Research and Test Department

TIE PERFORMANCE AT DES PLAINES: 1992 INSPECTION AND GAGE WIDENING TESTS

REPORT R-870

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OF AMERICAN
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Chicago, Illinois

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This report is the tenth progress report from the Des Plaines, IL crosstie test site. The test involves eight sections of crosstie configurations. Variables include crosstie length, cross-section and spacing. This report covers the 1992 inspection and performance measurements. In addition, results from static and dynamic gage widening tests using the Track Loading Vehicle are also included.

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EXECUTIVE SUMMARY

The tie test site at Des Plaines, IL was established in 1967 by the Association of American Railroads, the Railway Tie Association and the Chicago and North Western Transportation Company in 1967 which was the host railroad. The site was established to investigate track design/crosstie configuration issues. Then, as now, concerns about timber supply and the desire to lower track life cycle costs were the main reasons for conducting the test.

Periodic inspections were conducted by the sponsoring organizations. These have ranged from visual crosstie condition inspection to track performance measurements such as dynamic gage widening. A great deal has been determined about crosstie performance under heavy tonnage, tangent mainline conditions. The tradeoff between tie spacing, cross-section, length and average service life has been established for the test site conditions.

This report covers the latest inspections conducted by AAR. These inspections conducted in 1992 consisted of a series of manual tie condition and track performance measurements, as well as static and dynamic tests performed by the Track Loading Vehicle (TLV). These tests include:

- tie moisture content
- tie plate cutting
- unloaded gage
- unloaded crosslevel
- loose spike survey
- (vertically) unloaded gage widening (LTLF) test
- unloaded gage (TLV)
- loaded gage (TLV)
- dynamic gage widening
- static gage widening (vertically loaded)
- static vertical track modulus

Measurements of individual ties show differences between the original and the replacement ties. The time series of measurements made since 1986 are documenting how the ties change/deteriorate over time.

The gage widening tests show the importance of tie spacing on track performance. Use of wider tie spacing reduces the stiffness of the track. The average dynamic gage widening deflection increased .03 in/in tie spacing over the range of 19.5 to 29.25 in. spacing tested. While the test site track is very strong, well exceeding all safety limits, use of wider tie spacing would require a reassessment of current tie maintenance practices; which may rely on the redundancy supplied by standard tie spacing. The tests also show that selective tie replacement does improve the strength of the track. Static tests of gage widening showed higher lateral strengths at locations with new ties. The track is 26% stiffer laterally (gage widening) and 20% stiffer vertically at new tie locations than at original tie locations.

The test continues to provide useful information about crosstie performance and configuration tradeoffs under mainline heavy tonnage conditions.

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The Association of American Railroads (AAR), in conjunction with the Railway Tie Association (RTA) and the Chicago and North Western Transportation Company (CNW), has performed a series of tie tests at the Des Plaines, Illinois test site to determine the effect of tie length, cross-section, and spacing on tie performance. This report is the tenth in a series of progress reports based on these tests. Objective measurements of track and individual tie performance were made during 1992.

In addition to the "standard" series of tie performance measurements (e.g. unloaded gage and crosslevel, tie plate cutting, tie moisture content, etc.) made at previous inspections, measurements of vertical and lateral track stiffness under load were also conducted. The AAR Track Loading Vehicle (TLV) was utilized to perform a series of dynamic gage widening test; followed by a series of static vertical and lateral track stiffness tests. The results of these tests provide a good indication of track performance under severe load conditions. The effects of the tie design and condition parameters under test on track performance will be evaluated.

1.1 BACKGROUND

The Des Plaines test site consists of eight sections of treated wooden crossties of various sizes and spacings. The purpose of the test is to evaluate the performance of the eight test configurations subjected to actual traffic. The effects of tie cross-section, length and spacing on tie performance will be examined. Exhibit 1-1 lists the test section configurations and Exhibit 1-2 shows the site layout. More detailed information on the test

Test Section	Number of Test Ties	Tie Configuration (in x in x ft)	Tie Spacing (inches)
One	480	6 x 8 x 9	19.5
Two	477	7 x 9 x 10	19.5
Three	431	7 x 9 x 9	19.5
Four	479	7 x 9 x 8.5	19.5
Five	400	7 x 9 x 8.5	23.4
Six	291	7 x 9 x 8.5	27.5
Seven	321	7 x 12 x 8.5	29.3
Eight	399	7 x 12 x 8.5	23.4

Exhibit 1-1. Test Section Configurations.

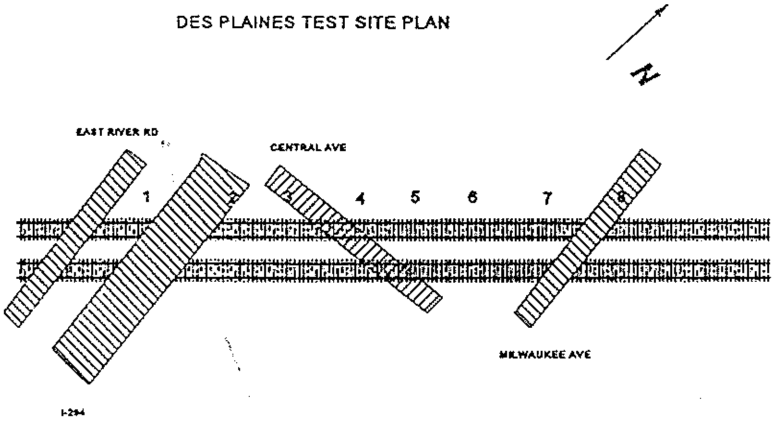

Exhibit 1-2. Des Plaines Test Site.

site may be found in previous progress reports.[1-9]*

Previous inspections have shown differences in tie performance among the eight test sections. Exhibit 1-3 lists the average life projections[9] for the ties in each test section.

Section #	**Tie Size Cross-Section (in x in)**	**Tie Length (ft)**	**Tie Spacing (in)**	**# Tie/ Mile**	**# of Test Ties**	**Cumm. # Removed**	**Cumm. % Removed**	**Proj. Avg. Life (yrs)**
One	6 x 8	9	19.5	3249	478	298	62.3	23
Two	7 x 9	10	19.5	3249	477	92	19.3	31
Three	7 x 9	9	19.5	3249	477	160	33.5	27
Four	7 x 9	8.5	19.5	3249	479	205	42.8	26
Five	7 x 9	8.5	23.4	2711	396	174	43.9	25
Six	7 x 9	8.5	27.5	2304	422	219	51.9	24
Seven	7 x 12	8.5	29.3	2166	319	249	78.1	21
Eight	7 x 12	8.5	23.4	2711	401	110	27.4	29

Exhibit 1-3. Projected Average Life from Tie Replacement Records.

1.1.1 Track Loading Vehicle

Gage widening tests were performed using the AAR Track Loading Vehicle (TLV). The TLV, operated from an instrumentation car, is equipped with two locomotive trucks with a fifth wheel set mounted underneath the center for applying computer controlled loads to the track and measuring its response while stationary or moving. Built on the

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* *Numbers enclosed in brackets refer to the References listed in Section 4.0.*

underframe of a 4,000-hp diesel-electric locomotive, the 263,000-pound TLV can apply forces close to the strength of the rails and other track-structure components such as ties, rail, fasteners, and ballast. However, with the state-of-the art computer controls, such forces can be abated just short of causing actual damage. As an added benefit, the TLV is capable of detecting wide gage and/or weak track. When this happens, a spot of yellow paint is deposited, providing a pinpoint location for preventive maintenance.

At the heart of the vehicle is an electro-hydraulic control and a computer system, which provide the high-speed controls vital to conducting tests without damaging track. The loads are applied to track through a center "load" bogie using servo-controlled hydraulic actuators. The computer controlled loads are applied by six independently controlled servo-hydraulic actuators: two for the vertical, two for the lateral, and two for the gage widening loading systems with force capabilities up to 55,000 lbs. The load bogie has its wheels positioned on a split axle, so that they can apply lateral pressure to the rails independently. The forces are sufficient to spread the gage of the rails. Lateral loads are applied to the track, and the loaded and unloaded track gages are measured. These measurements are used to determine the track gage widening resistance of in-place railroad track.

The TLV control system consists of a primary feedback control provided by the electro-hydraulic system, and a supervisory control by the computer system. The primary control system provides closed loop feedback control to the actuators, monitors motion and force limits, checks the status of the system components, and communicates with the external computer. During operation, the TLV primary control system deals with the small irregularities in the track vertical and lateral alignment, while the supervisory computer control system supplies commands to compensate for major changes in alignment. Active intervention by the computer is also required during transition from tangent to curve, to correct bogie lateral position. The continuous acquisition of data at rates up to 500 Hertz for 40 different measurements is also performed by the computer. The TLV is capable of applying vertical and lateral loads in excess of 39-tons on tangent and curve tracks up to 10 degrees. The maximum test speed at which continuous loaded gage measurements can be made was determined to be 35 mph. The repeatability and accuracy of the measurements were found to be excellent. The vehicle is capable of measuring dynamic gage widening strength of track and of identifying weak track locations under simulated heavy axle loads without causing permanent track damage.

The lateral component of the wheel/rail forces, results from the response of the vehicle to lateral track irregularities, and creep and flange forces which arise from vehicle curving behavior. The lateral forces act to spread the rails apart, resulting in dynamic gage widening, and fastener and tie deterioration. Most track inspection vehicles, such as track geometry cars, must depend on the dynamics of the vehicle to exert peak forces at any soft spot, in order to locate that point as a weak location. Given the differences in vehicle dynamics between the typical track geometry car and the average unit train coal car, or double stack vehicle, it is unlikely that the track geometry car will locate all of the weak spots in the track. Lateral loads measured in service have been as large as 30,000 lbs, depending on the axle load, speed, and the curvature of the track.[10,11] The GRMS applies vertical and lateral loads to track, and measures its response to determine relative track strength. The primary advantage of the TLV concept is the consistent application of peak vertical and lateral loads, independent of the vehicle dynamics of the measuring vehicle.

