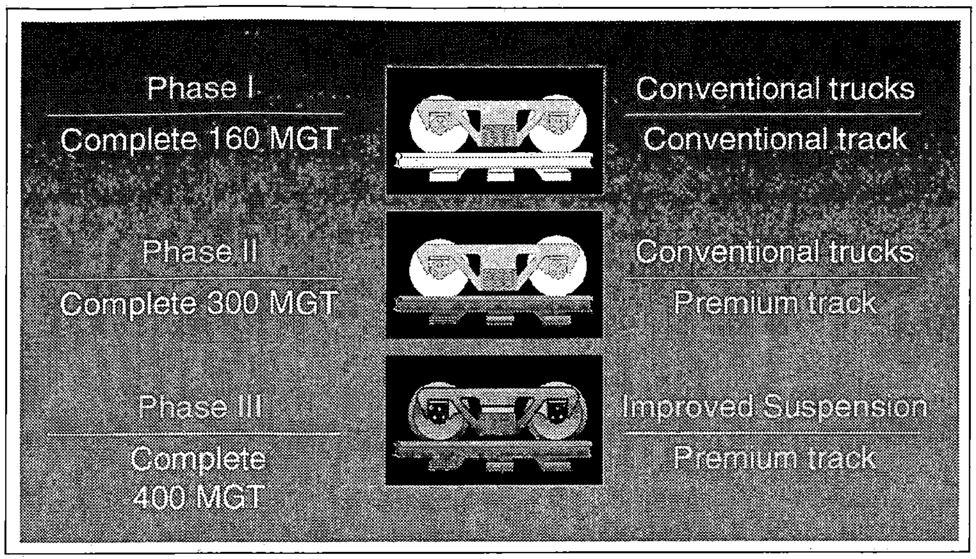


Exhibit 2. Track Component and Vehicle Suspension Truck Types during the First Three Phases of FAST/HAL Operations

4.0 FAST/HAL LOAD ENVIRONMENT AND LUBRICATION

When comparing the performance of ties and fasteners, it is important to consider the load environment. At FAST, instrumented wheelsets are used to measure dynamic vertical, lateral and longitudinal wheel/rail forces. They measure the loads "seen" by the test vehicle wheelsets as they travel along the changing geometry of the track.

During Phase II the load environments in Sections 7 and 25 were measured under the 39-ton axle load test vehicle that was equipped with instrumented wheelsets installed in standard three-piece trucks. For comparison, the test was repeated during Phase III with instrumented wheelsets installed in improved suspension trucks.

Section 7 is a 1,000-foot, 5-degree curve, with 300-foot spirals and 4 inches of superelevation. Train handling in Section 7 is typical of level running and the wheel/rail contact is conformal. Section 25 on the other hand, is a 2,700-foot, 5-degree curve with 300-foot spirals and 5 inches of superelevation. In Section 25, buff train handling conditions exist in the clockwise direction and draft in the counterclockwise direction. Section 25, which is also the site of the FAST Rail Grinding Test, contains rail profiles that include 2-point and conformal.

The consist used for the instrumented wheelset tests included one locomotive (263 kips), one instrumentation car, two buffer cars (315 kips), and one test car (315 kips) with 38-inch diameter instrumented wheelsets. In comparison, the test car used in the Phase II test was equipped with standard three-piece Super C-1 Wedgelock trucks. The test car used in the Phase III test had Buckeye Steel Casting improved suspension design trucks installed. The instrumented wheelset test consists ran in both clockwise and counterclockwise directions at 40 mph.

Typically, two wheelsets are installed in the same truck of the test car. Continuous vertical and lateral forces are processed from individual strain gage circuits on the wheels. Raw data is collected at a digital sample rate of 500 samples/second for each circuit and processed to produce the continuous data at the same frequency.

The Buckeye Steel Casting improved suspension trucks used for the Phase III test were designed for improved curving response with enhanced wheelset steering capability and resistance to truck warp. The design provides constant damping and is equipped with a D5 suspension, hydraulic dampers, and a primary suspension.

The lubrication policy on the HTL is to apply lubrication to the gage face of the high rail and light lubrication to the top of the low rail in all curves except the dry wear reverse curve in Section 7. However since the HTL is a closed system; i.e., a 2.7-mile loop of track with a captive fleet of cars, lubricant from the low rail of the other curves migrates to the dry wear zone and contaminates it somewhat. Since the Section 7 curve is the opposite direction from the other curves on the loop, in addition to cross tie test zones, it is also the site of the dry FAST Rail Wear Test.

Since lateral loads are less at the trailing axles, only the lateral loads at the lead axles of the lead trucks are presented here. Further, since train operations at FAST are conducted nearly equally in clockwise and counterclockwise directions, the values plotted in Exhibits 3 and 4 represent the average percentiles measured in both directions. Generally, Section 7 exhibits the lowest lateral loads and Section 25 the highest. Since the load environment of the Section 31 5-degree curve falls between that of Sections 7 and 25, it is not presented. The differential in running surface friction, due to high rail lubrication and rail profile, accounts for the higher lateral loading in Section 25.

Exhibit 3 compares the 50th percentile lateral loads measured on the high and low rails under standard and improved suspension trucks in Sections 7 and 25. The results show that on a typical (high rail and low rail) lateral load on the 6-degree curve in Section 25 under the standard trucks was approximately 8.1 kips. Compared to approximately 5.8 kips measured on the 5-degree curve in Section 7, the load environment of Section 25 was about 41 percent greater than that of Section 7 under standard trucks.

The use of improved suspension trucks during Phase III testing significantly reduced the lateral load environment; and thereby its effect on the performance of the crossties and fasteners tested at FAST. Typical median lateral loads decreased by about 57 percent in Section 7 under improved suspension trucks from 5.8 kips to about 2.5 kips. Similar results were seen in the Section 25 6-degree curve where the use of improved suspension trucks reduced the typical median lateral loads about 45 percent from 8.1 kips to 4.5 kips. Although the load environment was significantly reduced with the introduction of improved suspension, the loads measured in the Section 25 6-degree curve remained higher, at 4.5 kips, than those in the 5-degree curve of Section 7 at 2.5 kips.

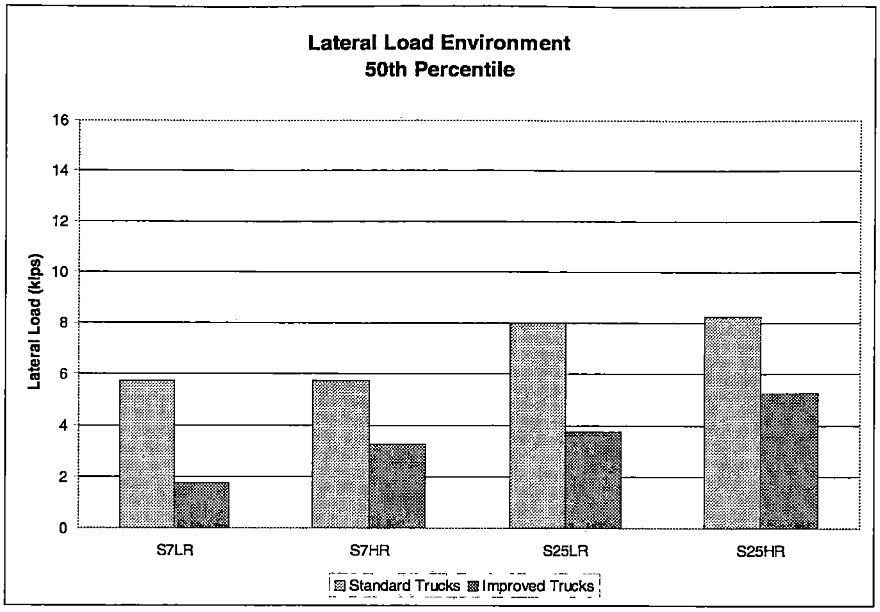


Exhibit 3. Median Lateral Loads on the High and Low Rails in Sections 7 and 25

As shown in Exhibit 4, at the 90th percentile the average lateral load (high rail and low rail) in Section 25 was about 13.3 kips under standard suspension trucks and 8.1 kips under improved trucks for a reduction of 39 percent. Similarly, the 5.5 kips measured in Section 7 under improved suspension was about 36 percent less than the 8.6 kips measured under the standard trucks.

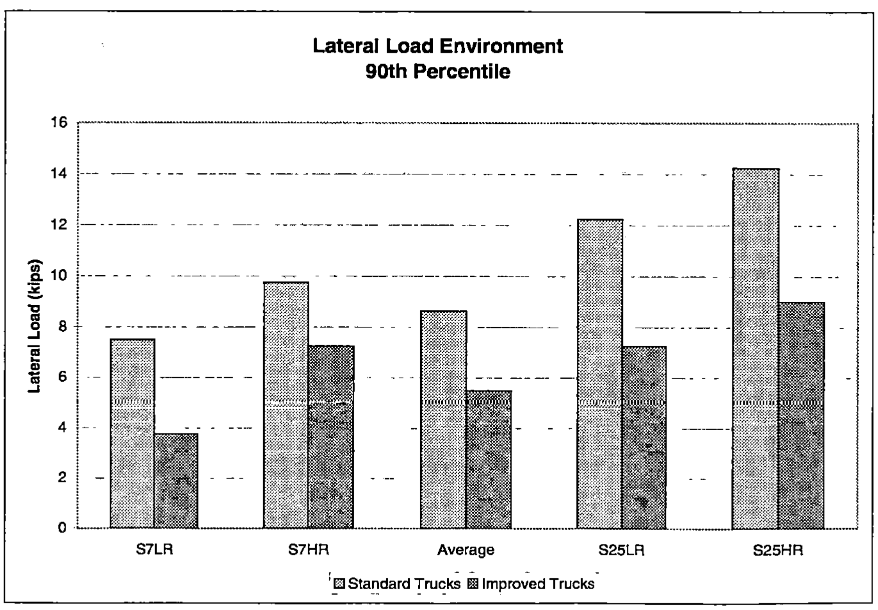


Exhibit 4. Lateral Loads at the 90th Percentile on the High and Low Rails in Sections 7 and 25

A summary of the lateral load environment and influencing operating conditions in the 5-degree curve of Section 7 and the 6-degree curve of Section 25 is shown in Exhibit 5.

Exhibit 5. Lateral Load Environment and Influencing operating Conditions in Sections 7 and 25

Wheel Load (kip)	Truck Type	Lubrication	Degree of Curvature	Operating Speed (mph)	Rail Profile	L_{50} (kip)	L_{90} (kip)
39	Standard	High rail slightly contaminated. Low rail light indirect	5	40	Conformal	5.8	8.6
		High rail gage face direct. Top of low rail light.	6	40	2-point	8.1	13.3
39	Improved	High rail slightly contaminated. Low rail light indirect	5	40	Conformal	2.5	5.5
		High rail gage face direct. Top of low rail light.	6	40	2-point	4.5	8.1

Where: L_{50} = Lateral load at the 50th percentile (average of the high and low rails) and L_{90} = lateral load at the 90th percentile (average of the high and low rails)

Exhibit 6 lists typical vertical loads in Sections 7 and 25. For the run presented here, V_L max = 56 kips occurred at Section 7 in the 5-degree curve on the low rail in the clockwise direction. V_L min = 40 kips occurred in the 6-degree curve on the low rail in the counterclockwise direction.

Exhibit 6. Typical Vertical Loads in Clockwise (CW) and Counterclockwise (CCW) Directions on the High (HR) and Low Rails (LR) in Sections 7 and 25

	50th Percentile Loads (kips)				90th Percentile Loads (kips)			
Section	HRCW	HRCCW	LRCW	LRCCW	HRCW	HRCCW	LRCW	LRCCW
7	38	44	48	44	43	52	56	50
25	43	48	43	36	48	54	47	40

5.0 TEST MATERIALS AND ENVIRONMENT

Due to the climatic, subgrade, and operating conditions under which tests are conducted at FAST, including the use of improved-suspension trucks which significantly reduce the lateral load environment, the performance of the ties and fasteners tested may differ in revenue service.

In addition to the typical solid-sawn wood and glue-laminated crossties, parallel strand lumber ties and plastic composite times are currently being tested.

According to manufacturer literature, Parallam® Parallel Strand Lumber (PSL) is a product of Trus Joist, and is manufactured at their plants located in Vancouver, BC, Colbert, GA, and Buckhannon, WV. Parallam PSL is primarily manufactured from Douglas fir and southern pine. Logs are initially debarked, conditioned, and peeled into veneer sheets. The veneers are dried and then stranded into 1/2-inch wide strips. At this point, the strands are coated with a waterproof structural adhesive conforming to the requirements of ASTM D-2559 for structural wood adhesives. After the strands are re-dried, they are randomly stacked into a billet form. The continuous mat is monitored to assure a consistent material density. The mate is then pressed to its final dimensions and is cured using microwave energy. Full billet dimensions of the finished product are 11″×19″×66′. Further chopping and ripping of the billet is possible, but certain sizes prove to be more economical than others.

U.S. Plastic Lumber Corporation (USPL) manufactures the plastic composite ties in test under the FAST program. According to manufacturer literature, the Duratie™ is a composite of recycled polymers, coated fiberglass, inorganic fillers, processing aids, and foaming agents to control product density. The primary source for the raw material polymer is high density polyethylene found in the post-consumer recycling stream. The tie's manufacturing follows fundamental plastic extrusion practices. Within these processes, the lower melt polymer materials are brought to their melting temperatures by the infusion of friction and external heat. The process continues with the introduction of pre-compounded fiberglass, fillers, and processing aids. Material formulations are controlled to maximize the fiber orientation for strength and stiffness along the extrusion axis. The hot flowing melt is transitioned from the extruder into specially designed and sized molds. Once filled, the molds are transported to several cooling states to transition the material into a hard crystalline state. Once cured, the material is purged from the mold and cut to the appropriate length. Both formulation and manufacturing process from the Duratie are protected through several Patents.

5.1 CLIMATE

The terrain surrounding TTC, located at approximately 5,000 feet mean sea level (MSL), consists of rolling plains, broken by normally dry arroyos, and is generally treeless, covered mainly with sparse bunchgrass and occasional cacti.

The climate is semi-arid and marked by large daily temperature variations. The normal daily high temperature is 69° F. It reaches 90° F or more about half the time during the summer, but is complemented by a low mean relative humidity of 50 percent. Temperatures reach 50° F or higher in the winter and drop to zero or below an average of eight times during the winter. The normal daily low temperature is 37° F. and the average annual snowfall is 31 inches. Cold spells are generally broken after a few days by Chinook winds, which are very dry, warm, downslope westerly winds. The mean wind speed is 9.6 mph. The probability of measurable precipitation in summer is one day out of four and one out of eight in winter. Annual rainfall is 11.9 inches. Summer rains usually occur in the form of afternoon thunderstorms.

5.2 SOIL AND BALLAST SECTION

Native subgrade is classified as loose to medium dense sandy silt. Ballast sections design geometry is similar in all the test zones consisting of slag, traprock, limestone, and granite. The ballast is typically 12 to 15 inches under tie with 12 to 15 inch shoulders at a 1.5:1 slope.

6.0 METHODOLOGY

6.1 TEST ZONES

The Phase I test zones shown in Exhibit 7, were installed in the 5-degree curves of Section 7 and 31, and the 6-degree curve of Section 25. The zones in Sections 7 and 25 were divided into subzones of 100 ties, each having a different rail fastening system or tie size. All but one subsection was made up of 80 hardwood (mixed hardwood) and 20 softwood (fir) ties. One hundred azobe (tropical hardwood) ties were installed in

Section 31 at 19.5 inch centers. Half of these azobe ties were equipped with American Railway and Maintenance of Way Engineering Association (AREMA) 14-inch tie plates with four cut spikes per tie plate, and the other half were equipped with AREMA 14-inch tie plates and double elastic spikes. An additional 80 azobe ties were installed at 24-inch centers, half with double elastic spikes and half with PANDROL® E-clip fasteners. All ties were installed using the same basic procedure: about 6 inches of ballast was removed beneath the ties using a Canron Track-Gopher; the existing ties were removed, and the pre-plated test ties were installed under existing rail. The track was re-ballasted and brought to final profile and alignment. All ties were new when installed.