The TLV is also capable of quantifying the relative strength differences between tracks, which may be in different stages of their maintenance cycles. This information can be used in conjunction with traffic requirements to efficiently prioritize timbering and/or fastener maintenance activities. Moreover, based on the specific load environment seen over the track, economic decisions can be made as to when and to what level the track should be maintained. The data collected by the TLV during the course of the AAR's research effort will support the establishment, in conjunction with the FRA research using the GRMS, of the requirements for a production track inspection system.

2.0 TEST METHODOLOGY

The performance of the ties was measured in 1992 by several methods. A series of static tie and track performance measurements were conducted. These measurements are done bi-annually and provide a time history of tie performance. In addition, a series of gage widening tests, both static and dynamic, give information about the performance of the track under loaded conditions. The gage widening test, measuring tie lateral support, gives a good assessment of tie performance in its most critical function.

2.1 STATIC TIE PERFORMANCE

The test section received its bi-annual inspection in 1992. A series of subjective and objective measurements of tie performance were taken on a sample of the ties. These measurements (tie moisture content, plate cutting, unloaded gage and crosslevel, lateral track strength and loose spike counts) provide information on tie condition and deterioration rates. The tests are briefly described below.

2.1.1 Tie Moisture Content

Moisture content measurements were made on a 5% sample of ties in each section. A resistance type moisture meter was used for measurements, and readings were taken with a one-inch probe at a point one foot from the gage side of the South rail. The same ties have been measured in previous inspections. Thus, moisture content-tie age comparisons may be made.

2.1.2 Tie Plate Cutting

Plate cutting measurements were made on a 10% sample of ties in each section with AAR plate cutting measurement device.[12] The same ties were measured in previous inspections. Thus, the original ties from this group have been measured more than once, allowing recent plate cutting rates to be determined.

2.1.3 Unloaded Gage and Crosslevel

This measurement was made with a gage bar on unloaded track and was taken at every 20th tie in each test section. Unloaded gage provides a mere indication of loaded gage, and can under-represent weak spots. This test measures the performance of groups of ties, a single good or bad tie does not materially affect these unloaded measurements.

2.1.4 Loose Spike Survey

In conjunction with other measurements, the inspector conducted a line spike kick test. This test consisted of lightly kicking each line spike to check for looseness. The spikes were coded by location as follows: 1 = south field side, 2 = south gage side, 3 = north gage side, 4 = north field side. A ten percent sample was inspected.

2.1.5 LTLF Lateral Track Strength

An assessment of track gage widening resistance was made using the Light Track Loading Fixture (LTLF). This device works by applying an outward (from the centerline) lateral load to the rails (without vertical load). Deflection of the rails is measured as a change in track gage. Tests were made at 60 tie intervals. This test measures one component of gage widening resistance: the lateral stiffness of the rail and fasteners. It gives a good indication of the condition of the tie plate areas of a cluster of ties around the test location.

2.2 GAGE WIDENING TESTS

Gage widening tests consisted of a series of dynamic runs across the entire test section and a series of static tests at discrete locations. All tests were conducted using the TLV.

2.2.1 TLV Dynamic Tests

The dynamic runs were conducted in the following sequence:

Run Number	Vertical Load (kips)	Lateral Load (kips)	Direction	Speed (mph)
1	33	18	WB	20
2	33	22	WB	20
3	33	24	WB	20

Unloaded gage and loaded gage are measured continously; with the data stored at a rate of 256 samples per second during the test. Delta gage, the difference between loaded and unloaded gage, is stored at the same rate. Unloaded gage is measured with a laser gage system near the front truck of the TLV. The measurement is on "unloaded" track in the sense that no lateral loads are applied close enough to the measurement point to have an effect on the measurement.

The dynamic test runs were made in sequence of increasing loading. After the first test run was completed; the train was "backed up" to the east of the test sections; then the next test was run. In this manner, all tests were conducted with westbound moves. The return eastbound move, with no applied lateral loading, also allowed the rails to return to "normal" position between test runs.

2.2.2 TLV Static Tests

A series of static gage widening and vertical modulus tests were conducted following the dynamic test runs. Two sites per test section were selected based on tie age and previous performance measurements. Exhibit 2-1 lists the test locations. Essentially, one original (installed in 1967) test tie and one replacement (installed in 1988 or 1990) test tie were selected. Ties were selected on the basis of prior lateral strength measurements. These measurements were made with a Light Track Loading Fixture (LTLF) a few weeks prior to the TLV tests. Other field performance data (such as unloaded gage, unloaded crosslevel tie plate cutting and tie moisture contents) are also available for these ties. The LTLF provides a different measure of tie lateral strength. The device applies a lateral load to the webs of the rails with no vertical load applied. It isolates the lateral strength of the tie/fastener. It does not test fastener hold-down force through rail rotation, or rail/tie friction force through vertical loading.

Tie Number	Tie Spacing (inches)	Install Date (year)	Comment
1280	19.5	1967	Old
1340	19.5	1990	New
2340	19.5	1967	Old
2400	19.5	1988	New
3120	19.5	1967	Old
3180	19.5	1990	New
4200	19.5	1990	New
4260	19.5	1967	Old
5260	23.4	1988	New
5320	23.4	1967	Old
6160	27.5	1967	Old
6280	27.5	1988	New
7240	29.25	1988	New
7300	29.25	1967	Old
8220	23.4	1967	Old
8280	23.4	1988	New

Exhibit 2-1. TLV Static Test Locations.

The loading sequence for static tests consisted of a vertical loading cycle (from 0 to 40 kips) with no lateral load applied followed by a lateral loading cycle (from 0 to 24 kips) with 33 kips vertical load applied. The vertical load was applied first with the lateral load being applied in 1 kip increments. Exhibit 2-2 illustrates the loading sequence. Six deflection measurements were taken: the vertical deflection of each rail at the point of load application (BRL and BRR); the lateral deflection of each rail head at the point of load application (LHDL and LHDR); and the lateral deflection of each rail base under the point of load application (LBDL and LBDR).

2.3 VERTICAL TRACK MODULUS

Vertical track modulus calculations were made from static load-deflection measurements. The sixteen test sites selected for TLV static gage widening tests were also used for the vertical track modulus tests. The tests involved using the TLV to apply vertical loads to the rails. The span of the TLV allows load to be applied through a single wheelset

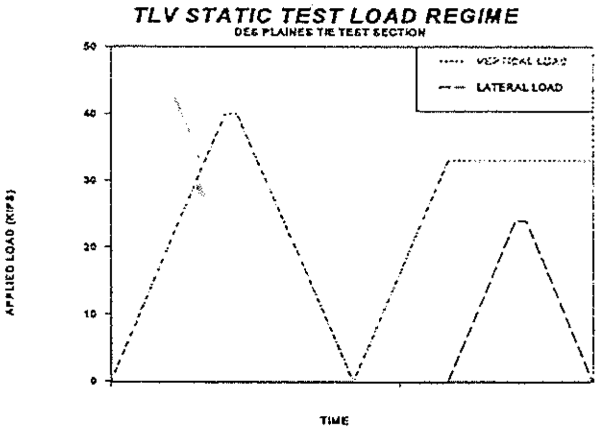

Exhibit 2-2. TLV Static Test Loading Sequence.

without interference from adjacent wheels. Vertical displacement was measured using a ground reference bar (see Exhibit 2-3). Railhead deflection cannot be measured from the TLV due to the frame bending which results from the load application. Vertical load was applied from 0 to 40 kips in 1 kip increments. The vertical deflection of each railhead was recorded. Track modulus was calculated for each test location. A beam-on-elastic-foundation theory was used to calculate track modulus.[13] This method is the simplest to perform in the field since only one deflection measurement location is required. The formula for track modulus is:

$$U = \sqrt[3]{\frac{P^4}{64EIy^4}}$$

where:

U = track modulus (lb/in^2)
EI = stiffness of the rail (lb-in^2)
P = applied wheel load (lb)
y = deflection under the applied load (inches)

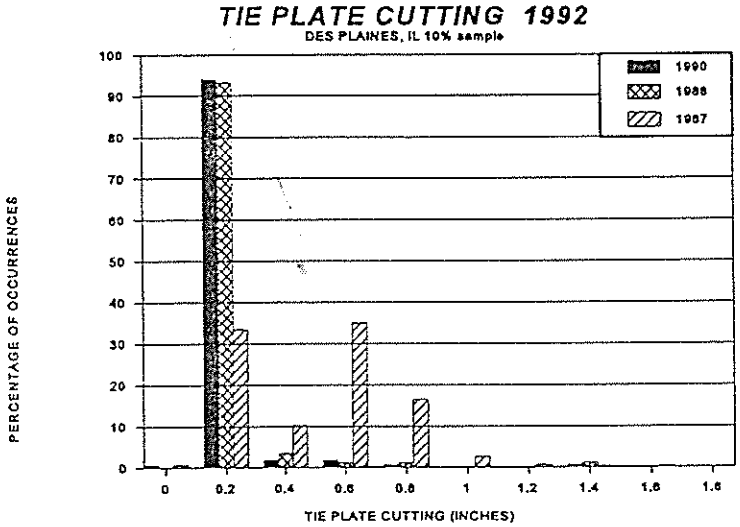

Exhibit 2-3. Vertical Track Modulus Test Set-up.

3.0 TEST RESULTS AND DISCUSSION

The results of the inspections and test measurements made in 1992 are presented in this section. The static tie performance measurements are part of a series of periodic measurements. These measurements look at individual tie condition and deterioration rates. The static and dynamic gage widening tests and vertical track modulus tests look at track performance (i.e. the performance of a group of ties).