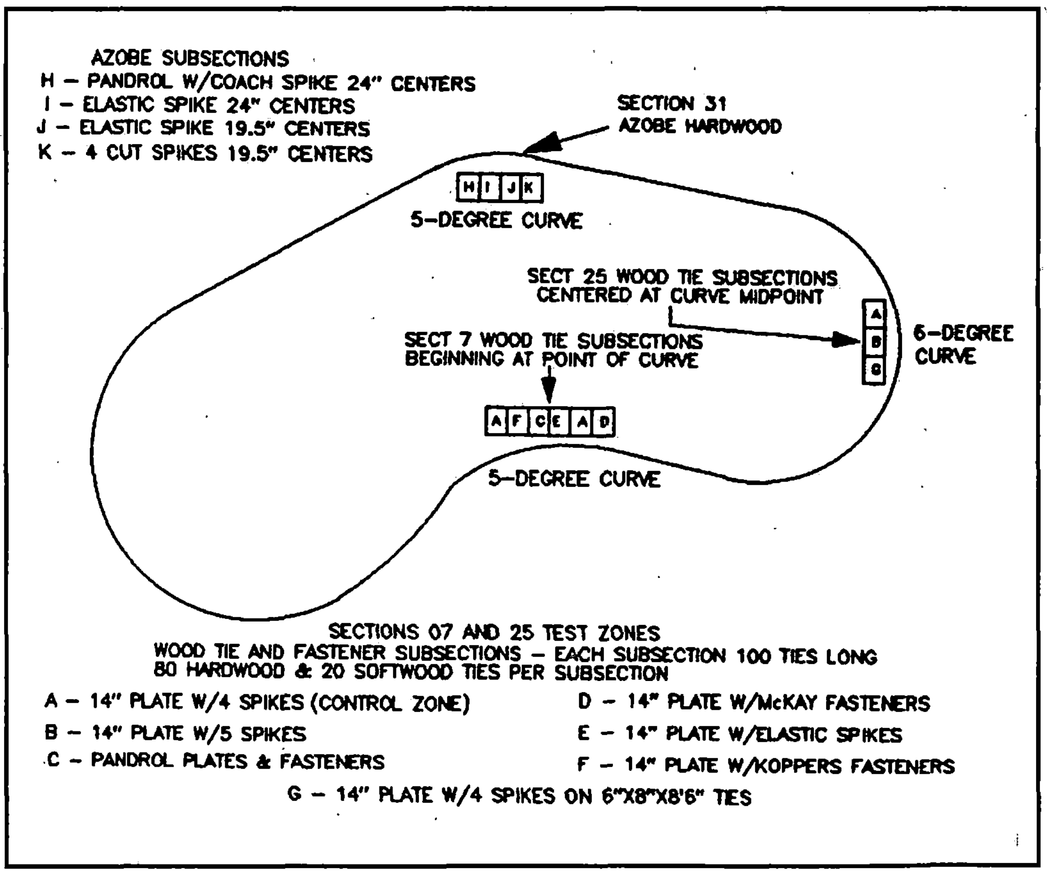


Exhibit 7. Location of the Wood Tie and Fastener Test Subzones on the HTL at the Start of Phase I

Phase II tests continued in the 5-degree curves of Sections 7 and 31 with the ties installed at the beginning of the test. At the start of Phase II, 100 Cedrite® reconstituted ties were installed in tangent Section 33. The Cedrite ties were installed at 24-inch centers with PANDROL E-clips and screw spike hold-downs.

The test zone in the 6-degree curve of Section 25 was expanded at the start of Phase II. Softwood tie subzones of hemlock fir (hem fir) and southern yellow pine were installed using cut spikes. In addition, subzones of red maple, red oak dowel-laminated, and Cedrite ties were installed. The oak laminated and part of the Cedrite ties were installed with PANDROL E-clips and lock spikes and the Red maple fastened with cut spikes. The original subzones of oak and Douglas fir, each with 4 and 5 cut spike segments remained in track.

Exhibits 8, 9, and 10 list the tie types, fastening systems, tie dimensions, and the accumulated tonnage of the Phase III Wood Tie and Fastener Test subzones. Exhibit 11 illustrates the fastening systems used in the various test subzones. In the 5-degree curve of Section 7, the oak tie subzones with cut spike, e-clips, and double elastic fasteners installed at the start of the test in 1988 are still in track, as are the Douglas fir ties with cut spike and e-clips. They have accumulated over 900 MGT. Alternative ties installed in Section 7 include laminated Southern yellow pine, Parallam PSL ties, and USPL plastic composite ties. All ties fastened with cut spikes are box anchored and all ties are spaced at 19.5-inch centers. Of the original 1988 installation, the oak ties are equipped with end plates, the Douglas fir are not.

Except for the oaks in subzone 11, which were installed in 1988, all ties and fasteners in the 6-degree curve of Section 25 have been installed since 1995 and have accumulated over 400 MGT. Of the oak and Douglas fir ties, 100 of each are fastened with cut spikes and 100 each with elastic fasteners. The alternative ties in Section 25 include oak dowel-laminated, vertical and horizontal laminated southern yellow pine, and Parallam ties. In this test zone, as in Section 7, all ties fastened with cut spikes are box anchored and all ties are spaced at 19.5-inch centers. End plates are installed on the original oak ties and the southern yellow pine ties.

The azobe ties that have been in track longest in the 5-degree curve of Section 31 have accumulated 500 MGT. One hundred are installed at 19.5-inch centers with cut spikes. The rest are installed at 24-inch centers – 37 with cut spikes and 41 with PANDROL E-clips. Every other tie of the 100 spaced at 19.5-inch centers and the 37 spaced at 24 inches is box anchored.

Fifty-three Cedrite ties are installed in the tangent of Section 33. They are spaced at 24 inches and are equipped with PANDROL E-clips and screw spike fasteners.

Exhibit 8. Details of the Subzones in Section 7 during Phase III

Section 7, 5;degree, 4-inch Superelevation, 614 Ties													
Tie Type	**Oak**	**Douglas Fir**	**Laminated/ SYP**	**Oak**	**Douglas Fir**	**Parallam/ Yellow Poplar**	**Oak**	**Oak Non-Test**	**USPL Plastic Smooth**	**USPL Plastic Modified**	**USPL Plastic Modified**	**Oak Non-Test**	**Oak**
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Tie No. (No. Ties)	1-80 (80)	81-99 (19)	100-200 (101)	201-279 (79)	280-300 (21)	301-360 (60)	361-398 (38)	399-429 (31)	450-474 (25)	475-476 (2)	477-498 (22)	499-558 (60)	559-609 (51)
Rail Fasteners	Cut Spikes	Cut Spikes	Cut Spikes	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	Double Elastic	Cut Spikes	PANDROL E-clip	Cut Spikes	PANDROL E-clip	SAFELOK/ Cut Spikes Mixed	SAFELOK
Hold Down	Cut Spikes	Cut Spikes	Cut Spikes	Lock Spikes	Lock Spikes	Screw Spikes	None	Cut Spikes	Screw Spikes	Cut Spikes	Screw Spikes	Spike Shoulder/ Cut Spikes	Screw Spikes
Anchors	All Boxed	All Boxed	All Boxed	None	None	None	None	All Boxed	None	None	None	None	None
End Plates	Yes	No	No	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes
Dimensions	7×9×8.5′	7×9×8.5′	7×9×8.5′	7×9×8.5′	7×9×8.5′	7×9×8.5′	7×9×8.5′		7×9×8.5′	7×9×8.5′	7×9×8.5′		7×9×8.5′
Date Installed	8/01/88	8/01/88	9/01/90	8/01/88	8/01/88	8/20/97	8/01/88	8/01/88	05/16/97	2/12/98	2/13/98	8/01/88	11/01/95
Tie Tonnage (MGT)	921.69	921.69	763.63	921.69	921.69	205.53	921.69	921.69	223.20	145.04	145.04	921.69	462.33

Exhibit 9. Details of the Subzones in Section 25 During Phase III

Section 25, 6-degree, 8-inch Superelevation, 1640 Ties																	
Tie Type	**Oak/Dowel Lam**	**Southern Yellow Pine**	**Southern Yellow Pine**	**Southern Yellow Pine**	**Southern Yellow Pine (3) /Oak Mix (1)**	**Douglas Fir**	**Southern Yellow Pine Vertical Laminated**	**Southern Yellow Pine Horizontal Laminated**	**Oak**	**Non-Test**	**Oak**	**Oak**	**Douglas Fir**	**Parallam/ Yellow Poplar**	**Oak Non-Test**	**Yellow Poplar**	**Southern Yellow Pine**
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tie No. (No. Ties)	-17 to 57 (75)	58-157 (100)	158-229 (72)	230-257 (100)	258-357 (100)	358-457 (100)	458-507 (50)	508-556 (100)	557-656 (100)	657-789 (133)	790-901 (112)	902-1001 (100)	1002-1101 (59)	1102-1160 (59)	1161-1202 (42)	1203-1305 (103)	1306-1404 (99)
Rail Fasteners	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	PANDROL E-clip	SAFELOK
Hold Down	Cut Spikes	Cut Spikes	Screw Spikes, LR 2 gage ,1 field HR 2 gage, 2 field	Screw Spikes, LR 1 gage, 1 field, HR 2 gage, 2 field	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Cut Spikes	Screw Spikes	Screw Spikes	Screw Spikes	Screw Spikes	Screw Spikes	Screw Spikes	Screw Spikes	Screw Spikes
Anchors	All Boxed	All Boxed	All Boxed	All Boxed	All Boxed	All Boxed	All Boxed	All Boxed	All Boxed	None	None	None	None	None	None	None	None
End Plates	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	Yes	No	Yes
Dimensions	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′		7x9x8.5′	7x9x8.5′	7x9x8.5′	7x9x8.5′		7x9x8.5′	7x9x8.5′
Date Installed	11/02/95	11/02/95	11/02/95	11/02/95	11/02/95	11/02/95	3/25/96	3/25/96	3/25/96	3/25/96	8/01/88	3/25/96	3/25/96	8/27/97	3/25/96	3/25/96	8/28/97
Tie Tonnage (MGT)	462.23	462.23	462.23	462.23	462.23	462.23	390.55	390.55	390.55	390.55	921.69	390.55	390.55	205.53	390.55	390.55	205.53
Fastener Tonnage (MGT)											394.40						

Exhibit 10. Details of the Subzones in Sections 31 and 33 During Phase III

Section 31. 5-degree, 4-inch Superelevation, 178 Ties				
Zone	**1**	**2**	**3**	**4**
Tie Type	azobe	azobe	azobe (24")	azobe (24")
Tie No. (No. Ties)	1-48 (48)	49-100 (52)	01-137 (37)	38-178 (41)
Rail Fasteners	Cut Spikes	Cut Spikes	Cut Spikes	PANDROL E-clip
Hold Down	Cut Spikes	Cut Spikes	Cut Spikes	Screw Spikes
Anchors	Every other boxed	Every other boxed	Every other boxed	None
End Plates	No	No	No	No
Dimensions	7'×9'×9'	7'×9'×9'	7'×9'×9'	7'×9'×9'
Date Installed	01/18/89	01/18/89	01/27/90	
Tie Tonnage (MGT)	512.52	512.52	450.91	450.91
Fastener Tonnage (MGT)		122.12	122.12	

Section 33, Tangent	
Zone	**1**
Tie Type	Cedrite (24")
Tie No. (No. Ties)	07-159 (53)
Rail Fasteners	PANDROL E-clip
Hold Down	Screw Spikes
Anchors	None
End Plates	No
Dimensions	7'×9'×9'
Date Installed	9/01/90
Tie Tonnage (MGT)	420.32

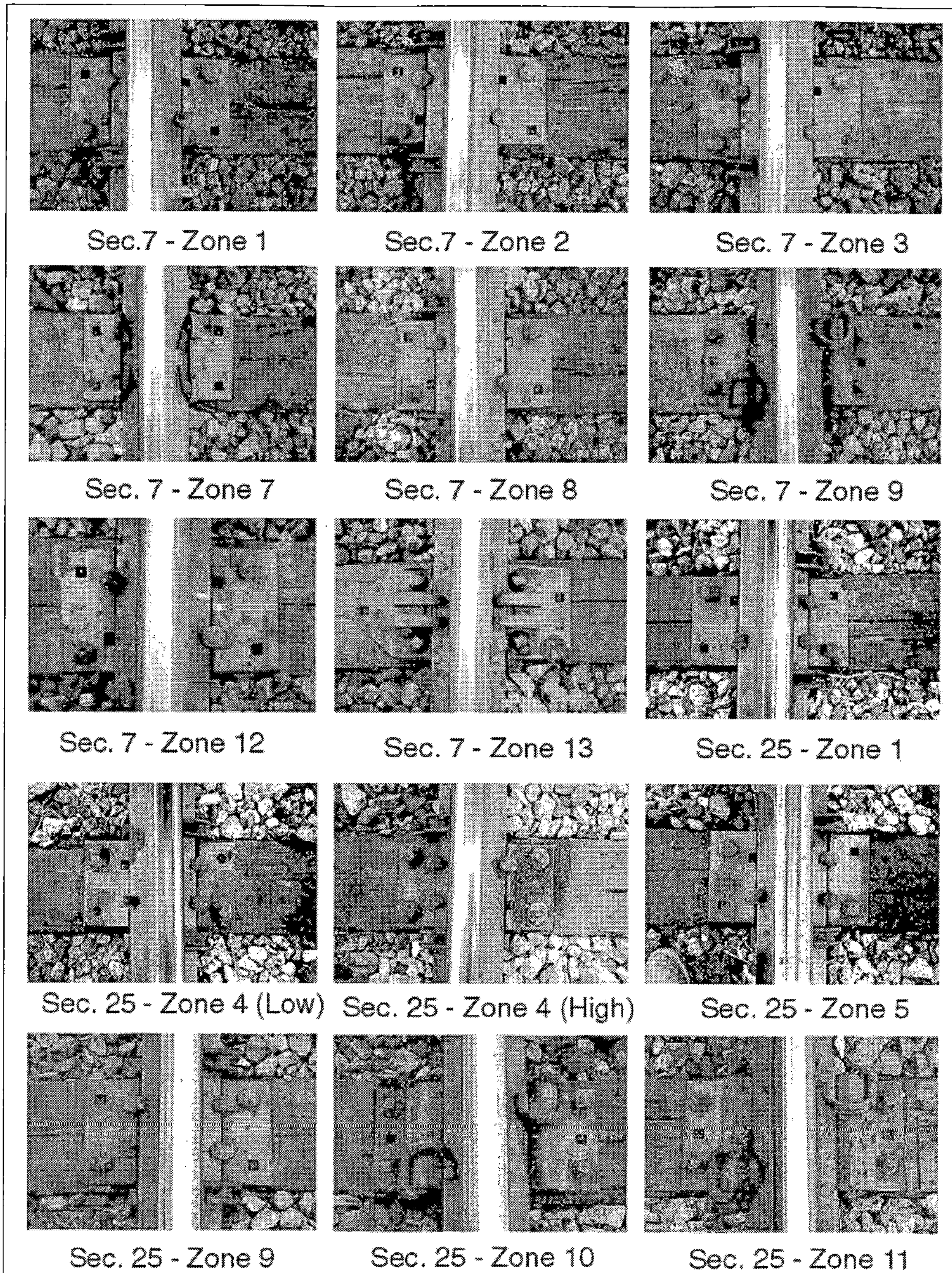


Exhibit 11. Fastening System Plan View of the Subzones Described in Exhibits 8, 9, and 10
(continued on next page)

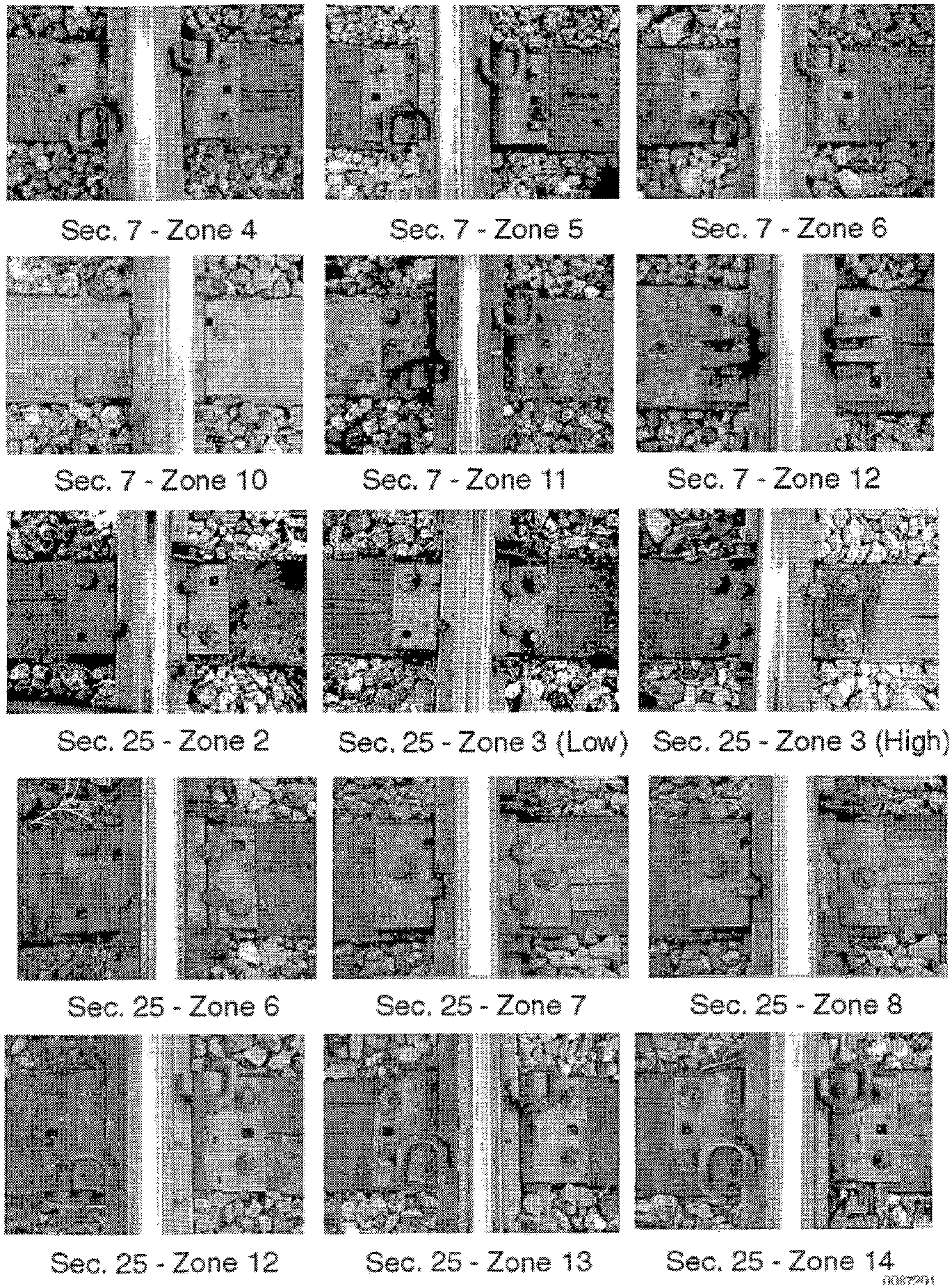


Exhibit 11 (continued). Fastening System Plan View of the Subzones Described in Exhibits 8, 9, and 10

6.2 GAGE RESTRAINT UNDER LOAD

6.2.1 Track Loading Vehicle (TLV) – Static / Dynamic Measurements

Track Loading Vehicle (TLV) measurements were used to compare the gage spreading response of various tie/fastener types to the application of simulated heavy axle loads. As seen in Exhibit 12, the TLV test consist is comprised of a locomotive, the AAR-100 Research Car, and the TLV. It is equipped with six servo-controlled electro-hydraulic actuators, a laser unloaded-gage measurement mechanism, and a split-axle wheelset loaded-gage measurement mechanism. The laser gage measurement system is located about 16 feet ahead of the centrally located split-axle wheelset. The TLV is operated from the AAR-100 Research Car which is equipped with the elecro-hydraulic actuator control system, a digital computer, data storage and display devices, analog-to-digital converters, keyboards, signal conditioning electronics, control-module electronics, and other hardware.