3.1 STATIC TIE PERFORMANCE

The results of several subjective and objective tie performance measurements are presented. These measurements include: tie moisture content, plate cutting, unloaded gage and crosslevel, lateral track strength, and a loose spike survey.

3.1.1 Tie Moisture Content

The results of the tie moisture measurements are given in Exhibits 3-1 and 3-2. The data is divided by test section and tie age. No major differences are seen (between test sections) amongst ties of a given age. The environment does not vary appreciably from one test section to the next. Most test sections are on a fill or at grade.

The 1990 ties were drier than the other two age groups. This group had a large portion of it's population with moisture contents of 20 percent or less. The 1988 and 1967 ties had similar average values (32.9 and 33.2 percent) and similar distributions (with "tails" of high moisture content ties).

The 1988 ties show a moisture content distribution similar to the larger sample (of 1988 ties) measured in 1990.[9] The distribution has skewed to the dry side slightly as the average moisture content decreased (from 36 to 33 percent) and the high moisture content

1967	Test Section	No. of Samples	Average (Percent)	STD Dev (Percent)
	One	9	25.67	6.83
	Two	22	33.14	14.50
	Three	14	31.71	9.30
	Four	14	37.29	16.29
	Five	12	29.42	11.18
	Six	8	31.50	4.03
	Seven	3	25.67	3.30
	Eight	16	40.19	14.43
	Total	98	33.17	13.13

1988	Test Section	No. of Samples	Average (Percent)	STD Dev (Percent)
	One	3	24.33	2.49
	Two	2	29.00	0.00
	Three	4	24.25	4.76
	Four	6	34.67	11.48
	Five	7	29.57	9.30
	Six	4	50.50	20.40
	Seven	3	30.33	4.50
	Eight	3	39.00	7.87
	Total	22	32.91	13.03

1990	Test Section	No. of Samples	Average (Percent)	STD Dev (Percent)
	One	12	19.00	4.80
	Two	1	0.00	0.00
	Three	6	19.67	2.21
	Four	4	25.00	6.08
	Five	1	19.00	0.00
	Six	4	36.00	14.02
	Seven	9	37.22	5.14
	Eight	2	36.00	6.00
	Total	38	26.74	10.44

Exhibit 3-1. Moisture Content Measurements at One Inch Depth.

"tail" increased.

The 1967 ties also show a moisture content distribution that is similar to the larger sample that was measured in 1990. The average moisture content remained about the same (33 vs. 32 percent). The tail of high moisture content ties decreased since 1990. Based on these samples, it is highly likely that most of the high moisture content ties were replaced during the 1990 renewal. It should be remembered that the remaining 1967 ties comprise a truncated sample; 44 percent of these ties have been removed.

3.1.2 Tie Plate Cutting

The results of the tie plate cutting measurements are presented in Exhibits 3-3 through 3-5. The results are grouped by test section and tie age. The values presented are the South Rail, North Rail, and Tie averages. The South and North rail averages consist of two measurements; one each from the gage and field sides of the rail. The tie average is the average of all four measurements.

Exhibit 3-3 lists the data by tie age. One can see the significant differences in plate cutting for each group. The newest ties show the fastest average rate of plate cutting at 0.05 in/yr. The 1988 ties have an average rate of 0.04 in/yr over four years. This rate has remained the same since 1990. The 1967 ties have an average rate of 0.02 in/yr over 25 years. The average plate cutting value has not changed since 1990. While the average plate cutting rate is probably lower for these ties, it should be remembered that the worst performers were probably removed since the 1990 measurement.

The initial rate of plate cutting/plate area compression is relatively high compared to subsequent rates. The ties of all ages show a tendency to cut more on the gage sides. The

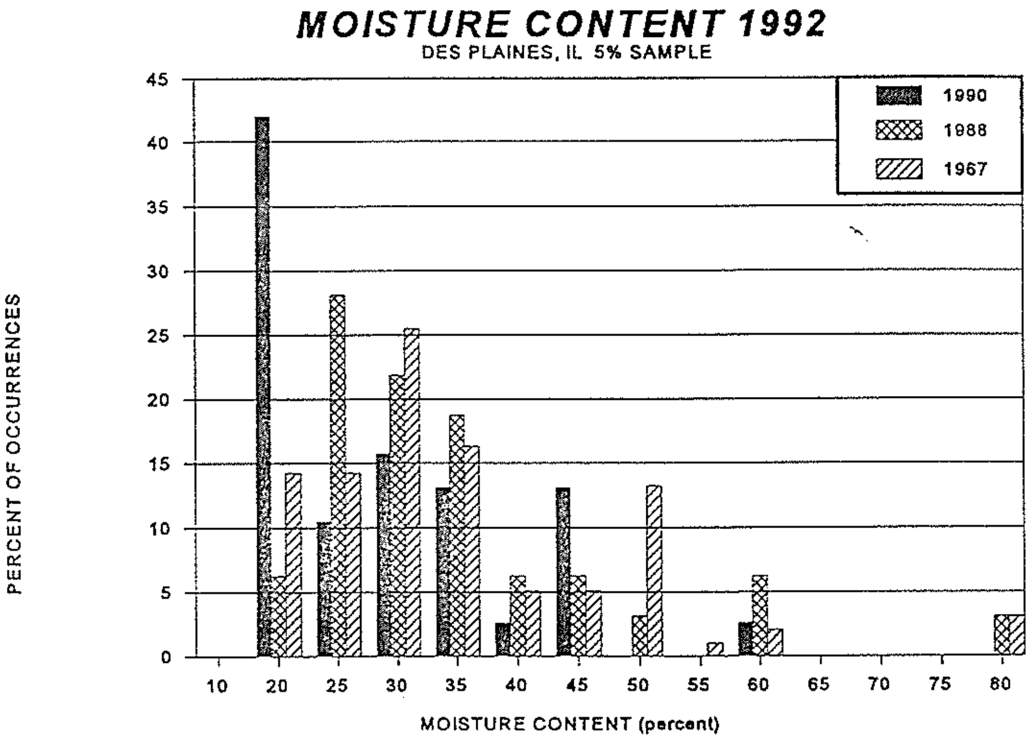

Exhibit 3-2. Moisture Content Distribution.

one each from the gage and field sides of the rail. The tie average is the average of all four measurements.

Exhibit 3-3 lists the data by tie age. One can see the significant differences in plate cutting for each group. The newest ties show the fastest average rate of plate cutting at 0.05 in/yr. The 1988 ties have an average rate of 0.04 in/yr over four years. This rate has remained the same since 1990. The 1967 ties have an average rate of 0.02 in/yr over 25 years. The average plate cutting value has not changed since 1990. While the average plate cutting rate is probably lower for these ties, it should be remembered that the worst performers were probably removed since the 1990 measurement.

The initial rate of plate cutting/plate area compression is relatively high compared to subsequent rates. The ties of all ages show a tendency to cut more on the gage sides. The effect is not large, it is probably a result of the track gage and wheel/rail contact point.

Average Plate Cutting (Inches)

Tie Group	No. of Samples	South Field (SF)	South Gage (SG)	North Gage (NG)	North Field (NF)	South Average (SF&SG)	North Average (NG&NF)	All Average
1967	196	0.50	0.55	0.57	0.49	0.52	0.53	0.53
1988	90	0.13	0.18	0.19	0.12	0.16	0.15	0.15
1990	65	0.09	0.11	0.12	0.09	0.10	0.10	0.10

Exhibit 3-3. Average Plate Cutting by Location and Tie Age Group.

AVERAGE PLATE CUTTING (inches)

1967	No. of Samples	South Average	STD Dev	North Average	STD Dev	All Average	STD Dev
One	21	0.55	0.11	0.60	0.14	0.58	0.11
Two	42	0.57	0.15	0.59	0.20	0.58	0.16
Three	27	0.57	0.18	0.51	0.17	0.54	0.15
Four	31	0.46	0.20	0.46	0.18	0.46	0.18
Five	16	0.45	0.12	0.47	0.15	0.46	0.13
Six	11	0.37	0.18	0.38	0.19	0.38	0.18
Seven	4	0.63	0.41	0.84	0.61	0.74	0.50
Eight	32	0.53	0.18	0.54	0.20	0.54	0.18

1988	No. of Samples	South Average	STD Dev	North Average	STD Dev	All Average	STD Dev
One	11	0.12	0.04	0.12	0.02	0.12	0.02
Two	5	0.13	0.03	0.12	0.02	0.12	0.02
Three	13	0.15	0.05	0.13	0.03	0.14	0.03
Four	13	0.14	0.05	0.14	0.08	0.14	0.06
Five	20	0.13	0.03	0.14	0.02	0.13	0.02
Six	9	0.21	0.16	0.23	0.21	0.22	0.18
Seven	11	0.25	0.33	0.22	0.31	0.23	0.32
Eight	6	0.13	0.03	0.12	0.03	0.12	0.03

1990	No. of Samples	South Average	STD Dev	North Average	STD Dev	All Average	STD Dev
One	16	0.08	0.03	0.08	0.04	0.08	0.03
Two	1	0.07	ERR	0.11	ERR	0.09	0.00
Three	8	0.09	0.04	0.09	0.04	0.09	0.03
Four	5	0.08	0.03	0.07	0.02	0.08	0.02
Five	4	0.11	0.04	0.15	0.04	0.13	0.03
Six	10	0.17	0.14	0.18	0.15	0.18	0.14
Seven	18	0.08	0.05	0.10	0.05	0.09	0.05
Eight	3	0.10	0.03	0.07	0.07	0.08	0.05

Exhibit 3-4. Average Plate Cutting by Age Group and Test Section.