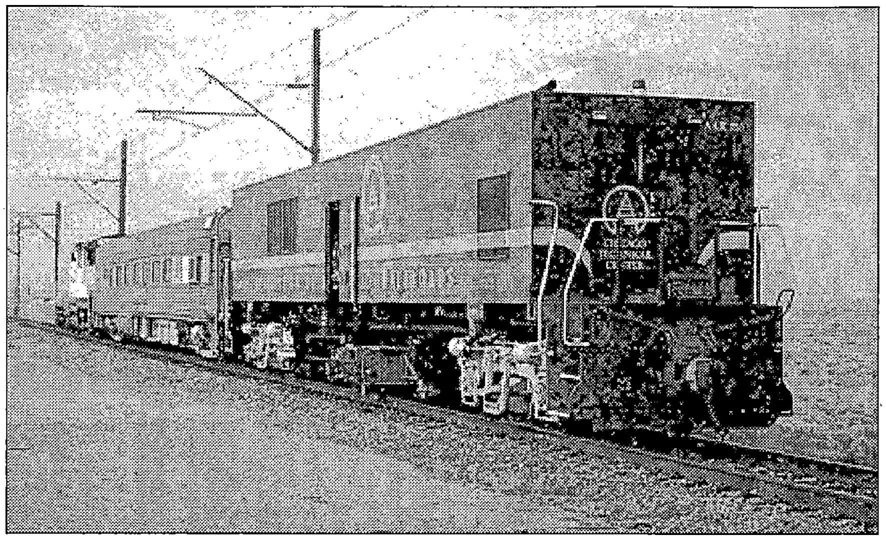


Exhibit 12. Track Loading Vehicle (TLV) Consist at TTC

The computer-controlled vertical and gage spreading loads were applied to the track structure by hydraulic actuators through the load bogie and the split-axle instrumented wheelset. The unloaded and loaded gages, as well as the gage spreading forces were measured continuously. The measurements were converted to digital format at a rate of 256 samples per second. The spatial differences in the locations of unloaded and loaded gage measurement devices, with respect to the loaded gage location at the split-axle wheelset, were compensated in the calculations by using the speed of the TLV at that instant.

The gage spreading loads used in the stationary tests varied from 2 to 26 kips under the 39-kip wheel load, a 0.05 to 0.7 lateral to vertical (L/V) load ratio. In-motion tests, run at 20 mph were made with gage spreading loads ranging from 10 to 24 kips under a 39-ton axle load, 0.3 to 0.6 L/V ratio. A 2-kip increment was used in the stationary and in-motion tests to arrive at the maximum gage spreading loads.

The resulting railhead deflections in the static tests were measured using wayside Linear Variable Differential Transformers (LVDT). Dynamic response was measured onboard at the gage spreading axle of the TLV.

6.2.2 Rail Force Calibration (605) Car: Static Measurements

The static and dynamic gage strength tests using the TLV were snapshots of track response to the applied vertical and lateral wheel loads. In comparison the Rail Force Calibration 605 Car (referred to herein as the 605 Car) measurements were used to look at the long-term degradation of gage strength with respect to traffic over the different tie/fastener combinations.

The 605 car is a converted ALCO locomotive redesigned to apply static vertical and lateral forces to the rail. Hydraulic actuators capable of applying a 40,000–pound vertical force to each rail and 20,000 pounds lateral gage spreading force are installed beneath the car body. Each actuator is equipped with a 50,000-pound load cell to output known force data. The car is used to calibrate rail mounted strain gage circuits that are designed to measure vertical and lateral rail force; determine vertical track stiffness; and determine lateral rail stiffness.

Lateral rail stiffness is used to quantify rail fastener performance as determined by measuring the lateral response of the railheads to the applied lateral and vertical forces. The static gage spreading 605 Car data reported here was acquired by maintaining a constant 40-kip vertical wheel load while applying a 20-kip lateral wheel load in 5-kip increments. The railhead deflection of both rails was measured and the sum defines the gage spreading strength. Data presented here represents the gage spreading response at a 0.5 L/V ratio (20 kip lateral / 40 kip vertical) as a function of MGT. Measurements were taken at five locations in each test subzone.

6.3 TRACK GEOMETRY DEGRADATION

The track geometry of the HTL is measured and recorded on a weekly basis. The gage degradation rate, in terms of inches per 100 MGT, for the various test subzones was calculated using Plasser EM80 track geometry car data.

The EM80 measures the following parameters:

- Profile from mid-chord offset from a 31-foot chord with 62-foot chord data calculated
- Alignment from mid-chord offset from a 31-foot chord with 62-foot chord data calculated
- Gage
- Cross level/Superelevation
- Twist over 31 feet and 11 feet

The profile, alignment, gage, and twist parameters are measured with rail contacting LVDTs and the cross level and superelevation is measured with an inclinometer. The car collects data at a rate of one sample per foot.

6.4 SINGLE TIE PUSH TEST (STPT)

Single Tie Push Tests (STPT) were conducted on the USPL plastic composite ties to compare the lateral resistance of single ties made of this composite material with that of typical wood ties.

Measurements were taken on five newly installed ties and on five ties after track consolidation (10+ MGT). The force required to push a single tie laterally through the ballast section was measured as a function of the tie displacement. Force was measured with a calibrated pressure transducer and displacement was measured with a displacement transducer (string pot). The lateral movement of the tie is typically between 3 and 5 inches. The force/displacement data was recorded with an XY plotter and the peak force required for the first inch of displacement is reported.

6.5 TIE WEAR TEST

An USPL plastic composite tie was subjected to 850,000 load cycles using the Tie Wear Machine (TWM) at TTC. The TWM is designed to apply a cyclic load to a short 136 RE rail section installed in fasteners attached to a tie.

The cyclic load consists of a nominal 22,000-pound vertical and 7,500-pound lateral outward resultant force followed by a 22,000-pound vertical and 3,750-pound inward resultant force. This loading sequence simulates the vertical rail seat forces and the pattern of outward (lead axle) and inward (trailing axle) lateral forces generated by a 39-ton axle load vehicle in a medium to high degree curve. The TWM operates at a rate of 200 cycles per minute. The tie is inspected for rail seat wear and fastener failure.

7.0 COMPONENT REPLACEMENT/OBSERVED BEHAVIOR

7.1 PHASE I

Phase I rail clip failures were limited to a Koppers prototype fastener in Section 7. During the initial 15 MGT, 23 of the 80 Koppers prototype installed in the softwood subsection lost toe load. At that point, the fasteners were removed from the softwood ties. The same prototype fasteners installed in the hardwood ties remained in service during the 160 MGT period with only 10 of the 320 clips failing. The typical failure mode on both hardwood and softwood ties was loss of toe load caused by the backing out of the U-shaped staple which served as the reaction device. Exhibit 13 shows a Koppers fastener in track.

During the 160 MGT accumulated in Phase I, there was no visual evidence of significant tie splitting in any of the test zones. The hardwood ties were equipped with anti-splitting devices (end plates) but the softwood and azobe ties were not.

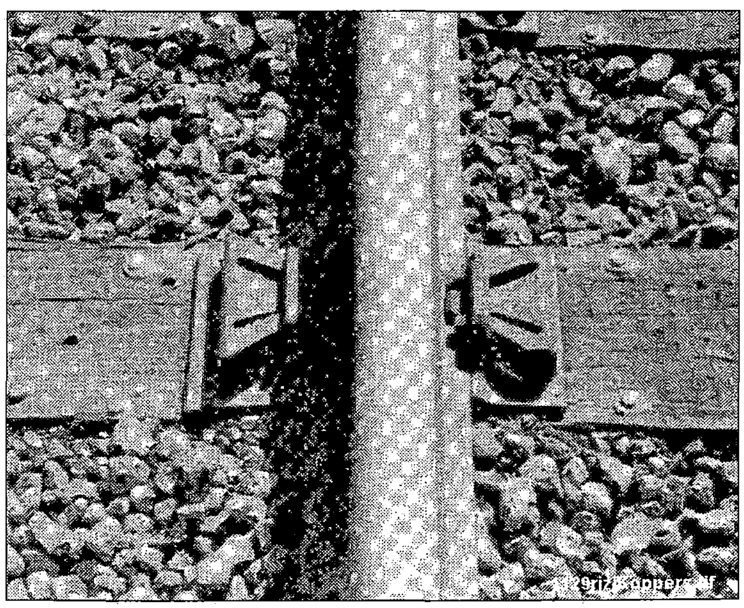


Exhibit 13. Koppers Prototype Rail Fastener

Tie skewing was evident in the double elastic spike subzone of Section 7 where tie spacing was 19.5 inches and in the Section 31 azobe subzone with double elastic spikes where spacing was 24 inches. Since the toe load of the double elastic spike fasteners is intended to provide resistance to skewing, rail anchors were not used. In neither case did the skewing significantly affect track geometry or stability.

In the cut spike subsections, excluding the azobe ties, longitudinal movement of the rail and anchored ties through the ballast section was observed during the initial 25 MGT of operations. The movement was noted in all curves and spirals of the HTL and was not a failure of the rail anchors but of the ballast in the tie cribs. By anchoring every tie, rather than every other tie, longitudinal rail forces were transmitted to the ballast section through twice the number of anchored ties and the movement ceased.

7.2 PHASE II

Cedrite reconstituted ties were tested in Section 25 during Phase II of HAL operations. Three test subzones were installed: one subzone was fastened with PANDROL E-clips and four screw spike hold downs; a second subzone was equipped with standard AREMA plates and four cut spikes; and the third test subzone was fastened with e-clips and four lock spike hold downs. Gage widening was not a problem with the Cedrite ties. Tie skewing, however, started a series of events that led to the eventual removal of all the Cedrite ties from Section 25.

Early in the phase, an attempt to straighten one of the skewed Cedrite ties resulted in cracking at the center of the tie. The subzone installed at the beginning of Section 25 was removed from test after 178 MGT of HAL traffic because 90 percent had developed cracks in the rail seat area.

After 124 MGT, numerous fractured lock spike hold downs were discovered in the Cedrite subzone at the end of Section 25. All the lock spike fractures occurred below the surface of the ties. When the manufacturer was informed, they suggested that perhaps it was necessary to have five lock spikes per tie plate when the track curvature is greater than 5 degrees. A fifth lock spike was installed.

In the same subzone, numerous ties became skewed. After 200 MGT, cracks were discovered on the PANDROL plates of the ties that were skewing. The skewing of the ties had pushed the PANDROL plates at an angle against the base of the rail initiating stress cracks at the plate corner that was in contact with the rail. To ensure that none of the cracked plates remained in track and to stop the ties from skewing, all the PANDROL plates were replaced with AREMA plates and cut spikes. All the ties were box anchored.

At the time the fastening system was changed, there were no visible cracks in the ties. After an additional 65 MGT of HAL traffic, however, the ties refitted with cut spikes and those in the subzone originally installed with cut spikes were removed when cracks in the rail seat area were discovered. The Cedrite ties in Section 25 were in track a total of 265 MGT with considerable maintenance requirements.

The Cedrite ties installed on tangent track at 24-inch spacing and fastened with PANDROL E-clips in Section 33 remain in service with over 400 MGT of HAL traffic and no significant maintenance requirements.

A red oak dowel-laminated tie subzone fastened with PANDROL E-clips and lock spike hold downs was installed in Section 25. Shortly after the installation, it was discovered that numerous lock spikes were fractured below the surface of the ties. Since this subzone consisted of laminated ties where installing a fifth spike was not possible due to the lamination, the lock spikes were removed and replaced with four screw spikes.

7.3 PHASE III

During Phase III, 100 spruce ties were installed in the 6-degree curve of Section 25 using PANDROL tie plates, e-clip rail fasteners, and four hold down screw spikes per plate. After approximately 3 MGT, the number of screw spikes that worked out of the ties was such that it was decided to remove the ties from test.

Phase III FAST operations between April 1996 and June 1998 accumulated 320 MGT of traffic on the HTL. During that period, the maintenance log indicates that less screw spike maintenance was required on the Douglas fir, southern yellow pine, oak, yellow poplar, and Parallam ties in the same 6-degree curve then would have been required on the spruce ties. Exhibit 14 is a drawing of a typical screw spike used at FAST. Pilot holes in softwood ties are 11/16-inch diameter; in hardwood ties they are 3/4-inch. Exhibit 15 shows that there are more screw spikes in oak ties (31 percent) than in any other specie. Only 2 percent of the screw spikes installed in oak required maintenance, whereas, 13 percent of those installed in Douglas fir were maintained. Maintenance of high rail screw spikes was required overwhelmingly more often than that of screw spikes installed on the low rail.

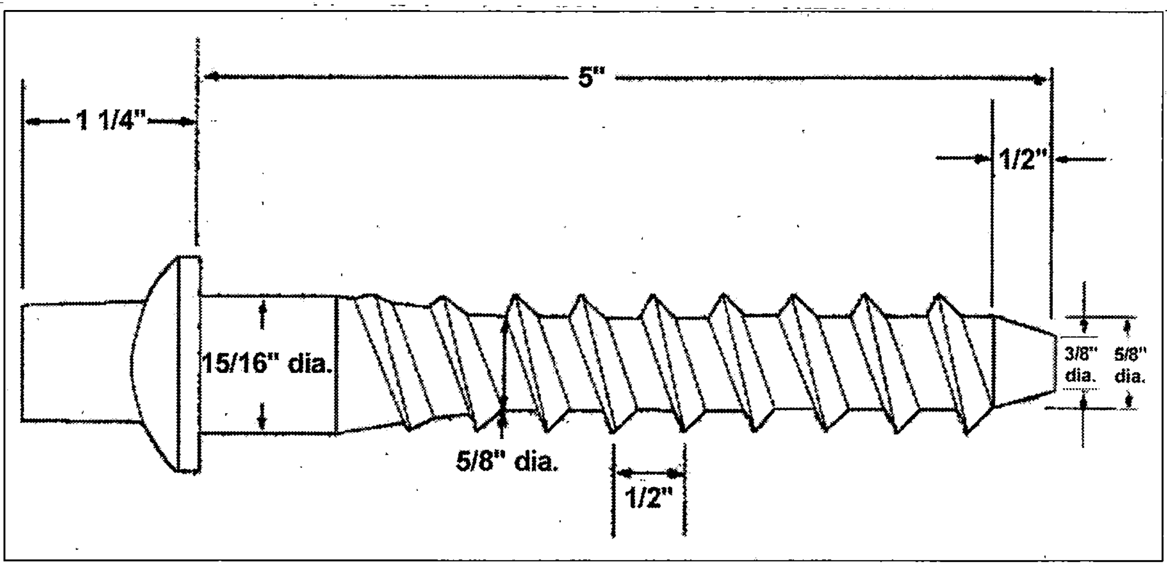


Exhibit 14. Pandrol® Drawing: Typical Screw Spike Used at FAST

Exhibit 15. Screw Spike Maintenance in the 6-degree Curve of Section 25 during a 320 MGT Period of Phase III Operations

Tie	Number of Ties (8 Screw Spikes/Tie)	Screw spikes Maintained per Specie (percent)	Tonnage Accumulated (MGT)	Low rail Maintenance per Specie (percent)	High rail Maintenance per Specie (percent)
Douglas fir	100	13	320	18	82
SYP	199	3	136	2	98
Oak	212	2	320	3	97
Yellow Poplar	103	3	320	18	82
Parallam	60	0	136	0	0
Total	674				

Threaded coil inserts, used in the screw spike holes after the screw spikes had worked out, were installed on the high side of the Douglas fir and yellow poplar test zones. The purpose of the coil is to enhance screw spike holding power in the tie when the screw spike is re-installed in the same hole. Exhibit 16 lists the tonnage cycles at which screw spike maintenance was required after the installation of the coils in Douglas fir and yellow poplar ties. The maintenance log indicates that the screw spikes re-installed with the threaded coil inserts in Douglas fir ties began to work out after only 24 MGT. The yellow poplar zone accumulated 157 MGT before maintenance was required.

Exhibit 16. Screw Spike Maintenance after Installing Threaded Coils in Douglas Fir and Yellow Poplar Ties

Douglas fir 400 Threaded Coils Installed		Yellow Poplar 400 Threaded Coils Installed	
Maintenance Cycle Cumulative Tonnage (MGT)	Maintained (percent) per Cycle	Maintenance Cycle (MGT)	Maintained (percent) per Cycle
24	2	157	0.8
36	1	204	6
64	1		
114	2		
157	2		
204	5		
280	7		

Thirty six MGT after the last maintenance was required in the Douglas fir tie subzone of Section 25, when the threaded coils were installed; 25 each or 3 percent of the screw spikes in that zone were replaced due to fractures. Exhibit 17 depicts a typical fractured screw spike. All the fractured screw spikes replaced were on the high side of the curve; 14 were on the gage side and 11 on the field side.

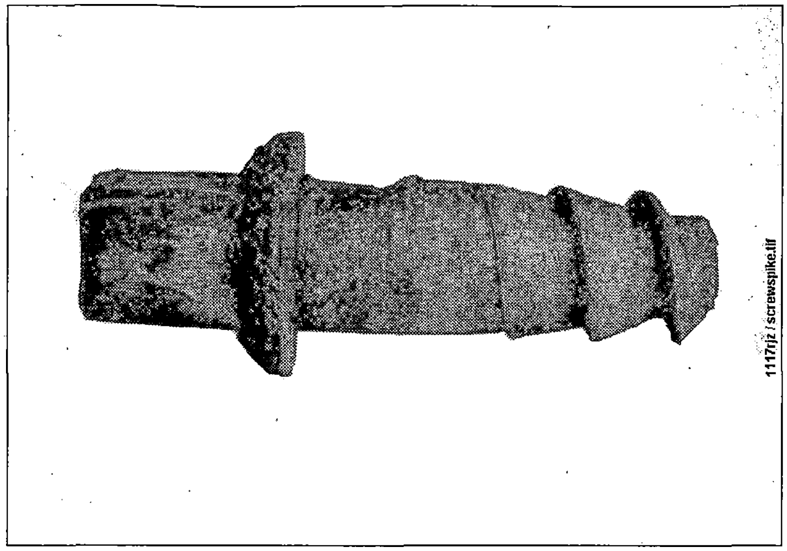


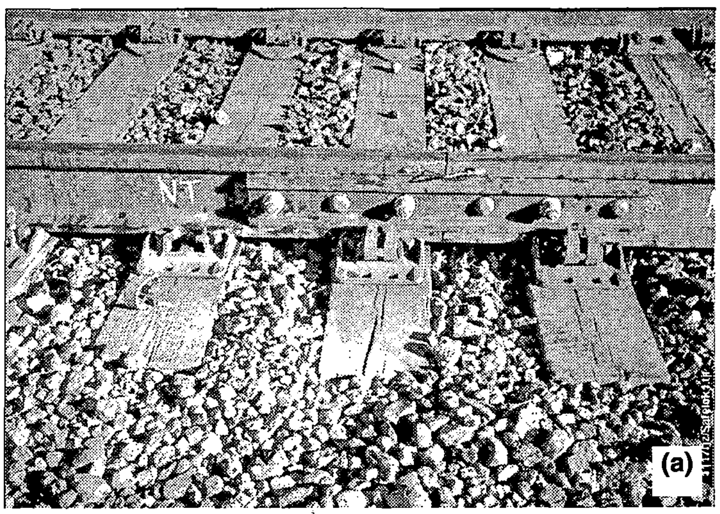
Exhibit 17. Fractured Screw Spike from Section 25

Five fractured samples were examined at TTCI's metallurgy lab. Each of the fractures on the forged screw spikes occurred between 2 and 2.5 inches below the head flat seating surface at thread roots that are directly in alignment with mechanical damage sustained at the screw spike shank/tie plate contact points. The initiation sites are directly below and in alignment with mechanical damage between the screw spikes and the interacting tie plate. In one instance, this damage produced deformation on the smooth shank portion of the screw spike penetrating to a depth of approximately 0.15 inch.

Due to dynamic loading, lateral forces are placed on the shank portion of the screw spikes where they contact the tie. These forces produced a cyclic bending moment on the part beneath the tie surface. The cyclic bending moment at the lower threaded portion of the screw spikes nucleated a fatigue crack at a thread root of each of the samples examined.

The lower density of the Douglas fir softwood ties may have exaggerated this condition by not holding the screw spike rigidly within the tie allowing the screw spike to move slightly. However, no fractures have been documented on other softwoods.

SAFELOK® rail clip failures occurred regularly in the 5-degree curve of Section 7 on wood ties near mechanical rail joints where vertical track deflection (that is, track pumping) is more severe than under continuous welded rail (cwr). The five SAFELOK rail clips examined at TTCI's metallurgy lab fractured at the top corner of the radius between the two toe load prongs. The rail clip fractures occurred primarily on wood ties fitted with SAFELOK tie plate model number 38190. Exhibit 18 shows one of the rail joints where clip fractures occurred and a typical fracture.



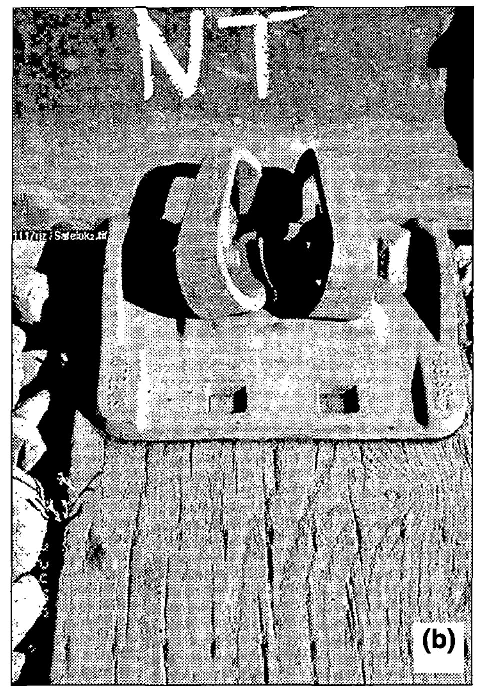


Exhibit 18. (a) One of the Rail Joints where SAFELOK® Rail Clip Fractures Occurred and (b) a Typical Fracture

Six rail clip wedges, provided by PANDROL, were installed in an effort to eliminate the problem. Installation is by impact after the rail clip is in place. Two of the wedges were installed on the low rail, one on the gage and one on the field side of the same tie. The remaining four wedges were installed on the high rail under the four rail clips of two adjacent ties. The clips installed at the low rail field side locations using wedges fractured several times at about 2.5 MGT intervals — about the same as without the wedge. Exhibit 19 shows a wedge in place between the rail clip and the tie plate and a fractured rail clip after about 2.5 MGT.

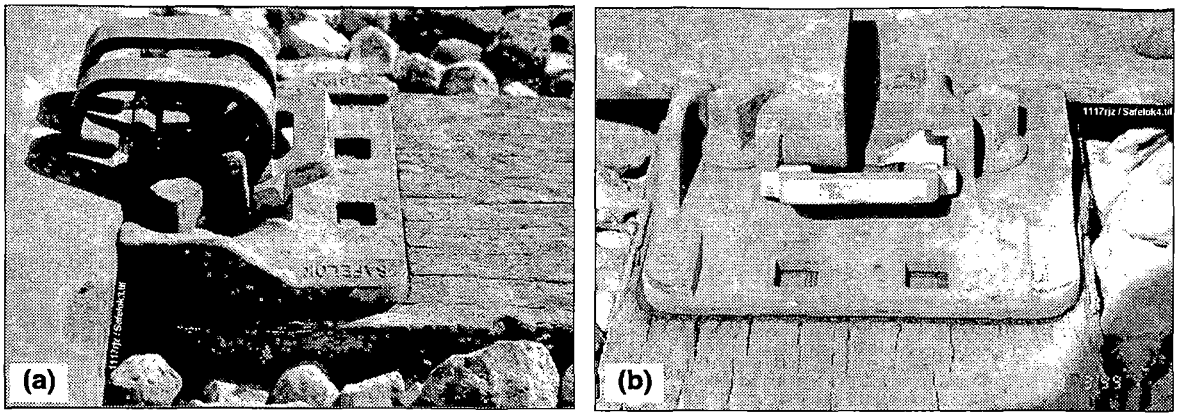


Exhibit 19. (a) SAFELOK® Rail Clip with Wedge and (b) Fractured Clip after about 2.5 MGT

Double elastic fasteners similar to the one shown in Exhibit 20 were in service in the 19.5-inch and the 24-inch spaced azobe tie subzones of Section 31 for 390 MGT. During a recent rail change, a number of the spike type elastic fasteners fractured below the tie surface as they were being removed. At that time all the double elastic fasteners in those two subzones were replaced with a typical cut spike system. Double elastic fasteners are still in service and are performing adequately in an oak tie subzone in the 5-degree curve of Section 7.

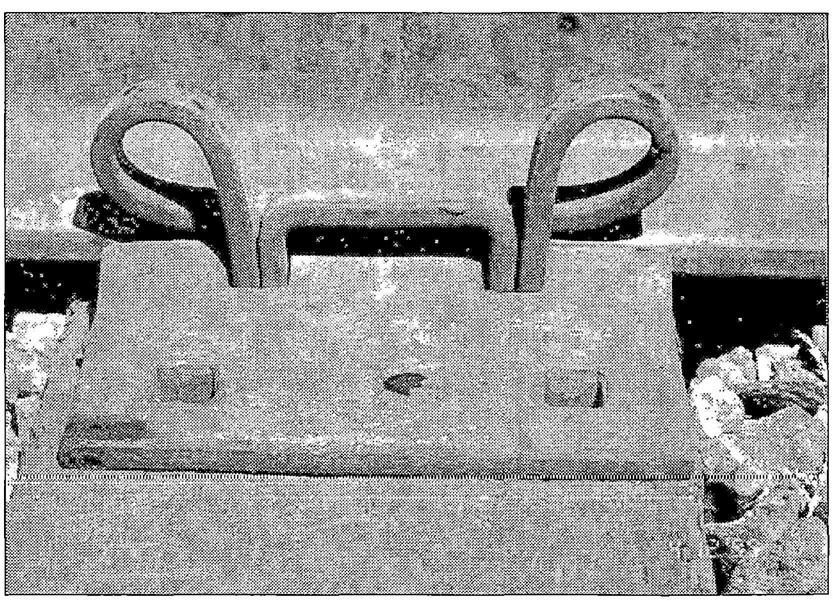


Exhibit 20. Double Elastic Fastener Similar to Those Removed from the Azobe Ties

7.3.1 Visual Inspection

Following are the observations made during the most recent visual inspection for splits, tie plate cutting, fasteners working out, and tie skewing on all the Wood Tie and Fastener Test subzones on the HTL.

- No significant tie plate cutting is occurring in any of the subzones.
- **SECTION 7**

  Oak and Douglas fir (866 MGT) - good condition.

  - Some splits on the field side of the DF

  Laminated southern yellow pine (707 MGT) - some splits on the high side field

  Plastic Composite (Smooth-sided 216 MGT, Rough-sided 138 MGT)

  - (3/4 inch, pre-bored) six screw spikes up over 1/2 inch but not over 2 inches
  - (5/8 inch, pre-bored) some cracks originating at screw spike holes
  - None of the cracks have propagated significantly during 100 MGT since initially detected
  - Crack study: The material in the area of three screw spike holes containing cracks (one with multiple cracks) was separated. The depth of the cracks was not greater than the length of the screw spike neck, approximately 2 inches.

  Parallam (150 MGT)

  - No splits
  - No screw spikes working out
- **SECTION 25**

  Oak dowel-laminated (406 MGT)

  - Majority of ties have splits originating from the hold down spike on the high side gage.

  Southern yellow pine (406 MGT)

  - Some splits high side field

  Vertical/Horizontal laminated southern yellow pine (334 MGT)

  - Few splits along laminations

Douglas fir (334 MGT)

– Numerous screw spikes losing contact with the plate (working up).

Parallam PSL (150 MGT)

– No splits

– No screw spikes working out

- **SECTION 31**

  Azobe (423 MGT) – Some of the 24-inch spaced, fastened with e-clips and screw spikes are skewed.

- **SECTION 33**

  Cedrite (392 MGT) – No problems

8.0 RESULTS

8.1 GAGE WIDENING

Since the beginning of HAL testing at FAST in 1988, track gage has been monitored using the EM-80 Track Geometry Car. The gage performance data presented here is derived from that source.

In the relatively low lateral load environment of Section 7, the median load during Phases I and II under the standard three-piece truck suspension was about 5.8 kips. Comparatively, the median load under the improved suspension trucks used during Phase III was about 2.5 kips.

In addition to cross tie testing, the 5-degree curve of Section 7 is also the location of the Rail Wear Test. The high rail of this curve is not directly lubricated in order to observe dry wear of the test rails. Data gathered as part of the Rail Wear Test was examined to determine how much of the measured gage widening was attributed to high rail gage-face wear. The results indicate that most of the gage widening in the test zone was due to rail wear.

The average measured gage widening rate of all the test zones in Section 7 was about 0.2 inch/100 MGT during standard suspension truck operations. During improved truck operations when rail wear was significantly reduced, the average measured gage widening was about 0.05 inch/MGT. Since most of the gage widening was due to rail gage-face wear and because the variance from the average was so small between the various tie and fastener sub zones, it was not possible to accurately quantify the gage widening that occurred solely due to differences in ties and fasteners.

The Parallam ties, installed in Section 7 with PANDROL E-clips and four hold down screw spikes per plate, have accumulated over 150 MGT. During that period, there has been no observed tie degradation, no screw spike work out, and no maintenance has been required.

The median lateral load in the 6-degree curve of Section 25 during Phases I and II was about 8.1 kips under the standard three-piece truck suspension. In comparison, the median load during Phase III was reduced to about 4.5 kips under the improved suspension trucks.

Exhibit 21 shows the track gage measured using EM-80 track geometry car data. Data in the center of the curve, labeled 160 additional MGT, represents gage degradation of the ties installed at the beginning of Phase I. After 360 MGT of HAL traffic, two of the three Douglas fir subzones of that original installation reached the FRA track safety standard gage limit for Class 4 track of 1 inch over standard gage (56.5 inches). Of the two subzones, one was fastened using four cut spikes per tie plate and the other using five cut spikes per plate. At that point, the two subzones were re-gaged and the fastening system changed to PANDROL plates, e-clips, and screw spike hold downs. Shortly thereafter, at 375 MGT, the third of the original Douglas fir subzones also reached the gage limit and it was re-gaged. This subzone, however, remained fastened with four cut spikes per tie plate. The Douglas fir ties in Section 7, having accumulated the same amount of tonnage, required no maintenance. Two hem fir and two southern yellow pine subzones also reached that limit after 200 MGT and they too were re-gaged.

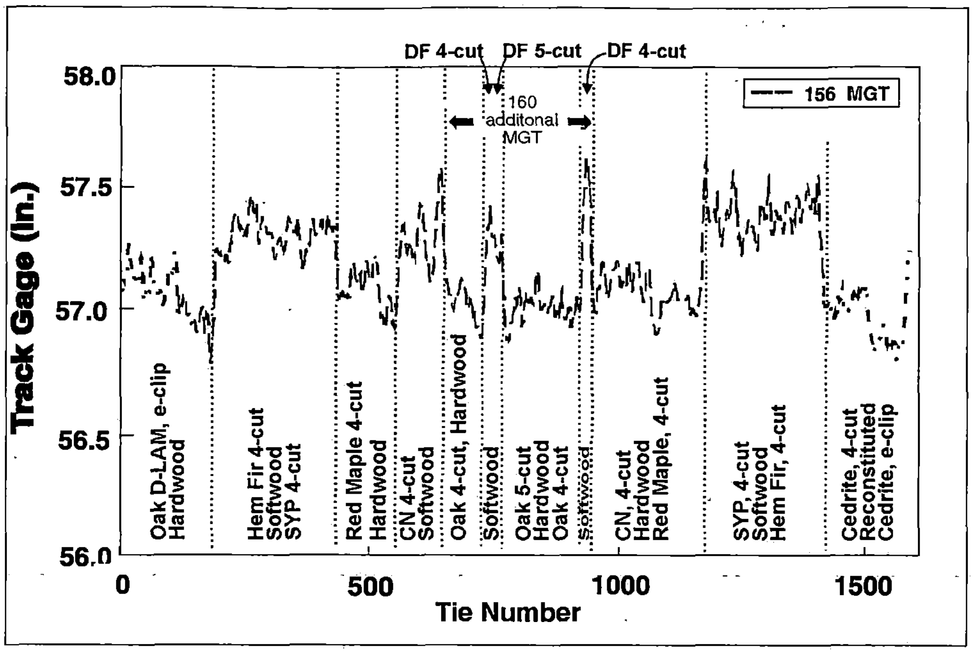


Exhibit 21. Measured Track Gage Using the EM-80 Track Geometry Vehicle

The most serious gage degradation problem to date occurred during Phase II operations with standard suspension trucks. Gage degradation requiring re-gaging occurred in several of the softwood subzones of Section 25.
Although the gage degradation rate over the Cedrite reconstituted ties was somewhat higher than over the hardwood ties under standard truck operations, re-gaging was not required during their time in service.

In addition to being one of the Tie and Fastener Test zones, Section 25 is also the site of the Rail Grinding Test where rail wear is measured at regular intervals. Nearly 70 percent of the gage widening measured in the hardwood, alternative, and phase III softwood test tie subzones of Section 25 was attributed to gage-face rail wear as it was in Section 7.

The average measured gage widening rate over the three hardwood test zones; oak with cut spikes; oak with e-clips; and yellow poplar ties with e-clips, installed during Phase III operations was about 0.03 inch per 100 MGT. And again, due to the small changes, it was not possible to accurately compare the different tie and fastener test zone.