There are differences in plate cutting performance among the eight test sections. As has been previously reported,[7,8,9] the dowel laminated 7 x 12 inch ties showed higher amounts of plate cutting. This is especially evident on the (section seven) ties with the very wide 29.25 inch spacing. Even after replacing half of the test ties in 1990 (after replacing 28 percent in 1988), the remaining section seven 1967 ties have the highest amount of plate cutting.

Exhibit 3-5 shows average tie plate cutting histograms for each age group of ties. The original (1967) ties are showing a two peak distribution. One group of ties has relatively low cumulative plate cutting (0.2 to 0.4 inches) and a current plate cutting rate that is nil. The other group has a higher amount of plate cutting (0.6 - 0.7 inches) and higher current rates. The stable group may be protected by good or new adjacent ties. The higher plate cutting group may be deteriorating and approaching the end of its useful life.

3.1.3 Unloaded Gage and Crosslevel

These measurements are affected by the tie replacement and track surfacing operations done by the railroad. Ties were replaced and the track surfaced in 1988, and again in 1990. The 1990 maintenance occurred after the 1990 inspection and measurements conducted by AAR.

The results of the gage and crosslevel measurements are shown in Exhibits 3-6 through 3-9. The entire test track has good surface and alignment; which is reflected in the gage and crosslevel measurements. By age group, the gage shows a slight increase with tie age. The crosslevel shows no relationship between crosslevel and age. These results correspond with the recent tie maintenance i.e., regaging occurs at the tie replacement

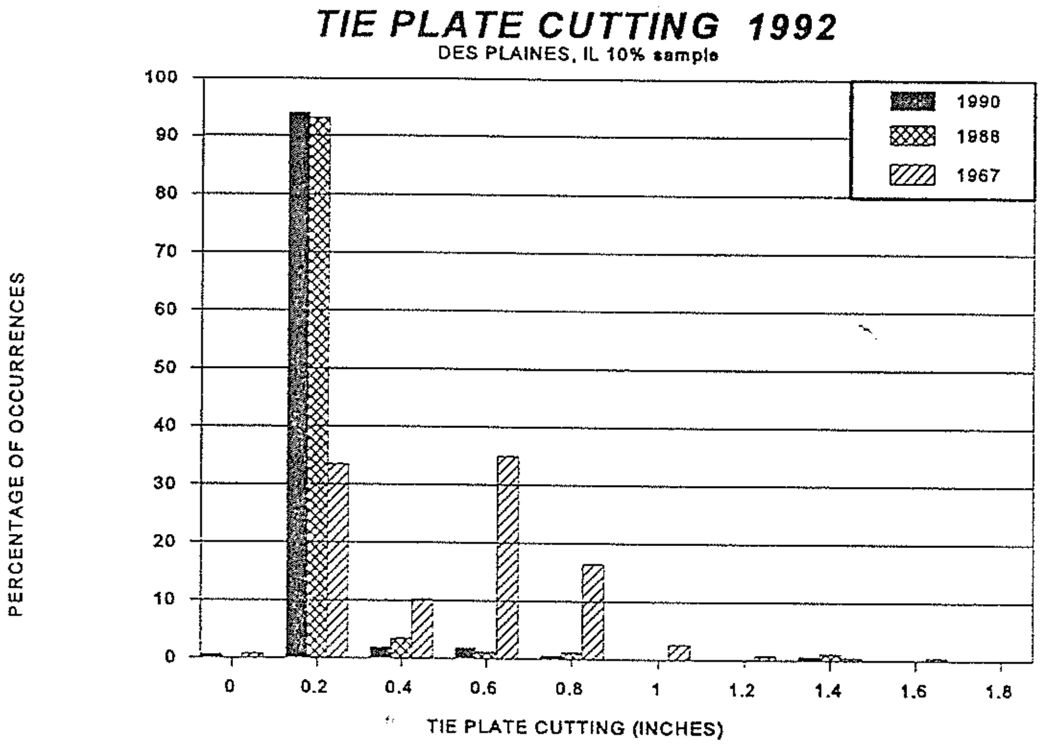

Exhibit 3-5. Plate Cutting Distribution.

1967	Test Section	No. of Samples	Gage Average (56+x/16 inches)	STD Dev (x116 inches)
	One	9	7.44	2.11
	Two	22	8.68	1.36
	Three	14	8.93	1.33
	Four	14	9.07	1.39
	Five	12	9.08	1.04
	Six	12	9.42	1.61
	Seven	2	9.50	2.50
	Eight	16	9.56	1.06
	Total	101	8.45	1.54

1988	Test Section	No. of Samples	Gage Average (56+x/16 inches)	STD Dev (x116 inches)
	One	3	7.33	0.94
	Two	2	9.00	1.00
	Three	4	9.75	0.83
	Four	6	9.00	1.29
	Five	7	7.57	0.90
	Six	6	8.50	0.76
	Seven	6	6.00	1.91
	Eight	3	8.67	0.94
	Total	37	8.08	1.65

1990	Test Section	No. of Samples	Gage Average (56+x/16 inches)	STD Dev (x116 inches)
	One	12	7.00	1.83
	Two	1	0.00	0.00
	Three	6	8.17	1.34
	Four	4	8.00	1.41
	Five	1	11.00	0.00
	Six	4	8.75	1.48
	Seven	8	5.50	1.87
	Eight	2	9.50	0.50
	Total	37	7.41	2.09

Exhibit 3-6. Unloaded Track Gage by Tie Age and Test Section.

1967	Test Section	No. of Samples	Crosslevel Average (x 116 inches)	STD Dev (x116 inches)
	One	21	1.29	1.69
	Two	42	1.93	2.23
	Three	27	1.44	1.91
	Four	31	1.13	1.56
	Five	16	1.94	1.60
	Six	23	1.65	2.06
	Seven	4	1.50	1.50
	Eight	32	0.47	0.71
	Total	101	1.39	1.83

1988	Test Section	No. of Samples	Crosslevel Average (x 116 inches)	STD Dev (x116 inches)
	One	11	0.82	1.40
	Two	5	1.60	2.06
	Three	13	1.08	1.73
	Four	13	1.08	1.38
	Five	20	1.70	2.55
	Six	11	1.73	1.71
	Seven	11	1.73	1.66
	Eight	6	1.33	1.37
	Total	37	1.39	1.89

1990	Test Section	No. of Samples	Crosslevel Average (x 116 inches)	STD Dev (x116 inches)
	One	16	1.81	1.78
	Two	1	0.00	0.00
	Three	8	3.38	2.18
	Four	5	1.60	0.80
	Five	4	1.00	1.73
	Six	10	1.00	1.41
	Seven	18	1.06	1.27
	Eight	3	0.67	0.47
	Total	37	1.52	1.73

Exhibit 3-7. Unloaded Crosslevel by Tie Age and Test Section.

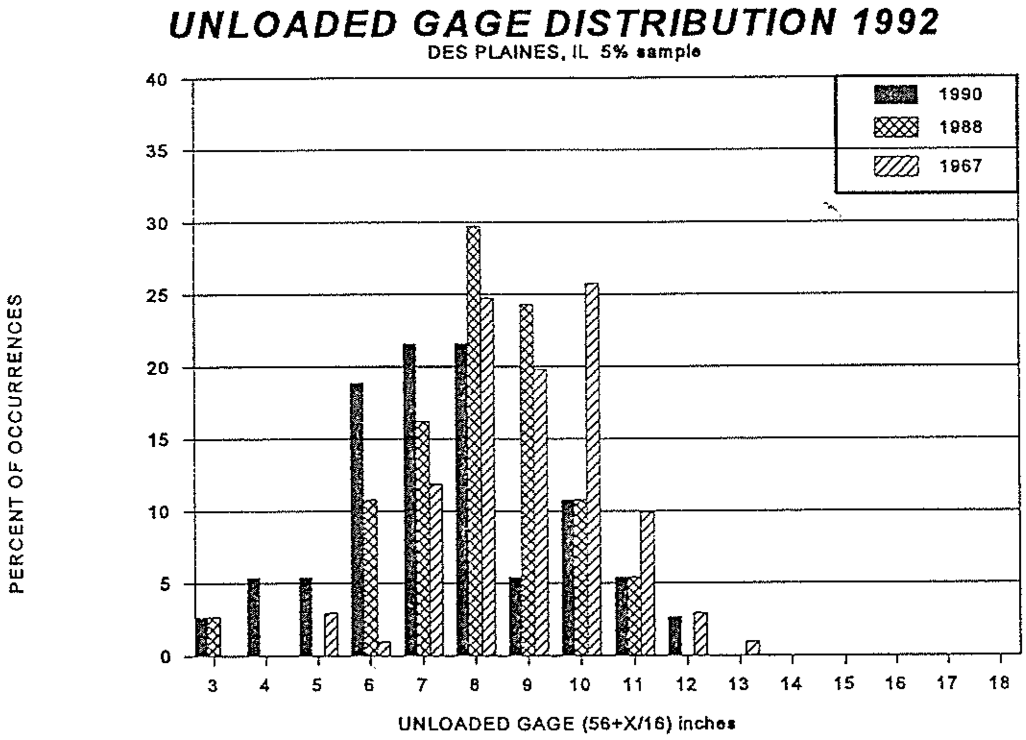

Exhibit 3-8. Track Gage Distribution.