The gage widening rate over the Parallam ties with e-clips and screw spikes; the dowel-laminated oak ties with cut spikes; and both the vertical and horizontal glue-lamination ties with cut spikes was comparable during Phase III improved truck operations.

At the beginning of Phase III, and the start of improved suspension truck operations, three southern yellow pine subzones were installed to compare cut spike hold down patterns. The tie sizes and the number of rail spikes per plate was the same in the three subzones, that is, they were 7″×9″×8.5′ and all had three rail spikes. The variable was the hold downs, where one subzone had two on both the high and low rails; the second had three on the low rail and four on the high rail; and the third had two hold downs on the low and four on the high rail.

Under improved suspension trucks, the number of hold down cut spikes did not affect the rate of gage widening over the three subzones.

The gage widening rate over the Douglas fir with PANDROL E-clips and the southern yellow pine with SAFELOK rail clips was comparable to that over the southern yellow pine with cut spike fasteners under improved suspension trucks. The average measured gage widening rate over all the softwoods tested during Phase III operations was 0.04 inch per 100 MGT.

Track gage degradation was also significant in the hem fir and southern yellow pine ties installed at the start of Phase II. Exhibit 21 also shows that gage in the two hem fir and two southern yellow pine subzones installed on either side of the original installation subzones were approaching the FRA track safety standard limit after just 156 MGT. The four subzones were installed using four cut spikes per tie plate. After 200 MGT of HAL traffic, the four subzones reached the limit and were re-gaged. Gage widening was so severe the track supervisor felt that re-plugging and re-gaging the ties with the existing cut spike system would allow gage widening again in a short period of service. Thus, the four subzones were re-fitted with PANDROL plates, e-clips, and screw spike hold-downs in an attempt to lengthen the gage life of the ties.

While the PANDROL plate, e-clip, screw spike hold down system improved gage retention, the screw spikes continually worked out of the ties under the dynamic loads of traffic. In an attempt to remedy the problem, threaded coil inserts were used in the hold down holes. Tie splitting may have been too severe for this type of repair. That severe tie condition was accelerated by rail plugs that were installed during a period when rail fatigue caused numerous breaks At the start of Phase III operations, the majority of the ties in Section 25 were replaced after 460 MGT of HAL traffic due to permanent damage from gage widening or severe split condition. The softwoods had gage widening. Although there was no major gage widening problem with the hardwoods, most had splits caused by the numerous rail plug changes during Phase II. The only ties that remained in test from the 1988 installation were the oaks fastened with cut spikes. And they were re-fitted with PANDROL plates, e-clips, and screw spikes after the start of Phase III to avoid further damage caused by the pulling and re-spiking done to change rail plugs.

To date, the ties in Section 25 with the highest exposure to HAL traffic – the oak with PANDROL E-clips and screw spike hold downs in subzone 11 – have accumulated over 900 MGT.

The following ties have been subjected to over 450 MGT of HAL traffic:

Oak dowel-laminated with cut spikes in subzone 1
Southern yellow pine with various cut spike patterns in subzones 2, 3 and 4
Mixed-tie oak/southern yellow pine with cut spikes in subzone 5
Douglas fir ties in subzone 6, also fastened with cut spikes

Ties with over 380 MGT in Section 25 include both the vertical and the horizontal glued laminated southern yellow pine ties; the oak with cut spikes in subzone 9; the Douglas fir with PANDROL E-clips and screw spike hold downs in subzone 13; and the yellow poplar also with PANDROL fasteners. The southern yellow pine ties in subzone 17 have accumulated nearly 200 MGT. See Exhibit 9 for details of each subzone.

The problem of screw spikes working out of the ties, primarily in the Douglas fir subzone, required maintenance during Phase III operations. However, none of the test ties in Section 25 have required re-gaging.

The azobe tropical wood ties installed with cut spikes and elastic fasteners in the 5-degree curve of Section 31, have had minimal gage widening during their nearly 500 MGT of service. The average gage in that subzone is 56.60 inches. The average gage in the Cedrite ties in Section 33 is 56.3 inches. Some tie skewing occurred in the subzones spaced at 24 inches during Phases I and II with no need for maintenance. Skewing did not worsen during Phase III.

8.2 GAGE RESTRAINT UNDER LOAD

8.2.1 Track Loading Vehicle (TLV) - Static and Dynamic Measurements

TLV measurements were used to provide a snapshot comparison of the gage spreading response of various tie/fastener combinations to the application of simulated stationary and in-motion heavy axle loads.

When the TLV test was conducted in March 1990, the HAL Program at FAST had accumulated about 150 MGT using the 125-ton car consist.

8.2.1.1 Results of Stationary Test

The gage spreading loads used in the stationary tests varied from 2 to 26 kips under the 39-kip wheel load, a 0.05 to 0.7 L/V ratio. A 2-kip increment was used in the stationary and in-motion tests to arrive at the maximum gage spreading loads. Results of the stationary tests reveal the effects of 39-ton axle loads on the gage spreading mechanism. The total gage (the sum of the two rail head deflections) is plotted at four L/V ratios for each fastener type at 39 kip wheel loads to characterize gage spreading strength.

To characterize gage spreading strength in Exhibit 22, the sum of the two railhead deflections or total gage spreading is plotted at four L/V ratios for each fastener type. At low L/V ratios, the difference in gage spreading between the cut spikes and the elastic fasteners is small. As the L/V ratio increases, however, the difference in gage spreading increases substantially. Gage spreading at an L/V ratio of 0.7 is more than five times the gage spreading at a 0.3 L/V ratio in the case of domestic hard/softwoods with four cut spikes in Section 7. Such a dramatic effect is not evident with the PANDROL E-clip or SAFELOK fasteners where only approximately a doubling of the gage spreading occurred when the L/V ratio was increased from 0.3 to 0.7.

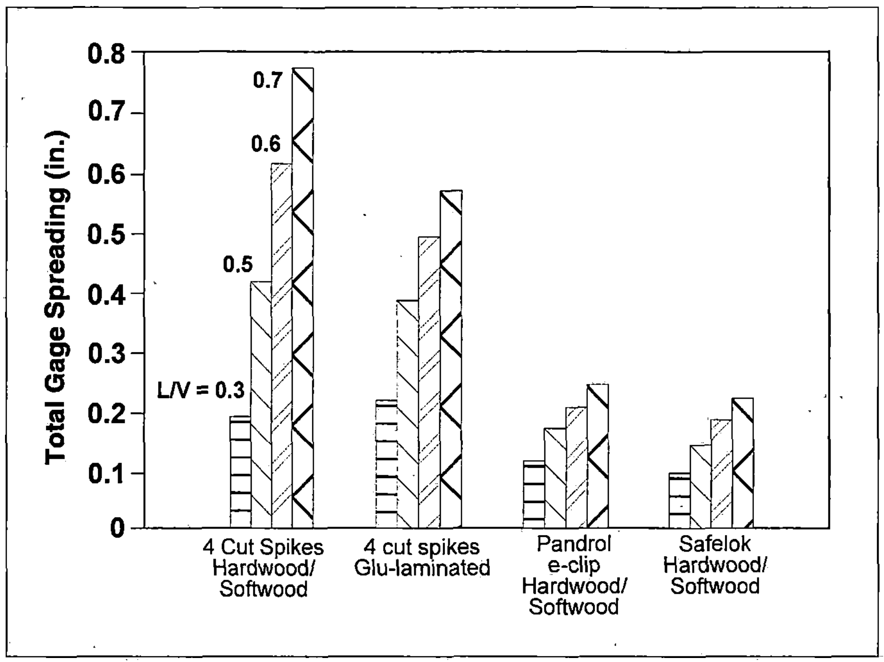


Exhibit 22. Comparison of Static Gage Spreading on Hardwoods and Softwoods using Different Fasteners, Section 7, 5-degree Curve

Exhibit 23 compares the gage spreading strength of different types of wood ties in Section 25 using a 22-kip gage spreading load under a 39-kip wheel load. With the exception of the Red Maple, there is no significant difference in the gage widening strength of these different tie types.

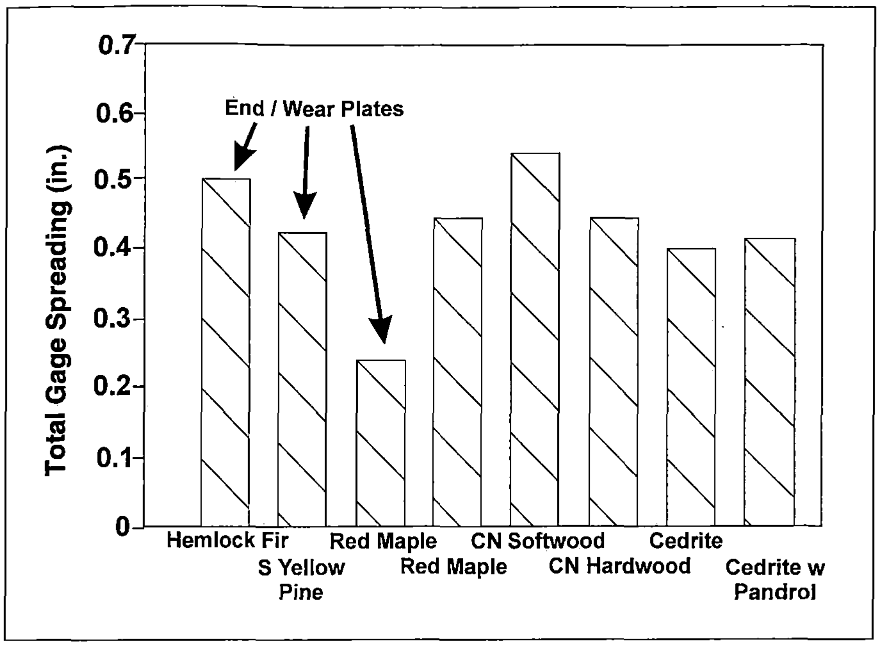


Exhibit 23. Comparison of Static Gage Spreading of Different Tie Types Fastened with Cut Spikes at 0.6 L/V (22-kip/39-kip), Section 25, 6-degree Curve

The static gage spreading results of azobe ties in Section 31 are given in Exhibit 24. The results pertain to gage spreading responses from the test zones with five cut spikes and elastic fasteners on ties at 19.5-inch centers, as well as double elastic fasteners and PANDROL E-clips on ties at 24-inch centers. A comparison to the results shown in Exhibit 22 reveals that for L/V ratios of 0.5 and above, the total gage spreading on azobe ties with five cut spikes is approximately half that of domestic hard/softwood ties with four cut spikes. It was found that azobe ties with five cut spikes provide comparable gage spreading strength to that of domestic hard/softwoods with PANDROL E-clips. The static responses of the double elastic fasteners on both the 19.5- and the 24-inch tie spacings are quite comparable to the response of the PANDROL E-clip fasteners at 24-inch spacing. Decreasing the tie spacing from 24- to 19.5-inch centers does not seem to create a significant improvement in gage spreading strength on the azobe ties.

The tangent test zone in Section 33 consisted of domestic hard/softwood ties with four and five cut spikes, Cedrite ties with PANDROL E-clip fasteners, and concrete ties with e-clips. A comparison of responses of the five cut spike domestic hard/softwood ties in this zone (Exhibit 25) to the response of the five cut spikes on azobe ties (Exhibit 24) clearly shows the much greater strength of the azobe ties over the domestic hard/softwood ties.

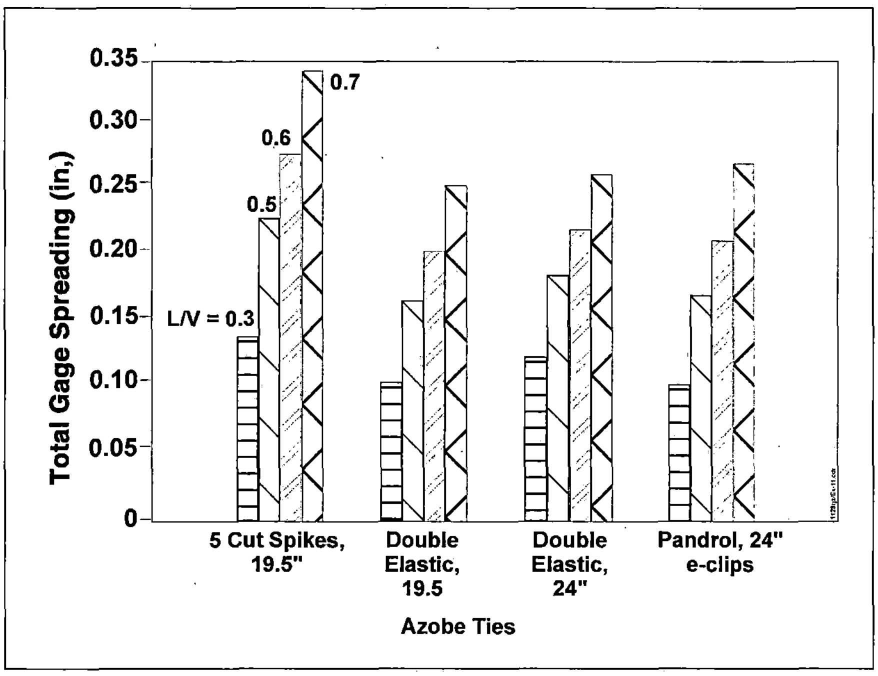


Exhibit 24. Comparison of Static Gage Spreading of Different Fasteners on Azobe Ties, Section 31, 5-degree Curve

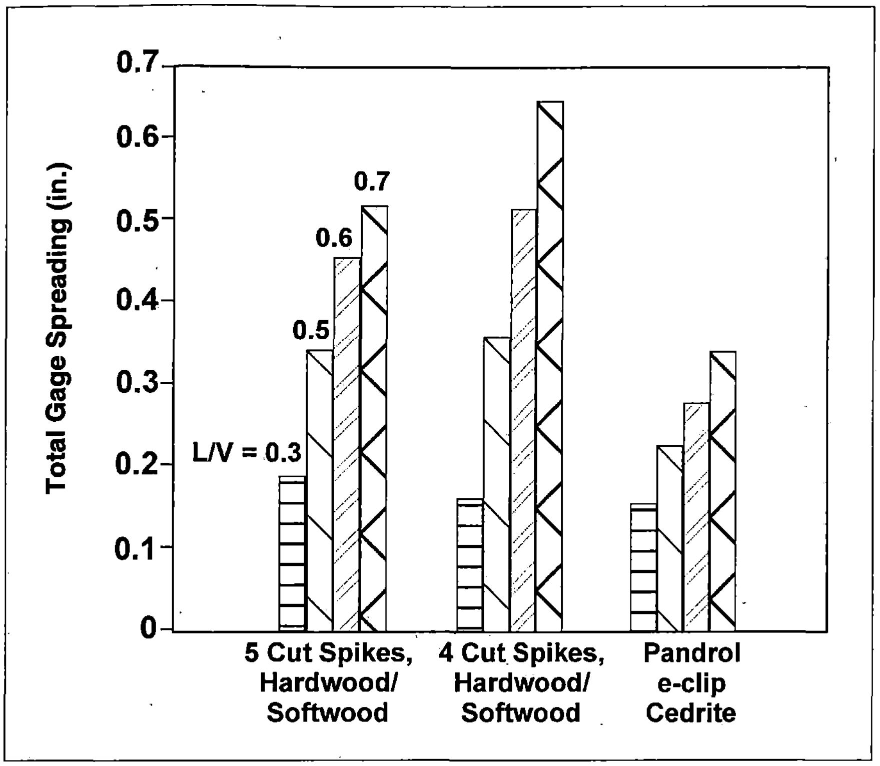


Exhibit 25. Comparison of Static Gage Spreading on Different Tie/Fastener Combinations, Section 33, Tangent Track

Exhibit 26 shows overall comparisons of the fasteners tested in Sections 7, 31, and 33 under 39-kip wheel loads. The exhibit shows that an increasing L/V ratio results in a much greater increase in gage spreading in the case of domestic hard/softwoods with four cut spikes than in that of elastic fasteners such as PANDROL E-clip and SAFELOK.

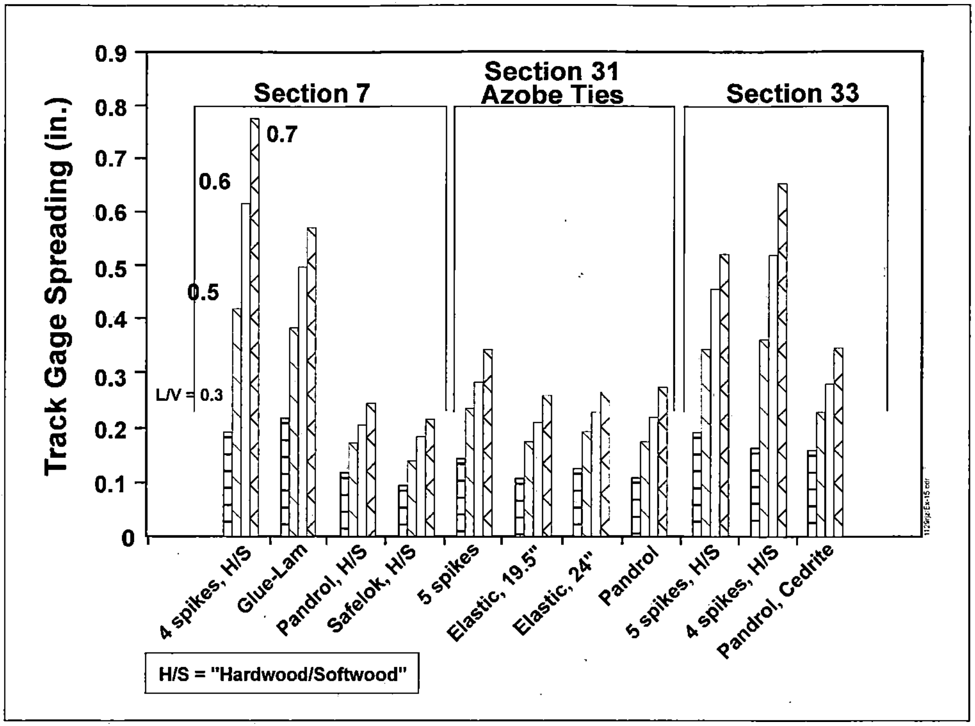


Exhibit 26. Comparison of Static Gage Spreading of Different Tie/Fastener Combinations in the Two 5-degree Curves (Sections 7 and 31) and the Section 33 Tangent Test Zone

8.2.1.2 Results of In-Motion Test

The in-motion tests, run at 20 mph, were performed with gage spreading loads ranging from 10 to 24 kips under a 39-ton axle load, 0.3 to 0.6 L/V ratio. A 2-kip increment was used in the in-motion tests to arrive at the maximum gage spreading loads.

Delta gage and track (gage) compliance are used to describe the gage spreading strength of the test zones in the moving tests. Delta gage is the direct difference between the loaded gage and the corresponding unloaded gage. Track compliance is the quotient between delta gage and its corresponding gage spreading load.

Exhibit 27 show the results of the TLV in-motion gage restrain tests conducted on the concrete ties of the 5-degree curve of Section 3.

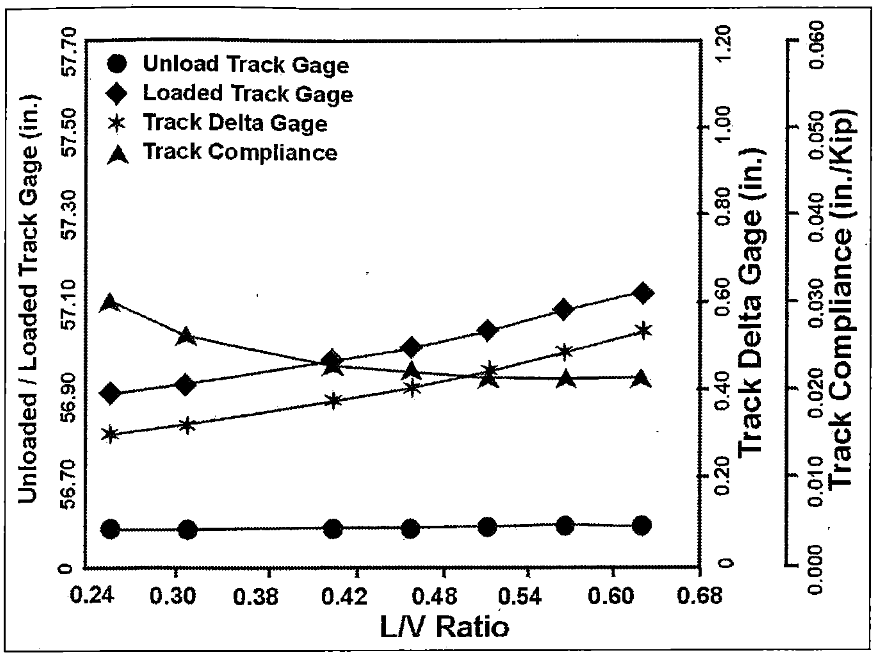


Exhibit 27. Concrete Ties with Pandrol E-clips, Unloaded, Loaded, Delta Gage and Track Compliance versus L/V Ratio where V=39 Kips

Exhibits 28 through 32 show the results of the TLV in-motion gage restrain tests where the unloaded and loaded gage, delta gage, and track compliance versus gage spreading load under 39-kip wheel loads for each tie/fastener combination in Section 7 are plotted.

The slopes (rate of change of gage spreading with respect to the gage spreading load) of the loaded gage and delta gage of the hard/softwood and glue laminated ties with cut spikes is steeper than those of the hardwood/softwood ties with double elastic fasteners, PANDROL E-clips, and SAFELOK rail clips, and the concrete ties with PANDROL E-clips.

Results show the following magnitudes of delta gage at a 0.6 L/V ratio (24-kip gage spreading load/40-kip wheel load) for the tie/fastener combinations tested:

- Hardwood/softwood with four cut spikes 0.75 inch
- Glue-laminated with four cut spikes 0.70 inch
- Hardwood/softwood with double elastic fasteners 0.47 inch
- Hardwood/softwood with PANDROL E-clips 0.45 inch
- Hardwood/softwood with SAFELOK rail clips 0.43 inch

Track compliance is the value of quotient of the delta gage and the applied gage spreading load. A comparison of track compliance of the tie and fastener combinations in Section 7 (Section 3 for the concrete ties) is given as the increment of gage in inches per kip of gage spreading load with respect to L/V ratio.

A very important characteristic to note from these curves is that, for cut spikes on hard/softwood ties and glue laminated ties, the track compliance stays approximately constant with increasing magnitudes of gage spreading load or the corresponding L/V ratio. On the other hand, in the case of the concrete ties with PANDROL E-clips and wood ties with e-clips and SAFELOK fasteners, the track compliance decreases with increasing load or L/V ratio. Since track compliance is the quotient between delta gage and the corresponding gage spreading load, constant compliance implies linearly increasing magnitude of delta gage with respect to gage spreading load. In other words, the behavior of hard/softwoods with cut spikes is like that of a linear spring. In contrast, in the case of concrete ties and wood ties with PANDROL and SAFELOK fasteners, gage hardening characteristics are apparent. That is, they provide increasing gage spreading strength at higher gage spreading loads. The occurrence of gage spreading stiffness with increasing gage spreading loads is one of the most important results from these tests.

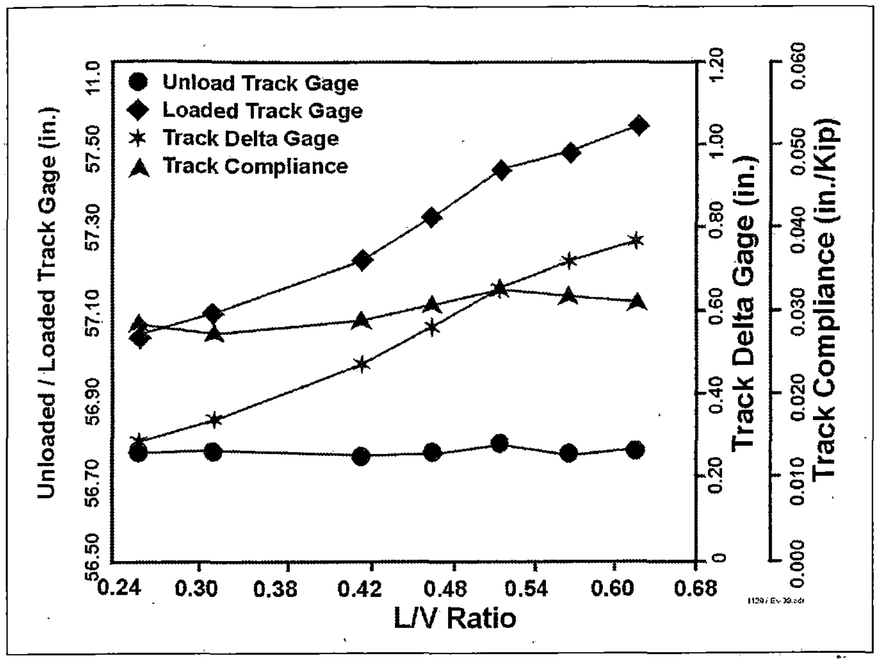


Exhibit 28. Hardwood/Softwood Ties with Four Cut Spikes, Unloaded, Loaded, Delta Gage and Track Compliance versus L/V Ratio where V=39 Kips

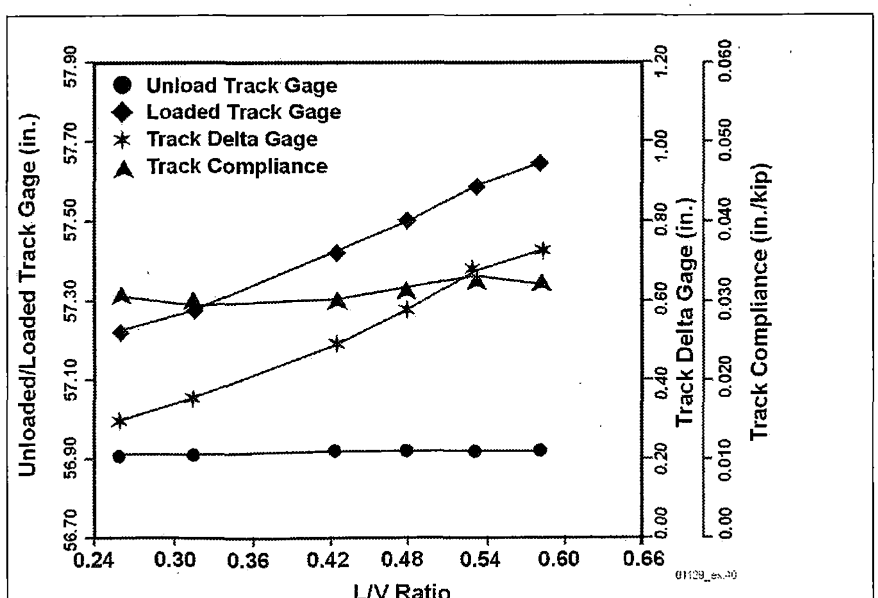


Exhibit 29. Glue Laminated ties with Four Cut Spikes, Unloaded, Loaded, Delta Gage and TRACK Compliance versus L/V Ratio where V=39 Kips

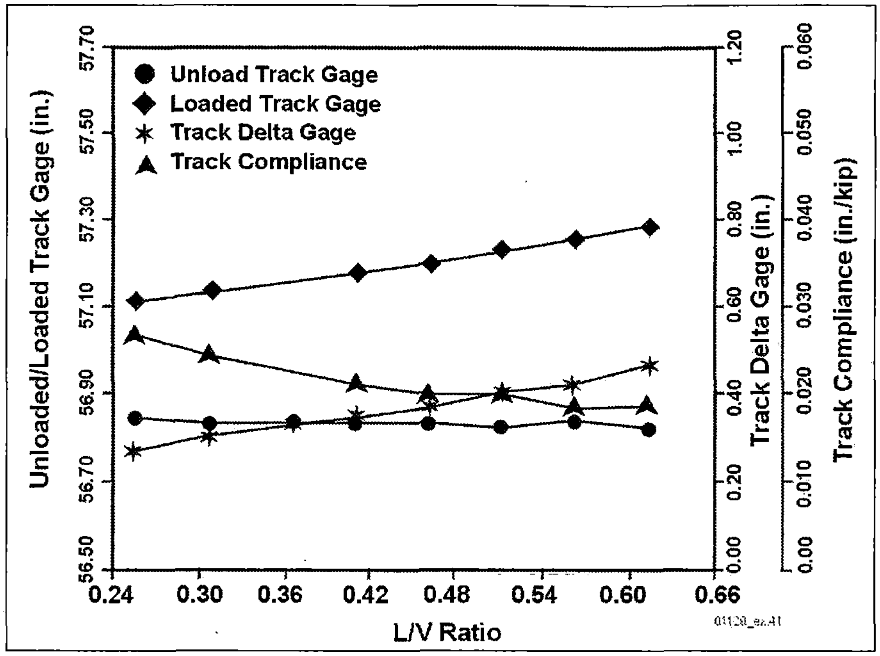


Exhibit 30. Hardwood/Softwood Ties with Pandrol E-clips. Unloaded, Loaded, Delta Gage and Track Compliance versus L/V Ratio where V=39 Kips

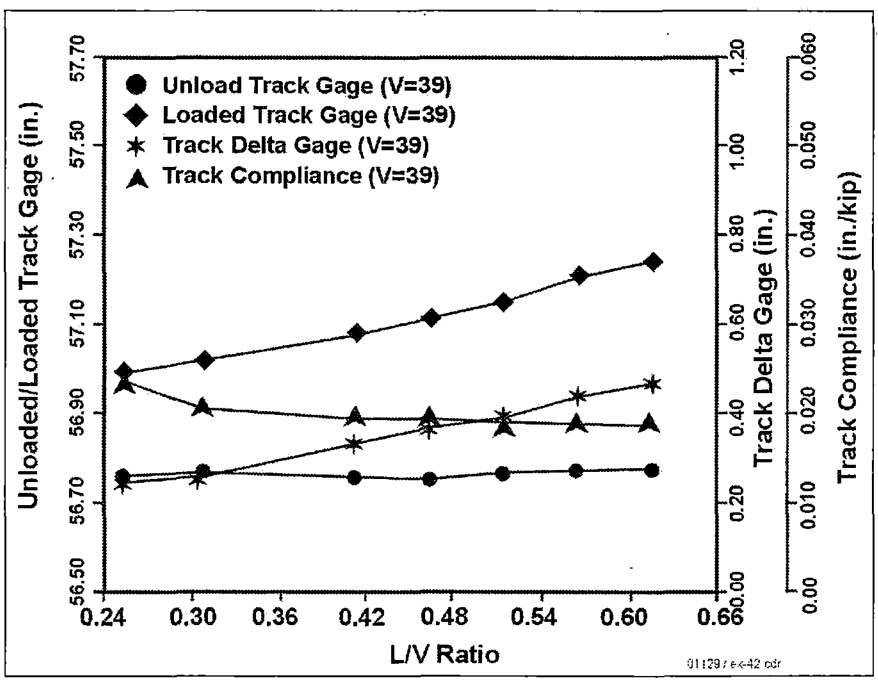


Exhibit 31. Hardwood/Softwood ties with Double Elastic Fasteners, Unloaded, Loaded, Delta Gage and Track Compliance versus L/V Ratio where V=39 Kips

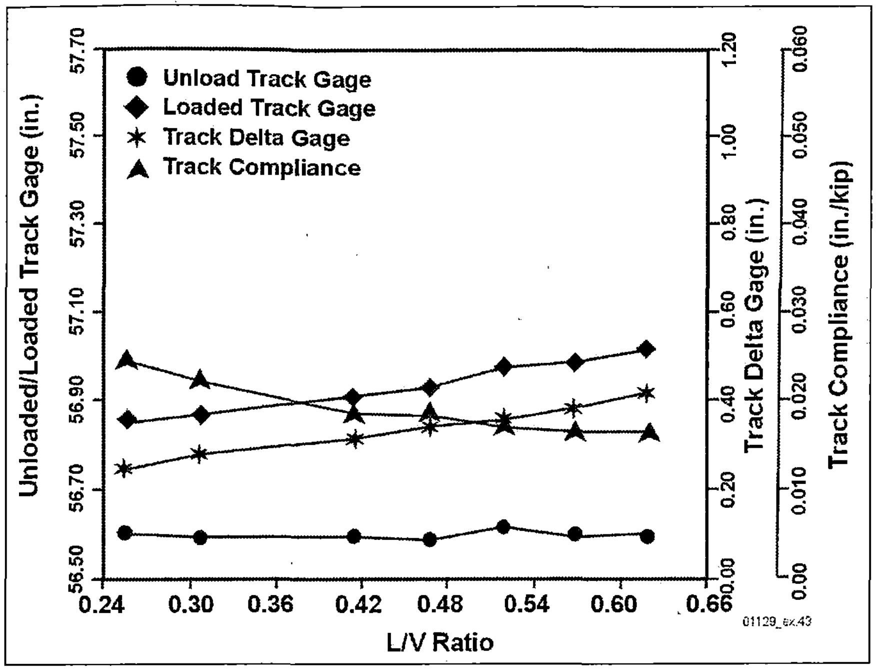


Exhibit 32. Hardwood/Softwood ties with SAFELOK® Fasteners. Unloaded, Loaded, Delta Gage and Track Compliance versus L/V Ratio where V=39 Kips

8.2.2 Rail Force Calibration (605) Car — Static Measurements

The static and dynamic gage strength tests using the TLV were snapshots of track response to the applied vertical and lateral wheel loads. The 605 Car measurements, on the other hand, were used to look at the long-term degradation of gage strength with respect to MGT of traffic over the different tie/fastener combinations.

Results of Phase I testing indicate that there is no significant difference in the measured and observed performance of the four and five cut spike systems. Comparatively, the Koppers fasteners exhibited a tendency to lose toe load; particularly on softwood ties resulting in removal of the system after 15 MGT.

Some tie skewing was documented during Phase I. In both of the subzones where skewing occurred, the ties were fastened with double elastic fasteners. In the azobe subzone of Section 31, the ties were spaced at 24 inches. However the double elastic subzone in Section 7, where the tie spacing was 19.5 inches, also experienced some skewing.

In neither case did the skewing affect track geometry or stability. There were no other fastening system failures or fastener maintenance required during the Phase I test period.

The gage spreading response of numerous fastening systems to static 0.5 L/V (20 kip Lateral/40kip Vertical) loads, using the 605 Car, was tested. The results are presented as the calculated gage spreading degradation rate in terms of inches per 100 MGT. Results of tests in the 5-degree curve of Section 7 indicate that differences in gage spreading strength occur between fastening systems and truck suspension types rather than between tie types.

Exhibit 33 compares oak, Douglas fir, and glued laminated ties fastened with cut spikes under standard and improved suspensions with oak and Douglas fir ties fastened with PANDROL E-clip elastic fasteners, again under standard and improved trucks. The results show that the average calculated gage spreading degradation rate was nearly five times greater with cut spike fasteners than with PANDROL E-clip elastic fasteners during Phases I and II under the standard suspension trucks. Under the improved trucks, the difference in gage spreading degradation became very small between the two fastening systems.