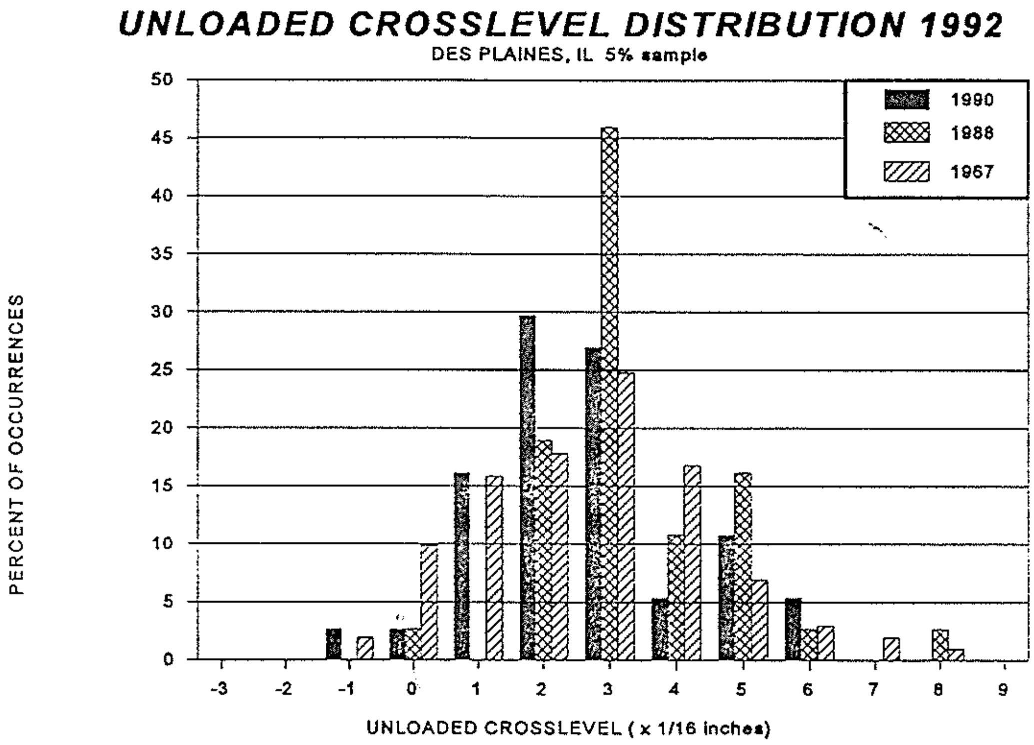

Exhibit 3-9. Crosslevel Distribution.

locations, whereas surfacing occurs throughout the test section.

The relationship between test section (i.e. tie spacing) and unloaded gage and crosslevel is weak. There appears to be a slight increase in average gage with tie spacing among the 1967 ties. There appears to be no relationship between average crosslevel and tie spacing.

Recent tie/track maintenance has affected these relationships. Sections with more failed/replaced ties are more affected than the rest. However, one can conclude that the tie configuration differences between the eight test sections do not greatly affect track performance in this operating environment.

3.1.4 Loose Spike Survey

The results of the loose spike "kick" survey are presented in Exhibits 3-10 through 3-12. The results by age are quite interesting. The 1990 ties have no loose spikes. The 1988 ties have about 2% loose spikes after 4 years in track. About 48% of the remaining 1967 ties have loose spikes after 25 years in track.

Exhibit 3-11 shows the relationship between the percentage of ties with loose spikes and tie age. Spike loosening is a time-dependent process. It is also a very localized process; few ties have all spikes loose. As the table in Exhibit 3-12 shows, spike loosening is almost equally likely to occur at any of the four rail hold-down locations. Also, few ties have more than two loose spikes.

The mechanism(s) that produce spike loosening are poorly understood. Based on these observations, it appears likely that mechanical loading is only one of several factors. The local condition of the wood in the spike hole areas is a major factor. Many times a spike on one side of the rail will still be tight when the spike on the other side of the rail is loose. Chemical and biological degradation are likely contributors based on the time of occurrence. Mechanical action, from splitting, and repeated load fatigue may also contribute.

1967	**Test Section**	**No. Ties**	**No. Loose**	**Percent Loose**
	One	21	12	57
	Two	42	20	48
	Three	27	13	48
	Four	31	11	35
	Five	16	7	44
	Six	23	7	30
	Seven	4	3	75
	Eight	32	21	66
	Total	196	91	48

1967	**Test Section**	**No. Ties**	**No. Loose**	**Percent Loose**
	One	11	0	0
	Two	5	0	0
	Three	13	0	0
	Four	13	0	0
	Five	20	0	0
	Six	11	1	9
	Seven	11	1	9
	Eight	6	0	0
	Total	90	2	2

1967	**Test Section**	**No. Ties**	**No. Loose**	**Percent Loose**
	One	16	0	0
	Two	1	0	0
	Three	8	0	0
	Four	5	0	0
	Five	4	0	0
	Six	10	0	0
	Seven	18	0	0
	Eight	3	0	0
	Total	65	0	0

Exhibit 3-10. Loose Spike Survey Results by Tie Age and Test Section.

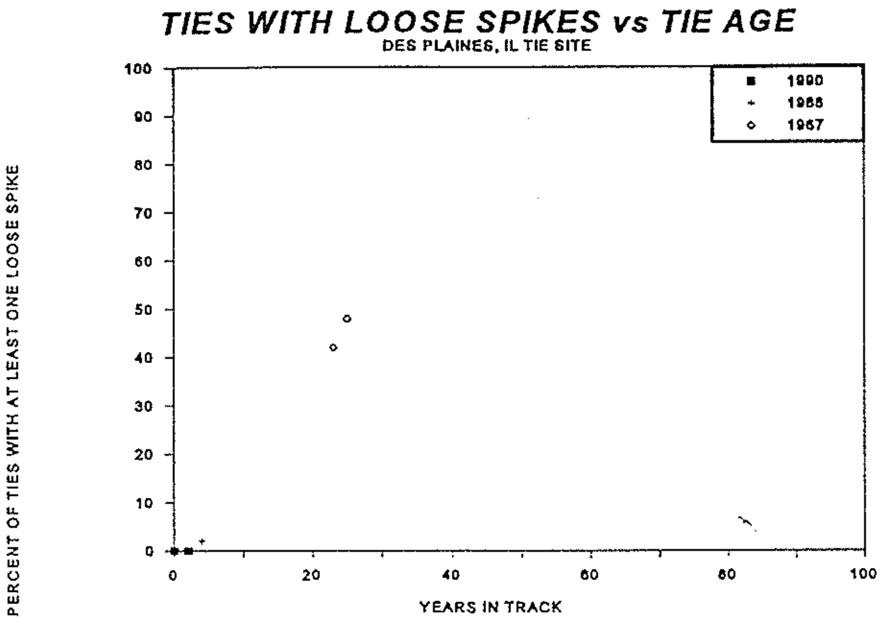

Exhibit 3-11. Percent Loose Spikes vs. Tie Age.

Loose Spike Count

Tie Age Group	South Field		South Gage		North Gage		North Field	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1967	39	19.9	35	17.9	29	14.8	37	18.9
1988	2	2.2	1	1.1	1	1.1	2	2.2
1990	0	0.0	0	0.0	0	0.0	0	0.0

Exhibit 3-12. Loose Spike Count By Location on Tie.

3.1.5. Lateral Track Strength (LTLF)

The results of testing the lateral strength of the track with the LTLF are given in Exhibits 3-13 and 3-14. These results show calculated lateral stiffnesses (with no vertical load) of 20,000 to 50,000 lbs./in. As Exhibit 3-14 also shows the newer ties are generally stronger, with few values below 25,000 lbs./in. The 1967 ties represent a truncated sample; with (presumably) the weakest ties removed.

The LTLF test measures the strength/condition of the fasteners and tie plates of a cluster of ties around the load application point. It does not directly measure the gage widening resistance of the track.

3.2 GAGE WIDENING TESTS

The results of gage widening tests conducted at the test site using the TLV (TLV) are presented below. The results from the dynamic runs are presented in Section 3.2.1. Three vertical and lateral load combinations were selected for testing. In sections 3.2.2 and 3.2.3, the results of static tests of individual ties are presented.

3.2.1 Dynamic Gage Widening

Exhibits 3-15 through 3-17 are statistics from the dynamic gage widening tests made at the test section using lateral loads of 18, 22, and 24 kips. The results of the 18 and 22 kip runs show no exceedences of the AAR defined inspection limits of 57.75 inches loaded gage and 1.25 inches delta gage (loaded gage - unloaded gage). At 24 kips lateral load, two exceptions were found. The first was an exception of both loaded gage and delta gage limits. The location of the exception was on the west (far) end of the bridge and approach over Central Avenue in test section three (see Exhibit 3-18). The bridge ties, being part of the structure of the bridge, are not part of the tie test. The bridge approaches have the typical "dips" or low spots near the bridge. The ties and fasteners appear to be deteriorated in this area. Also, the spalls and metal flow on the rails suggest that a lot of energy is being expended here as cars bounce through. Exhibit 3-19 shows this location.

The second exception occurred in section six (7" x 9" x 8.5' ties on 27.5 inch spacing). It was a loaded gage exceedence (of 57.75 inches). No obvious track defects were seen at this location. There are three field welds in the weak area.

It should be remembered that a loading of 33 kips vertical and 24 kips lateral is quite extreme and would rarely, if ever, occur in tangent track. Such a loading is applied for research purposes only.

Exhibit 3-20 is a summary of the dynamic gage widening tests. The effect of tie spacing can be seen in this exhibit. The correlation between gage widening and tie spacing is quite good. For all three lateral loading levels the average gage widening increases by about .03 inches per inch of increase in the tie spacing (from the standard of 19.5). The amount of maintenance (i.e. percentage and distribution of new ties installed) also affects this relationship. Further, one can see the large effects of increasing lateral loading from 18 kips to 22 kips or 24 kips (under a 33 kip vertical load). This additional deflection, in the range of 50 to 100 percent of the deflection at 18 kips is large, because we are exceeding the resistance provided by the vertical load.

3.2.2 Static Gage Widening

The results of the 16 static gage widening tests are presented in Exhibits 3-21 through 3-25. The head and base lateral deflections of each rail were measured during each test. In addition, the vertical deflection of each rail was also measured. Note that the average lateral base deflection is 0.09 inches, while the average lateral head deflection is 0.38 inches under the 33 kip vertical and 24 kip lateral loading. Thus, about one fourth of the deflection is due to translation of the rail, the rest is due to rail rotation and bending.