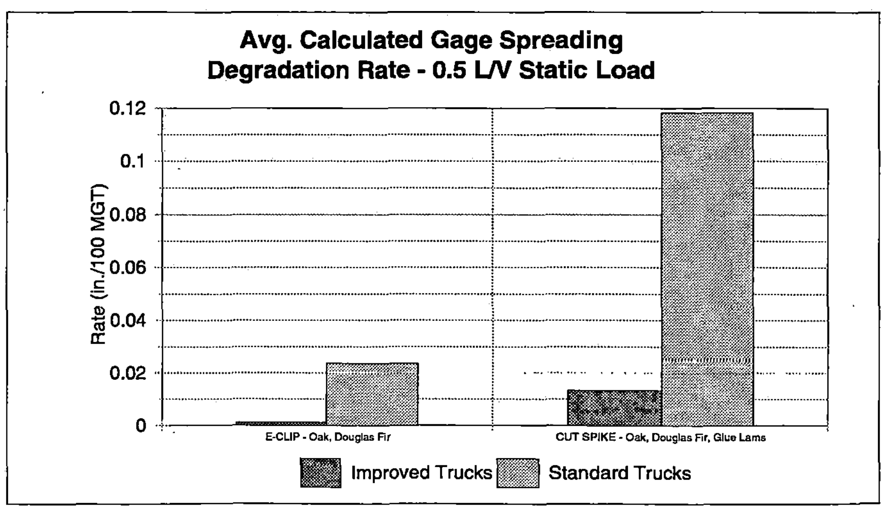


Figure 33. Average Calculated Gage Spreading Degradation Rate Under Static 0.5 L/V Loads in the 5-degree Curve of Section 7

The oak ties with SAFELOK elastic fasteners and the Parallam ties with PANDROL E-clips currently in track were installed during Phase III when the improved suspension trucks were in operation; therefore, no comparison can be made with standard truck performance. The results under improved suspension, however, show no significant gage spreading degradation. The USPL plastic composite ties were also installed during the improved suspension phase. The degradation rate of these ties, 0.02 in./100 MGT, is comparable to that of the other tie types with PANDROL E-clips under standard suspension conditions.

During Phase II operations, many of the fasteners in the combined Wood Tie and Fastener Test and Rail Grinding Test zone of Section 25 were disturbed regularly due to rail plug replacement and re-gaging. Exhibit 34, however, shows about 50 percent increase in gage restraint when the hem fir and southern yellow pine subzones, which were originally fastened with cut spikes were re-gaged and refitted with PANDROL E-clip elastic fasteners.

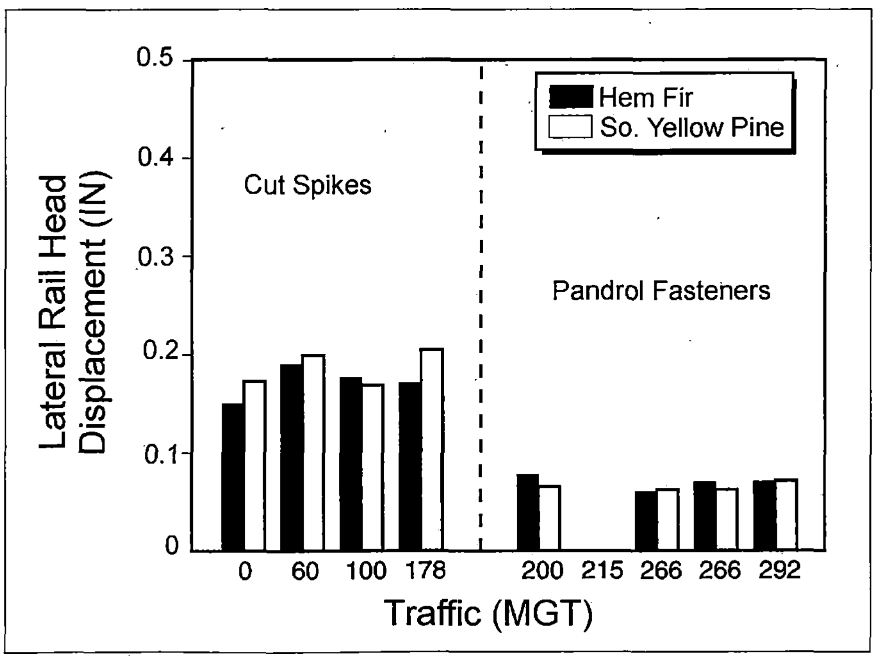


Exhibit 34. Comparison of Gage Restraint of Hem Fir and Southern Yellow Pine Ties Refitted with Pandrol E-clips after Re-gaging

Exhibits 35, 36, and 37 illustrate the calculated gage spreading rate of the softwood, hardwood, and alternative ties tested in Section 25 during Phase III. The gage spreading degradation rate of the Douglas fir and southern yellow pine softwood ties and the oak ties, all fastened with cut spikes in Section 25 under improved trucks, was comparable to that of the Douglas fir and oak ties fastened with PANDROL E-clips in Section 7 under the standard truck conditions.

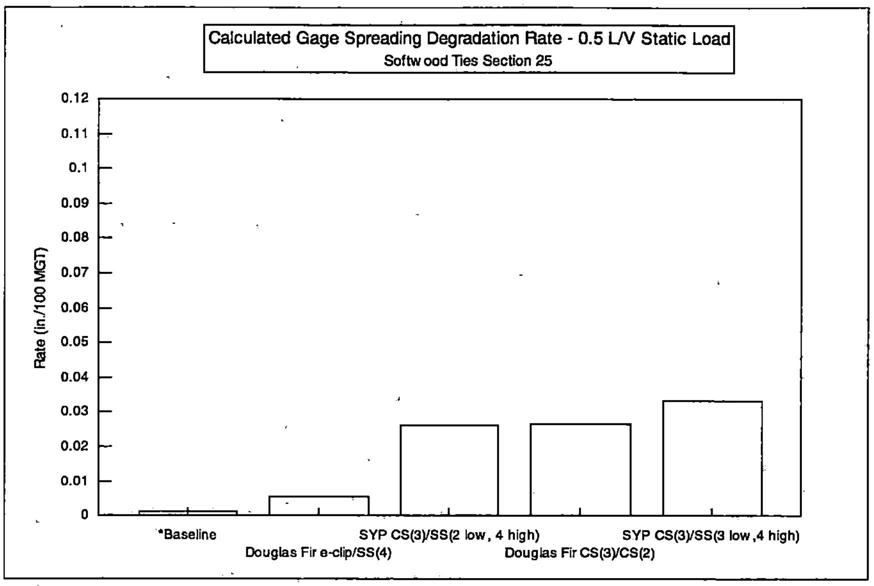


Exhibit 35. Calculated Gage Spreading Degradation Rate of Softwood Ties under Static 0.5 L/V Load Ratio in the 6-degree Curve

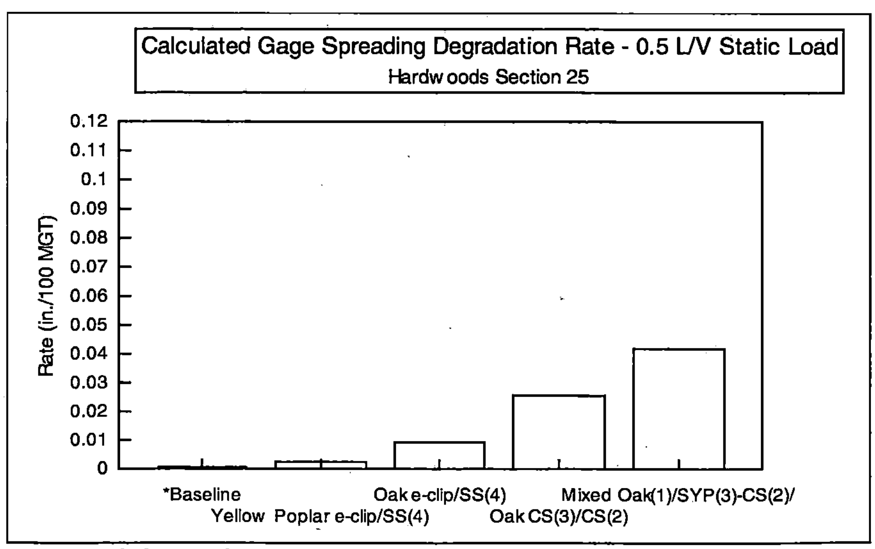


Exhibit 36. Calculated Gage Spreading Degradation Rate of Hardwood Ties under Static 0.5 L/V Load Ratio in the 6-degree Curve

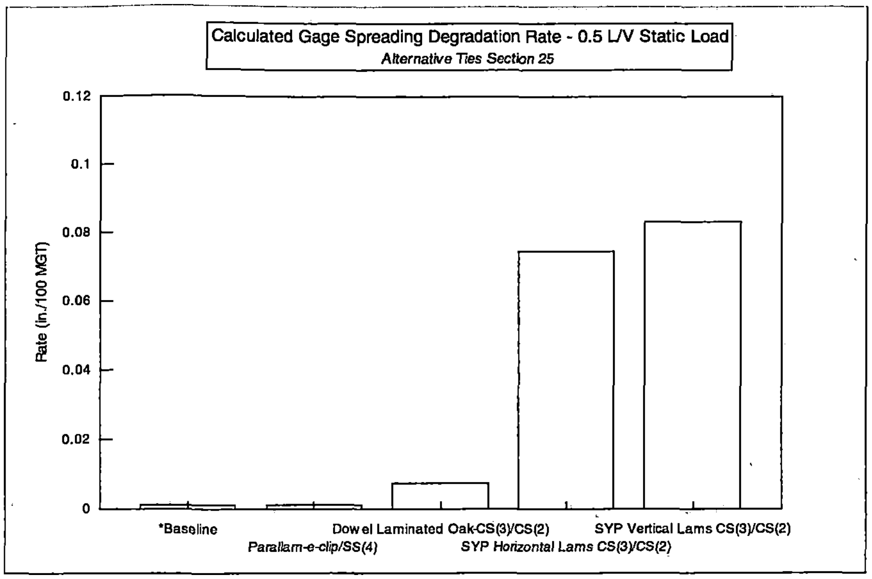


Exhibit 37. Calculated Gage Spreading Degradation Rate of Alternative Ties under Static 0.5 L/V Load Ratio in the 6-degree Curve

The southern yellow pine, Douglas fir, and oak ties fastened with cut spikes (shown in the two previous exhibits) were all equipped with three rail spikes per tie plate. The southern yellow pine ties were equipped with screw spike hold downs where one zone had two on the low rail and four on the high rail and the other zone had three on the low rail and four on the high. The oak and Douglas fir subzones, on the other hand, were equipped with two cut spike hold downs per tie plate on both the high and low rails. The results show that under improved suspension truck operations, there was no significant difference in gage spreading strength degradation among the combinations. the rate was about 0.03 inch per 100 MGT in each case. The mixed tie specie test subzone, where three southern yellow pine ties were installed for each oak tie, degraded at the slightly higher rate of 0.04 in./100 MGT, but performed almost three times better than the ties fastened with cut spikes under the standard trucks in Section 7. As in Section 7, the greatest difference in gage spreading degradation in Section 25 occurred between fastener types, where e-clips out-perform cut spikes, and between the different lateral load environments of the standard and improved suspension trucks.

The alternative ties tested in Section 25 include vertical and horizontal glued laminated southern yellow pine ties, dowel laminated oak ties, and Parallam PSL ties.

The results shown in Exhibit 38 indicate little difference between the gage spreading degradation rate of the vertical and horizontal glue laminated ties. In comparison to the two solid-sawn southern yellow pine subzones and the Douglas fir and oak subzones, all fastened with three rail spikes, the glued laminated ties did not perform as well. The gage spreading degradation rate of the laminated ties was 2.5 times greater than that of the other ties mentioned.

The gage degradation rate of the azobe ties installed with cut spikes and PANDROL E-clips in the 5-degree curve of Section 31 and the Cedrite ties fastened with cut spikes in the tangent of Section 33 was minimal.

8.3 EFFECT OF WHEEL LOAD

Tie plate cutting is a mode of tie failure that is directly influenced by vertical wheel loading, and therefore; can be considered a key indicator of tie performance under 39-ton axle load traffic. Tie plate cutting was measured during Phase I with a fixture that is aligned to indexing holes located at each corner of the tie plate. The change in tie plate height relative to the tie surface is measured with dial indicators on stems that rest on lag screws that have been glued into the tie. The average tie plate cutting depth for 7″×9″ and 6″×8″ ties with four cut spikes per tie plate in Section 25 during Phase I is shown in Exhibit 38. Tie plate cutting occurred primarily on the field side of the low rail on the softwood ties. The cutting caused the cant of the rail to decrease. The 6″×8″ softwood ties show the most field side cutting on both the high and low rails; however, the 6″×8″ inch hardwood ties show the least amount of field side cutting of the ties in the section. The least amount of cutting for any tie type occurred on the gage side of the high rail. The negative value shown for the 7″×9″ softwood ties indicates that plates are lifting slightly from the tie surface on the gage side of the low rail when the rail is not under load.

None of the wood tie test zones showed any significant degradation in track geometry. Other than repair of a track buckle in Section 7 at 45 MGT, neither of the original test zones in Sections 7 or 25 were surfaced or lined during the initial 160 MGT of Phase I HAL operations.

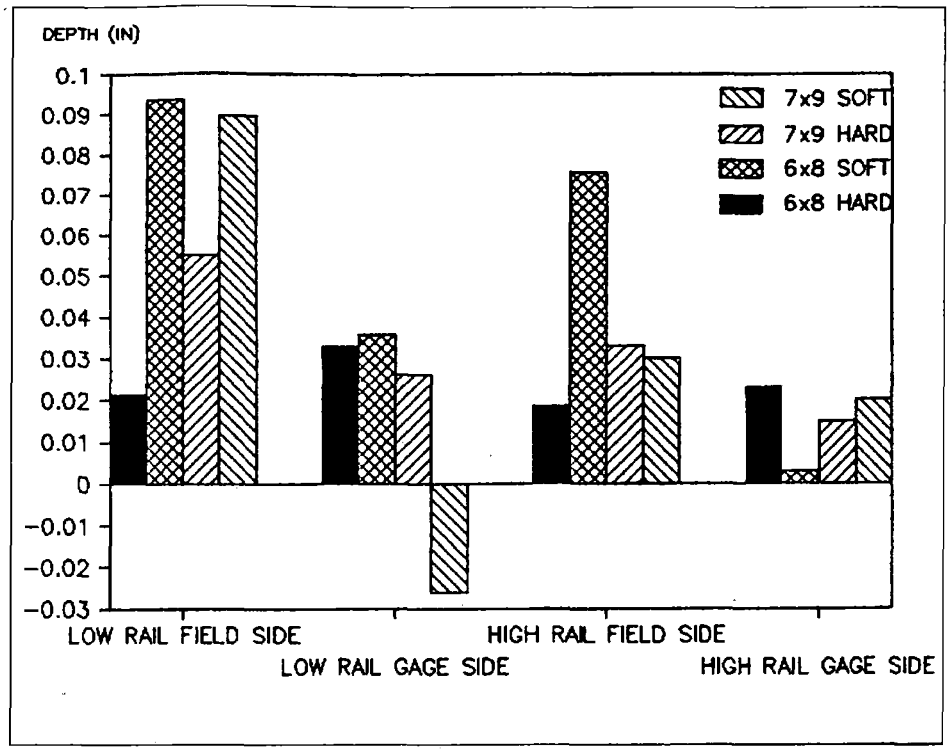


Exhibit 38. Average Tie Plate Cutting Depth on Hardwood and Softwood Ties in Section 25 after 160 MGT

Tie plate cutting has not been a problem during Phase III testing in any of the test zones.

8.4 EFFECT OF SPACING

Some tie skewing was documented during Phase I. In both of the subzones where skewing occurred, the ties were fastened with double elastic fasteners. In the azobe subzone of Section 31 the ties were spaced at 24 inches. However the double elastic subzone in Section 7, where the tie spacing was 19.5 inches, also experienced some skewing. In neither case did the skewing affect track geometry or stability.

During Phase II, skewing continued in both the 19.5-inch and the 24-inch spaced azobe subzones in Section 31. However, the majority of the tie straightening maintenance occurred in the subzones with 24-inch tie spacing.

Tie skewing was not a problem in any of the test zones during Phase III.

8.5 EFFECT OF TIE DIMENSIONS

The cross section and length of all the ties currently in test are provided in Exhibits 8, 9, and 10. There was no evidence that differences in tie dimensions provided major differences in tie performance in terms of track surface maintenance requirements.

8.6 EFFECT OF MATERIAL/DESIGN

As is customary with new alternative material ties, a USPL plastic composite tie was tested at the Component Test Lab (CTL) at TTC using the Tie Wear Machine. The tie was subjected to 850,000 cycles as a safety pre-requisite to out-of-face installation on the High Tonnage Loop and the loads of 39-ton axle cars. Results of the Tie Wear Test revealed no significant rail seat wear or fastening system degradation. The initial out of face installation of the USPL ties in the 5-degree curve of Section 7 consisted of 25 smooth-sided ties fastened with the same fastening system tested in the lab; that is, four screw spike hold downs and PANDROL E-clips. Since the interaction of ballast with the plastic composite ties was not known, single tie push tests were performed to compare the lateral resistance of these ties as they were pushed through the ballast section, with that of typical wood ties.