Using the loads and deflections measured, gage widening stiffnesses and total gage widening are calculated. Differences in performance were observed among the eight test sections. The largest factors were nominal tie spacing and tie age.

Gage widening was positively correlated with tie spacing. Gage widening stiffness is inversely correlated with tie spacing. Calculated gage widening stiffnesses ranged from 24,000 to 54,000 lbs/in of gage widening. The stiffness was calculated from the deflection at 24,000 lbs of load applied to each rail.

There were distinct differences between the 1967 ties and the replacement ties (1988 and 1990). The 1967 ties had more gage widening, 26% on average, than the replacement ties. A closer look at the data shows the differences to be in the head deflection. The base deflections of both groups are equal (Exhibit 3-24). The difference is due to rail bending and rail rolling. Tie plate area and fastener condition likely account for the difference in performance observed.

Further study of the effect of adjacent ties on lateral strength showed that the age of these ties did affect lateral strength. Exhibit 3-25 is a plot of lateral strength vs. number of 1967 ties in a cluster of 5 centered on the test location.

3.2.3 Comparison of Static TLV and LTLF Tests

Comparison of TLV and LTLF lateral gage widening test results shows the differences between a (vertically) loaded test and an unloaded one.

Exhibit 3-15 shows LTLF (V=0, L=10 kips) and static TLV (V=33, L=24 kips) test

1967	Test Section	No. of Samples	Average (lbs/in)	STD Dev (lbs/in)
	One	3	23600	4418
	Two	7	24367	5221
	Three	5	25920	2352
	Four	2	24000	0
	Five	2	20000	4000
	Six	5	19314	2756
	Seven	1	16000	0
	Eight	5	23429	6781

1988	Test Section	No. of Samples	Average (lbs/in)	STD Dev (lbs/in)
	One	1	36000	0
	Two	1	24000	0
	Three	1	28800	0
	Four	3	25600	2263
	Five	5	25234	3169
	Six	2	20571	0
	Seven	2	28800	0
	Eight	1	20571	0

1990	Test Section	No. of Samples	Average (lbs/in)	STD Dev (lbs/in)
	One	4	34200	3118
	Two	0	NA	NA
	Three	1	48000	0
	Four	3	28800	0
	Five	0	NA	NA
	Six	0	NA	NA
	Seven	3	26057	3879
	Eight	1	28800	0

Exhibit 3-13. LTLF Lateral Stiffness at 10,000 lbs by Tie Age and Test Section.

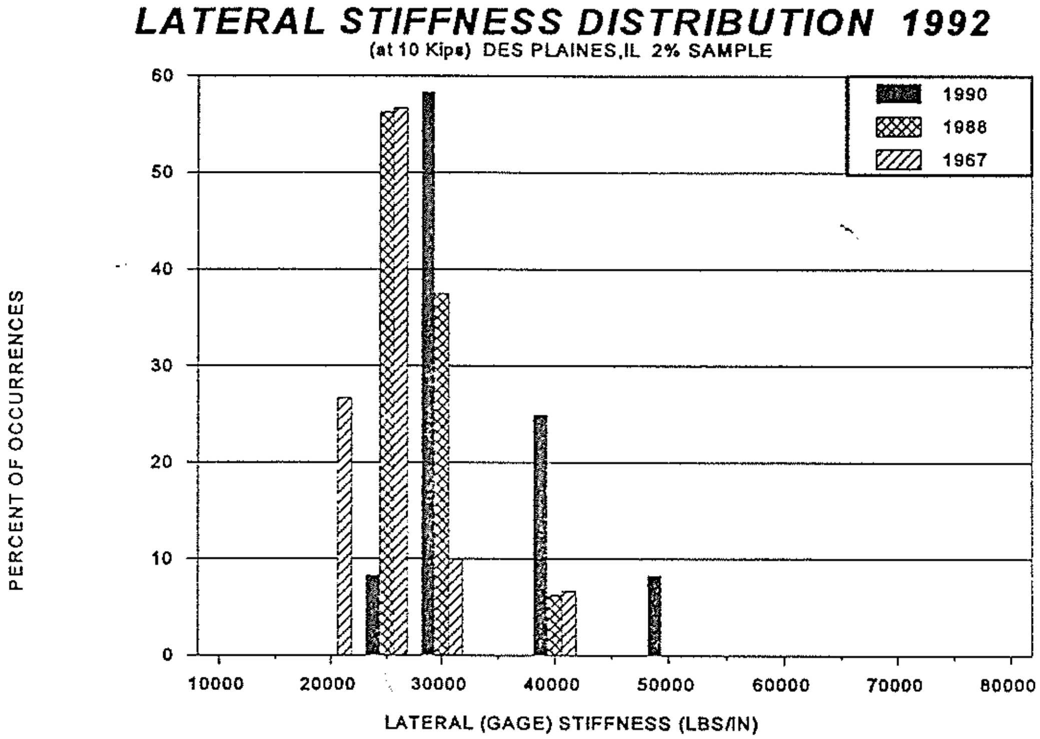

Exhibit 3-14. LTLF Lateral Stiffness Distribution.

Test Section	Unloaded Gage		Loaded Gage		Delta Gage	
	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)
One	56.32	0.14	56.74	0.1	0.42	0.07
Two	56.41	0.1	56.77	0.07	0.37	0.06
Three	56.46	0.09	56.87	0.09	0.42	0.09
Four	56.46	0.07	56.86	0.05	0.41	0.06
Five	56.47	0.08	56.9	0.7	0.44	0.07
Six	56.49	0.1	56.94	0.11	0.45	0.09
Seven	56.28	0.15	56.76	0.14	0.48	0.07
Eight	56.48	0.09	56.91	0.06	0.43	0.05

Exhibit 3-15. TLV Dynamic Gage Widening Test Results (18 Kips Lateral Load).

Test Section	Unloaded Gage		Loaded Gage		Delta Gage	
	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)
One	56.33	0.14	56.94	0.10	0.60	0.08
Two	56.44	0.09	56.98	0.09	0.54	0.08
Three	56.48	0.09	57.09	0.11	0.62	0.11
Four	56.48	0.07	57.09	0.05	0.61	0.06
Five	56.49	0.07	57.16	0.08	0.67	0.08
Six	56.64	0.10	57.21	0.11	0.70	0.09
Seven	56.31	0.15	57.04	0.15	0.73	0.07
Eight	56.50	0.08	57.18	0.07	0.68	0.07

Exhibit 3-16. TLV Dynamic Gage Widening Tests Results (22 Kips Lateral Load)

Test Section	Unloaded Gage		Loaded Gage		Delta Gage	
	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)	Mean (inches)	Std. Dev. (inches)
One	56.36	0.14	57.07	0.13	0.72	0.09
Two	56.45	0.09	57.13	0.10	0.69	0.08
Three	56.48	0.09	57.22	0.11	0.74	0.10
Four	56.49	0.07	57.22	0.07	0.73	0.08
Five	56.51	0.07	57.32	0.08	0.81	0.08
Six	56.54	0.10	57.38	0.13	0.84	0.10
Seven	56.37	0.14	57.21	0.17	0.83	0.08
Eight	56.52	0.08	57.35	0.10	0.83	0.09

Exhibit 3-17. TLV Dynamic Gage Widening Test Results (24 Kips Lateral Load).

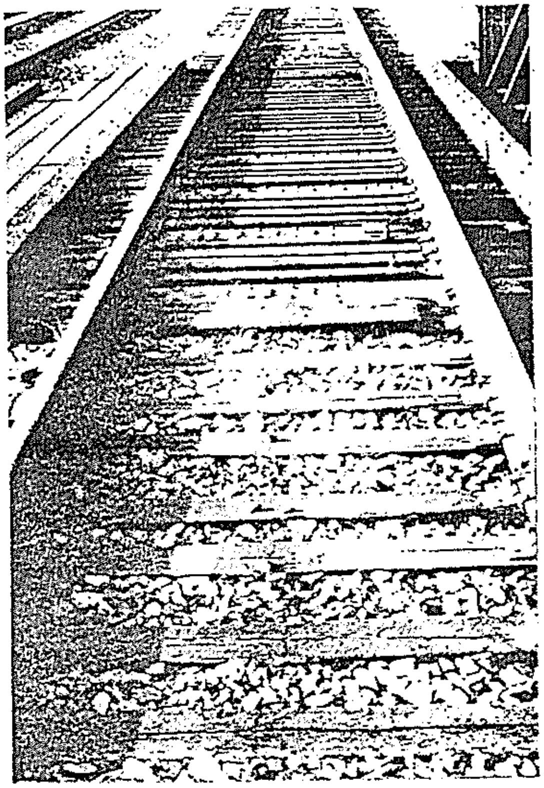

Exhibit 3-18. TLV Dynamic Test "Wide Gage" Spot 1.

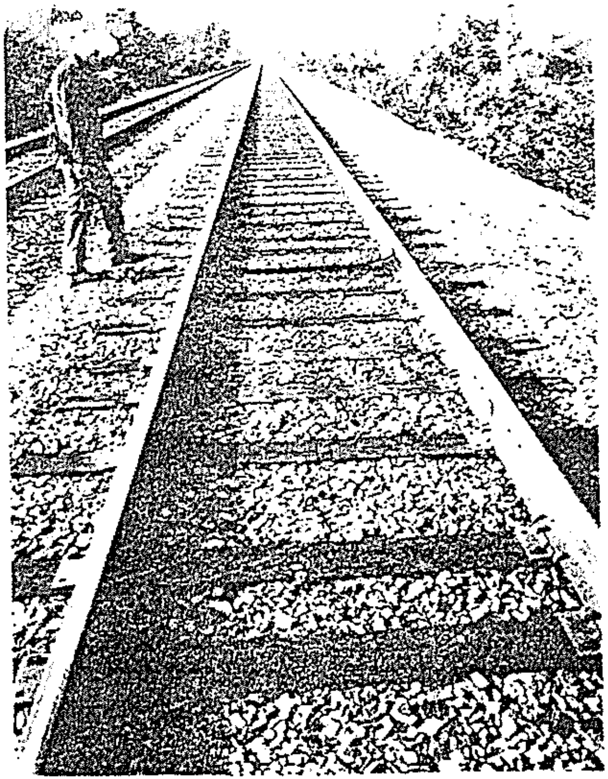

Exhibit 3-19. TLV Dynamic Test "Wide Gage" Spot 2.