For the purpose of Single Tie Push Tests, consolidated track is defined as the ballast/tie interaction condition that exists after the passage of 10 MGT of traffic over the test zone.

The Single Tie Push Test results plotted in Exhibit 39 show that:

- The difference between single-tie lateral resistance under newly installed versus consolidated condition was less for the plastic composite ties than for the wood ties. That is, the lateral resistance of the plastic ties when newly installed was closer to their resistance after consolidation than was the case with the wood ties..

- The lateral resistance provided by typical consolidated-track single wood ties was nearly 70 percent greater than that of single smooth-sided plastic ties at consolidated-track conditions.

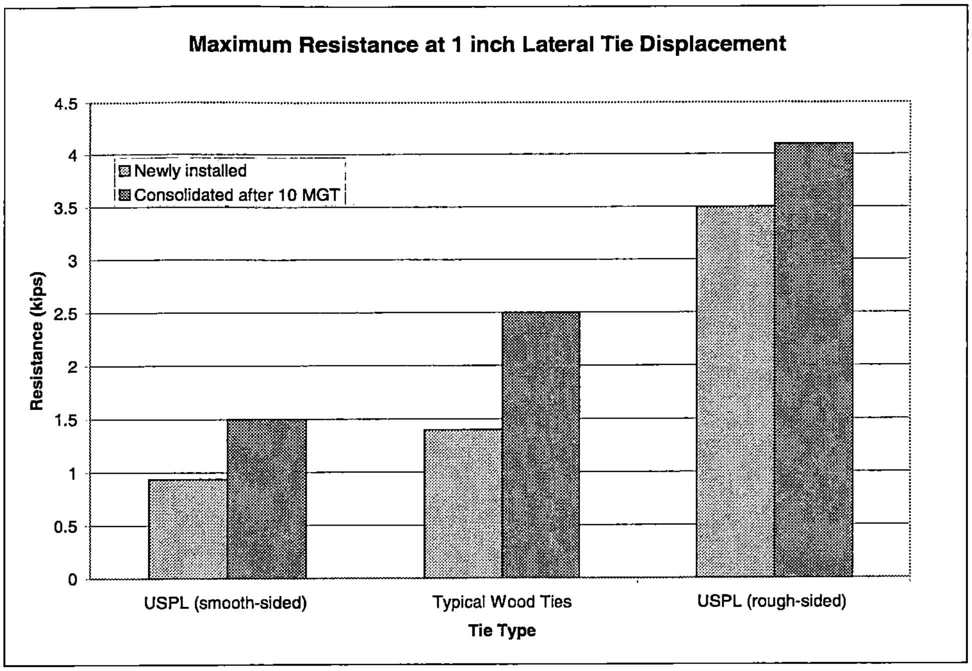


Exhibit 39. Maximum Single Tie Resistance at 1 inch Lateral Displacement

To increase resistance to lateral displacement, USPL developed a rough-sided plastic tie (shown in Exhibit 40) where the two side and bottom surfaces consist of square raised welts. The raised welts are intended to enhance the locking action between tie and ballast.

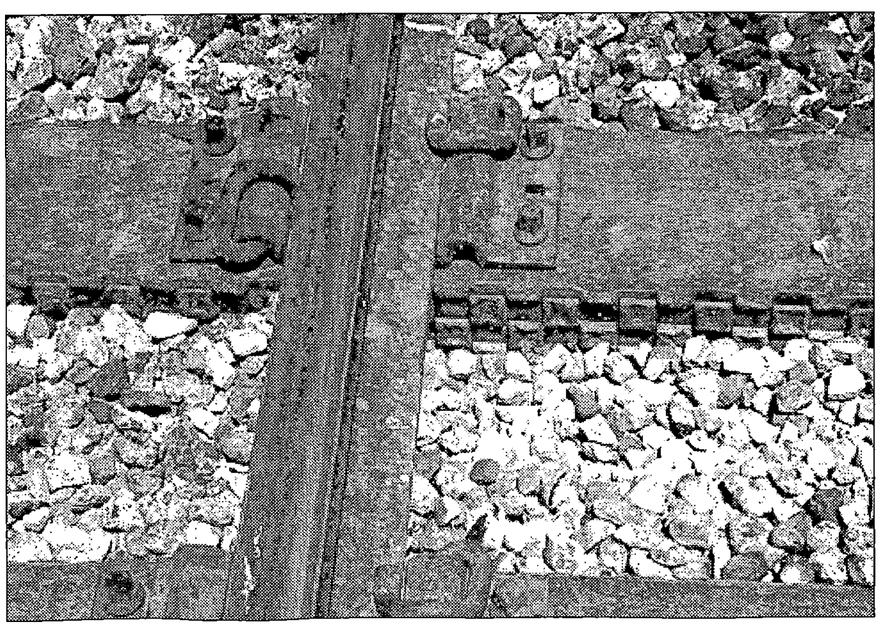


Exhibit 40. US Plastic Lumber Rough-sided Plastic Composite Tie

The second installation of USPL plastic composite ties consisted of 24 of the rough-sided ties and was made adjacent to the smooth-sided zone; two were fastened with cut spikes and the remaining 22 were fastened with four screw spike hold downs and PANDROL E-clips.

Single Tie Push Tests were done again to compare the performance of the rough-sided versus the smooth-sided ties through the ballast section, to compare the resistance of newly installed ties with that of ties in consolidated-track conditions (10+ MGT); and to compare the rough-sided ties with typical wood ties. Exhibit 39 shows that:

- The rough-sided newly installed ties provided an increase in lateral resistance over the smooth-sided newly installed ties of more than 200 percent.
- The rough-sided ties in consolidated-track condition provided over twice the lateral single tie strength of the smooth-sided ties in consolidated-track condition.
- The rough-sided plastic composite ties in consolidated track condition provided over 60 percent greater single tie lateral resistance to the applied load than typical single wood ties under similar conditions.

The initial installation, that is the smooth-sided ties, was pre-bored with a 3/4-inch drill bit for the 15/16-inch screw spikes. After 57 MGT, three of the screw spikes worked up approximately 1 inch. Since then, the smooth-sided ties have accumulated 205 MGT with no additional screw spikes working up.

The rough-sided ties were pre-bored at 5/8 inch. After 36 MGT, longitudinal and transverse cracks originating at screw spike hold down holes were found on nine ties. The majority of the longitudinal cracks measured between 1 and 2 inches past the end of the plates; however, one was 4.5 inches long. There has been no significant crack growth 92 MGT after the cracks were documented, and none of the screw spikes in the rough-sided tie test zone -- including locations where cracks are present -- have worked out.

As shown in Exhibit 14, the root diameter of the screw spikes used in the plastic ties is 5/8 inch and the threads are 15/16 inch. The 5/8-inch pilot hole is adequate for the threaded portion of the screw spike. When the screw spike reaches the 15/16-inch unthreaded neck portion, however, the material splits.

A crack study was performed to measure the internal depth of the cracks and determine how much of the tie cross section was affected. Three of the cracks found on ties 488 and 492 were opened. The cracks were found to be no deeper than approx. 2.5 inches; this depth corresponds with the length of the smooth, non-threaded, neck portion of the screw spikes. The screw spikes removed from these two cracked ties had not worked out. They were still in tight contact with the plates. To isolate the areas affected by the cracks, the rail seat areas were cut out using a band saw. The tie samples were taken to the TTCI Components Test Lab where they were pried open using wedges. Separating the material along the cracks was difficult; the level of resistance to separation was such that neither continued cracking nor screw spike work out under normal in-track conditions appeared to be imminent.

In addition to the screw spike/e-clip installations, two of the rough-sided ties were installed with cut spikes and pre-bored with a 9/16-inch drill bit. There have been no cracks or spikes working out of these two ties.

9.0 DISCUSSION

Improved suspension trucks have greatly reduced the lateral loading on the track in curves. Under the reduced loading of premium suspension trucks, many products provided acceptable service under 39-kip wheel loads. During the 39-kip wheel load standard truck operation, ties with premium fasteners performed appreciably better than ties with cut spikes. Exhibit 41 lists performance under the various operating scenarios.

Exhibit 41. Summary of Performance under the Different Operating Scenarios

Operation	Performance under 33 Kip wheel load	Performance under 39 kip wheel load
Conventional Track, Conventional Trucks	Gage widening and rail wear	HAL Phase I 160 MGT: No significant track geometry degradation during the short phase. Elastic fasteners provided better gage restraint than cut spikes. Light tie-plate cutting.
Premium Track, Conventional Trucks	NA	HAL Phase II 300 MGT: 6-degree curve: Softwood ties required re-gaging after 200 MGT. Hardwood ties gage-widened less rapidly. A manufactured wood tie developed rail seat cracks. Light tie-plate cutting by the end of the phase. Some tie skewing of 24-inch spaced ties.
Premium Track, Improved Suspension Trucks	NA	HAL Phase III 400 MGT: Average lateral load environment reduced 57percent. Projected gage widening life increased from 500 to 2000MGT No gage maintenance was required. No significant tie-plate cutting.
Premium Track, Improved Suspension Trucks and Dry-Rail Operation	NA	HAL Phase IV: No significant change in crosstie performance was documented during the 56.6 MGT of Phase IV.
Premium Track, Conventional Trucks and Lubricated-Rail Operations	NA	HAL Phase V: 9/99 – In progress.

The majority of the gage widening in all the test zones was attributed to rail wear except for the Douglas fir, hem fir, and southern yellow pine ties that reached the FRA Track Safety Standard limit of 1 inch over standard gage during the standard truck operations of Phase II. With that in mind, Exhibit 42 lists the projected gage life and gage widening rates calculated from gage measurements taken over the course of the test.

Exhibit 42. Projected Gage Life and Gage Widening Rates

Phase	Tie Types	Projected Gage Life	Gage Widening Rate
Phases I and II	Hardwood ties, Alternative ties	500 MGT	0.2 in./100 MGT
Phase III	Hardwood ties, Softwood ties, Alternatives	2000 MGT	0.05 in./100 MGT

10.0 FUTURE TESTING

Future cross tie testing at FAST will emphasize new and unproven materials or materials/fastener systems. The performance of existing materials and fastener systems has been shown for a variety of heavy haul operating conditions during the first three phases of HAL testing at FAST.

Among the lessons learned from the long-term tests conducted:

- Test zones should be, at minimum, 200 feet. This allows for 100 ties spaced at 2-foot centers or 123 ties spaced at 19.5-inch centers. Shorter sections are often dominated by outside factors such as transition effects, rail joints, or disturbances caused by rail changes or other required maintenance.
- Stiffness transition zones may be required if greatly different ties are placed in adjacent test sections. End effects often dominate test section performance. A bump in the track can cause vertical motions for up to 200 feet.
- Overlapping rail, tie, and ballast test sections in the same track introduce many compounding factors in analyzing the performance data. For example, rail tests tend to dominate tie tests when there are many "plugs" installed. This is especially true in cut spike fastener test zones.
- Rail with similar age, properties, and design profiles must be used in comparison tie sections. These factors may greatly affect gage widening and lateral loading.
- The load environment must be carefully defined so that comparisons with future test sections are meaningful. Dependent on lubrication and grinding policy, the curves in the HTL have widely different load environments.

  The focus on new testing will be on fewer test sections under more controlled testing conditions. Use of larger test section sizes and pre-screening of potential test candidates, by the proposed AREMA performance specifications, will ensure that limited cross tie testing resources are devoted to providing a good evaluation of the best products.

Certain test sections will continue into future phases of testing to provide baselines and continuity of performance. These sections will provide evidence of the unforeseen effects of certain variable changes. Performance measurements will continue to emphasize the ability to hold gage.

The industry needs a cross tie that provides uniform and predictable service at a low life cycle cost. Cross tie/fastener systems should:

- Hold gage
- Hold alignment
- Minimize rail rotation
- Minimize rolling resistance
- Survive and attenuate impacts
- Electrically isolate the rail for signal systems
- Provide vertical (truck surface) stability

The optimal cross tie material and/or design for heavy haul service has not been developed. TTCI's theoretical modeling work of track and vehicles supplements the FAST testing in developing an understanding of track behavior. Future work will focus on finding a more optimal tie/track system.

11.0 SUMMARY AND CONCLUSIONS

The main objective of the Tie and Fastener Test is to quantify the performance of numerous tie types and fastening systems under 39-ton axle load traffic. An additional objective is to compare the results gathered during the 460 MGT logged in Phases I and II of FAST/HAL operations under standard three-piece trucks, to the results of Phase III testing using vehicles equipped with improved suspension trucks. These trucks provide the benefit of improved curving response with enhanced wheelset steering and resistance to truck warp.

The load environment at FAST under the 315-kip car improved suspension (i.e., passive steering) trucks is, in the lateral plane, less severe than the typical 263-kip car wheel load environment in revenue service. Thus, the use of FAST as a "proof test" for application of new cross tie/fastener products in revenue service during Phase III can be questioned.

Major Findings

The findings listed below have been grouped into these categories: Effect of Truck Suspension, Failure Modes, Effect of Species and Materials, Effect of Fasteners, FAST Test Section Effects.

Effect of Truck Suspension:

Truck suspension has been the largest single factor in tie performance during the HAL experiment. The use of premium suspension trucks with better steering capabilities has greatly improved the performance of all ties tested under 39-kip wheel loads.

- Improved-suspension trucks provided a reduction of about 50 percent in the average lateral loads as compared with standard three-piece trucks.
- The gage-widening rate of ties in the 5-degree curve was affected more by the reduced lateral load environment under the improved-suspension trucks during Phase III than by tie species type or fastening system.
- The projected gage-widening life of all ties in the 5-degree curve, based on a 1-inch limit, increased from 500 MGT under standard-suspension trucks to 2,000 MGT under improved-suspension trucks.
- In the 6-degree curve, during standard-truck operations in Phase II, two hem-fir and two southern yellow pine subzones reached 1 inch over standard gage after 200 MGT. Two Douglas fir subzones reached the same limit after 360 MGT. These subzones were fastened with cut spikes.
- The gage-spreading strength degradation of softwood ties with e-clip and SAFELOK fasteners under standard trucks was comparable to that of softwood ties with cut spikes under improved suspension trucks in Section 7 at 0.5 L/V static loads.

Failure Modes:

Gage widening is the largest cause of wood tie maintenance at FAST. Lateral loading resulting in gage widening, tie splitting, and spike killing are all seen. Vertical loading problems have been minimal, except at abrupt test section stiffness changes. The dry climate of southeastern Colorado prevents wood decay from being a significant factor.

- Tie-plate cutting has not been significant at FAST under improved trucks. Although cracks in ties have not been a major problem, most occur on the field side of high rails.

- The cracks originating at the high-side gage hold-down spikes on the majority of the Oak dowel-laminated ties have not affected track strength while in service for 470 MGT.

Effect of Species/Materials:
Under the more severe load environment of standard trucks, Oak hardwood tie performance, in gage widening, was superior to the performance of softwood ties. Under the more benign load environment of premium trucks, the performance of hardwoods and softwoods was equally good. Both achieved markedly improved gage widening performance. In addition, azobe and various laminated wood ties performed well, resisting gage widening under premium trucks.

- Ties in the 5-degree curve of Section 7 that have not required re-gaging during 920 MGT of service include:

  - Oak with cut spike, e-clip, and double elastic fasteners

  - Douglas Fir ties with cut spike and e-clip fasteners

- In the 6-degree curve, during standard truck operations in Phase II, two hem-fir and two southern yellow pine subzones reached 1 inch over standard gage after 200 MGT. Two Douglas fir subzones reached the same limit after 360 MGT. These subzones were fastened with cut spikes.

- Although higher than in solid hardwood tie track, the gage-widening rate of the mixed-specie subzone in the 6-degree curve, where three southern yellow pine ties were installed for every oak tie, was a low 0.07 inch per 100 MGT under improved-suspension trucks.

- There has been no significant gage degradation in the azobe cut-spike (520 MGT) and elastic-fastener subzones of the 5-degree curve in Section 31.

- During Phase III improved-truck operations, the average measured gage widening rate over the parallel-strand lumber ties with e-clips, the dowel-laminated oak ties with cut spikes, and both the vertical and the horizontal glue-laminated ties with cut spikes was comparable at about 0.02 inch per 100 MGT.

- Cedrite ties, spaced at 19.5 inches and held down with four screw spikes, were removed after 178 MGT during standard-truck operations due to rail-seat cracks in 90 percent of the 6-degree curve installation. The installation in the tangent test zone, spaced at 24 inches and held down with four screw spikes, remains in service after more than 400 MGT.

- Spruce ties, pre-drilled at 3/4 inch for screw-spike hold-downs, were removed from service after 3 MGT due to a number of screw spikes working out.

- The USPL plastic composite ties developed cracks originating at hold down screw spike holes due to the small size of the pre-drilled hole (5/8 inch). The cracks have not propagated during the past 100 MGT. The condition is not affecting track strength.

- The rough-sided USPL plastic composite ties, consolidated by over 10 MGT of traffic, provided 60 percent more lateral resistance in the Single Tie Push Test than wood ties under similar conditions.

12. Trevizo C., "1st Annual AAR Research Review," Proceedings – Volume 1: FAST/HAL Test Summaries, Pueblo, Colorado, November 6-9, 1995.

13. Peter E. Klauser, Curtis L. Urban, Robert L. Florom, "On-Track Test Results For The Heavy Axle Load Alternative Suspension Project," Report No. R-896, Association of American Railroads, October 1996.

TTCI
Transportation
Technology Center, Inc.

55500 DOT Road
P.O.Box 11130
Pueblo, Colorado 81001-0130 USA

A SUBSIDIARY OF THE ASSOCIATION OF AMERICAN RAILROADS