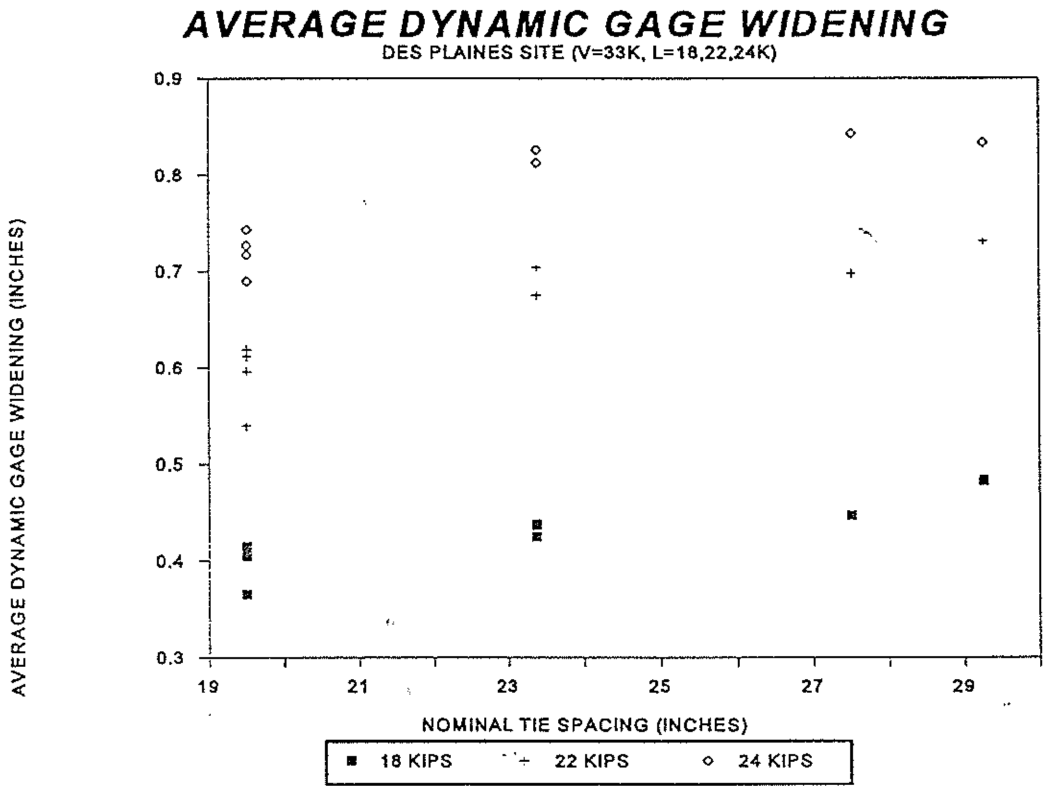

Exhibit 3-20. TLV Dynamic Gage Widening Test Summary.

				Lat. Head Displ.		Lat. Base Displ.	
Tie Number	**Install Date (year)**	**Tie Spacing (inches)**	**Comments**	**Left LHDL (inches)**	**Right LHDL (inches)**	**Left LBDR (inches)**	**Right LBDR (inches)**
1340	90	19.5	New	0.28	0.24	0.05	0.04
2400	88	19.5	New	0.22	0.30	0.09	0.04
3180	90	19.5	New	0.28	0.26	0.06	0.04
4200	90	19.5	New	0.28	0.28	0.05	0.03
5260	88	23.4	New	0.32	0.38	0.09	0.10
6280	88	27.5	New	0.38	0.42	0.16	0.16
7240	88	29.25	New	0.44	0.48	NA	0.12
8280	88	23.4	New	0.42	0.42	0.16	0.12
1280	67	19.5	Old	0.34	0.28	0.08	0.08
2340	67	19.5	Old	0.42	0.50	0.08	0.12
3120	67	19.5	Old	0.36	0.30	0.06	0.03
4260	67	19.5	Old	0.40	0.32	0.05	0.05
5320	67	23.4	Old	0.50	0.58	0.10	0.10
6160	67	27.5	Old	0.42	0.42	0.09	0.07
7300	67	29.25	Old	0.54	0.62	0.16	0.15
8220	67	23.4	Old	0.38	0.44	0.06	0.09
AVG				0.37	0.39	0.09	0.08
STD DEV				0.08	0.11	0.04	0.04

Exhibit 3-21. TLV Static Gage Widening Test Results: Deflections.

Tie Number	Install Date (year)	Tie Spacing (inches)	Comments	Gage Widening (inches)	Lateral Stiffness (lbs/in)
13400	90	19.5	New	0.52	53846
2400	88	19.5	New	0.52	53846
3180	90	19.5	New	0.54	51852
4200	90	19.5	New	0.56	50000
5260	88	23.4	New	0.70	40000
6280	88	27.5	New	0.80	35000
7240	88	29.25	New	0.92	30435
8280	88	23.4	New	0.84	33333
1280	67	19.5	Old	0.62	45161
2340	67	19.5	Old	0.92	30435
3120	67	19.5	Old	0.66	42424
4260	67	19.5	Old	0.72	38889
5320	67	23.4	Old	1.08	25926
6160	67	27.5	Old	0.84	33533
7300	67	29.25	Old	1.16	24138
8220	67	23.4	Old	0.82	34146
AVG				0.76	38935
STD				0.19	9413
MAX				1.16	53846
MIN				0.52	24138

Exhibit 3-22. TLV Static Gage Widening Test Results: Stiffnesses.

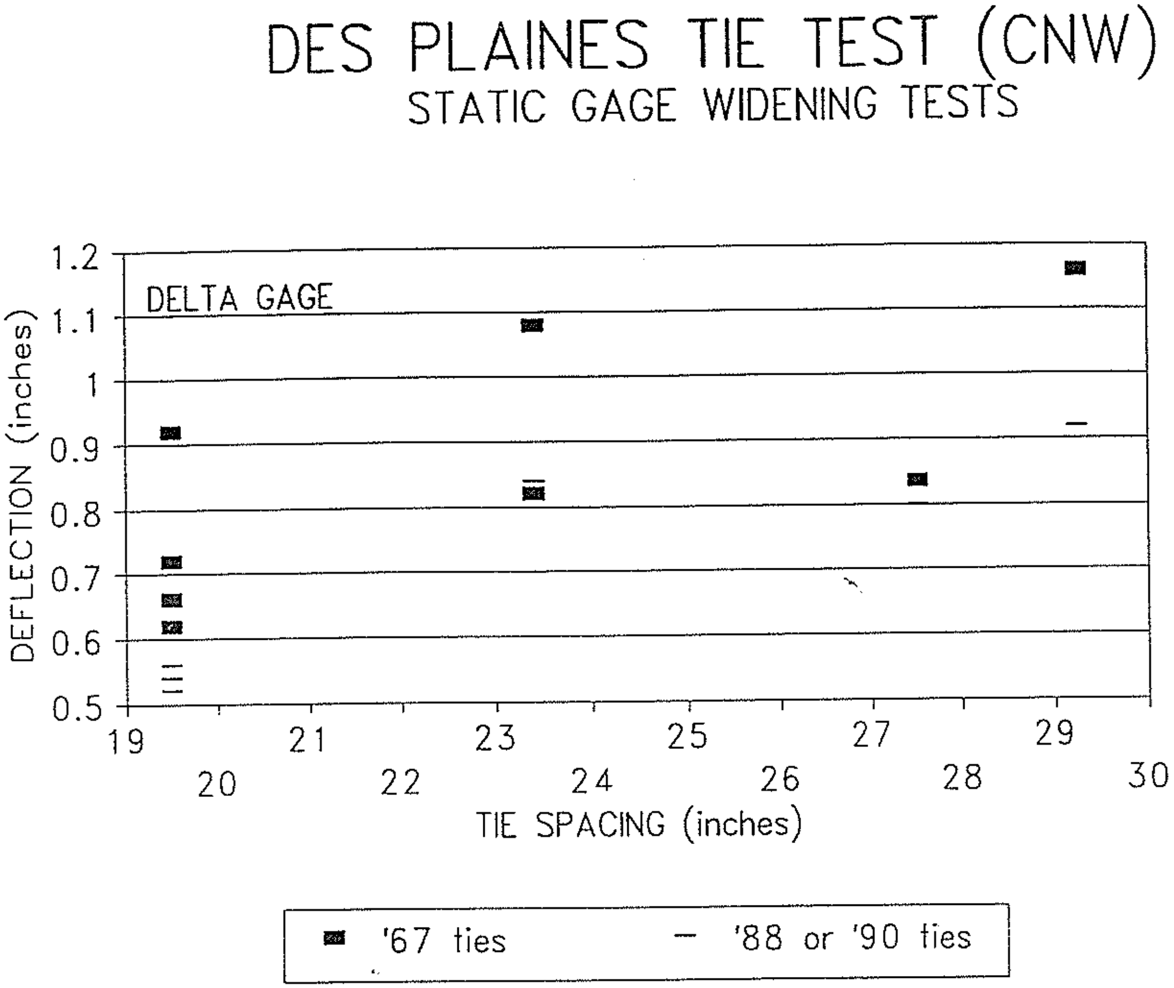

Exhibit 3-23. TLV Static Gage Widening vs. Tie Spacing

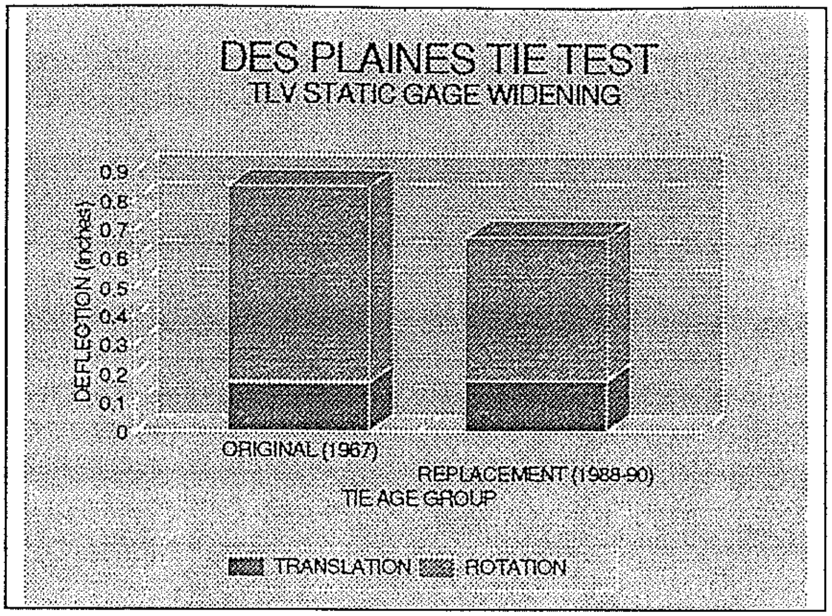

Exhibit 3-24. Lateral Rail Deflection by Mode and Tie Age.

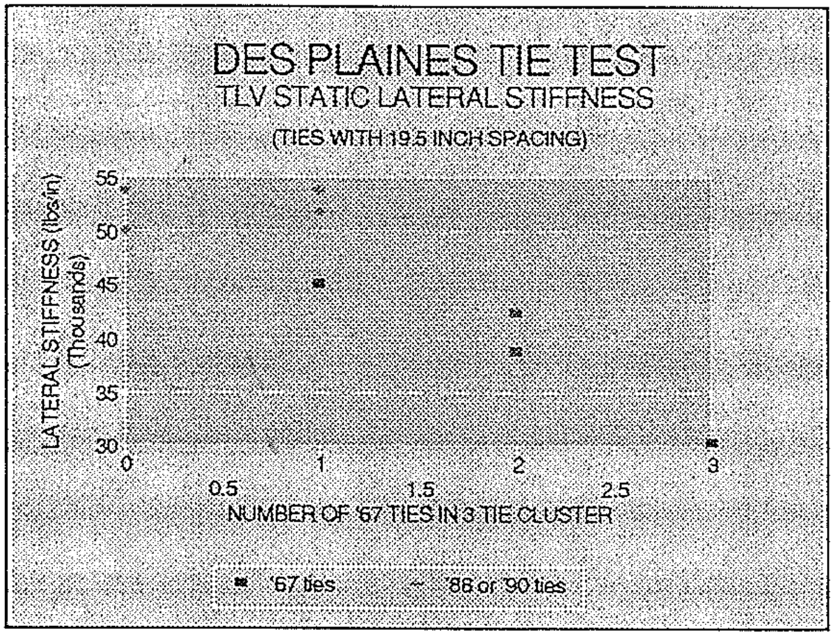

Exhibit 3-25. Lateral Stiffness vs. Condition of Adjacent Ties.

results for the same locations. The vertical loading and higher lateral loading in the TLV tests result in larger stiffnesses.

Correlation between the two tests is quite good ($r^2 = 0.93$) for the 1967 ties. The correlation between the two tests is poor ($r^2 = 0.19$) for the replacement ties. Since the LTLF tests the lateral resistance of the fasteners alone, there must be a good correlation between this factor and the loaded lateral resistance (e.g. TLV test) in the 1967 ties. For the new ties, other factors are more significant in determining loaded lateral strength.

The practical significance of this finding is that the LTLF can probably be used as a substitute/supplement to the TLV in most wood tie revenue track tests. Ease of usage, and operating cost savings, make the LTLF test an obvious choice for small-scale, time series testing.

3.3 VERTICAL TRACK MODULUS

The results of the static modulus tests are given in Exhibits 3-27 through 3-29. The deflections for each rail at 40,000 lbs are shown. The average value (per tie) was 0.14 inches; with a standard deviation of 0.03 inches. One side/rail (the South rail) was consistently stiffer than the other. This may be due to differences in subgrade stiffness; the South rail is adjacent to the eastbound track. The longitudinal stress state of the rails may be different, as well. This can alter the vertical load-deflection relationship, too.

Differences in stiffness were noted among the test sections. The track with wider spaced ties generally had lower vertical stiffnesses. Exhibit 3-28 is a plot of track modulus vs. tie spacing.

Another factor which affected track modulus was the age of the tie(s) being tested. Exhibit 3-29 lists track modulus by tie age group. The average value for the 1967 ties tested was 3670 lbs/in/in. The average value for the new ties (1988 and 1990) was about 20%

higher at 4275 lbs/in/in.

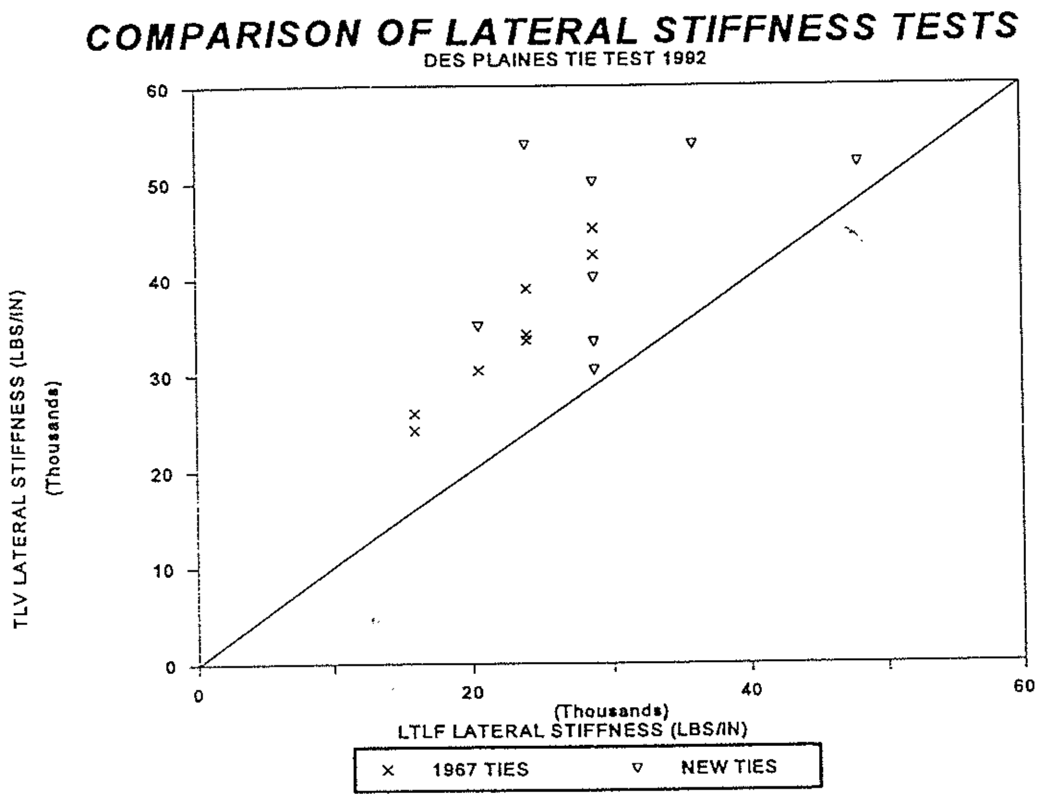

Exhibit 3-26. Comparison of Static Lateral Stiffness Tests.

Tie Number	Install Date (year)	Tie Spacing (inches)	Comments	Left BRL (inches)	Right BRR (inches)	Avg (inches)	Vertical Stiffness (lbs/in)	Track Modulus @40000 lbs (lbs/in/in)
1340	90	19.5	New	0.10	0.11	0.11	380952	5608
2400	88	19.5	New	0.15	0.10	0.13	320000	4445
3180	90	19.5	New	0.15	0.05	0.10	400000	5985
4200	90	19.5	New	0.16	0.10	0.13	307692	4218
5260	88	23.4	New	0.18	0.13	0.16	258065	3336
6280	88	27.5	New	0.18	0.11	0.15	275862	3647
7240	88	29.25	New	0.17	0.17	0.17	235294	2950
8280	88	23.4	New	0.17	0.10	0.14	296296	4011
1280	67	19.5	Old	0.12	0.10	0.11	363636	5271
2340	67	19.5	Old	0.15	0.13	0.14	285714	3821
3120	67	19.5	Old	0.16	0.11	0.14	296296	4011
4260	67	19.5	Old	0.16	0.12	0.14	290909	3914
5320	67	23.4	Old	0.24	0.20	0.22	181818	2092
6160	67	27.5	Old	0.15	0.11	0.13	307692	4218
7300	67	29.25	Old	0.19	0.19	0.19	210526	2543
8200	67	23.4	Old	0.20	0.10	0.15	266667	3486
AVG				0.16	0.12	0.14	292339	3972
STD				0.03	0.04	0.03	55962	1005

Exhibit 3-27. TLV Static Vertical Modulus Test Results.

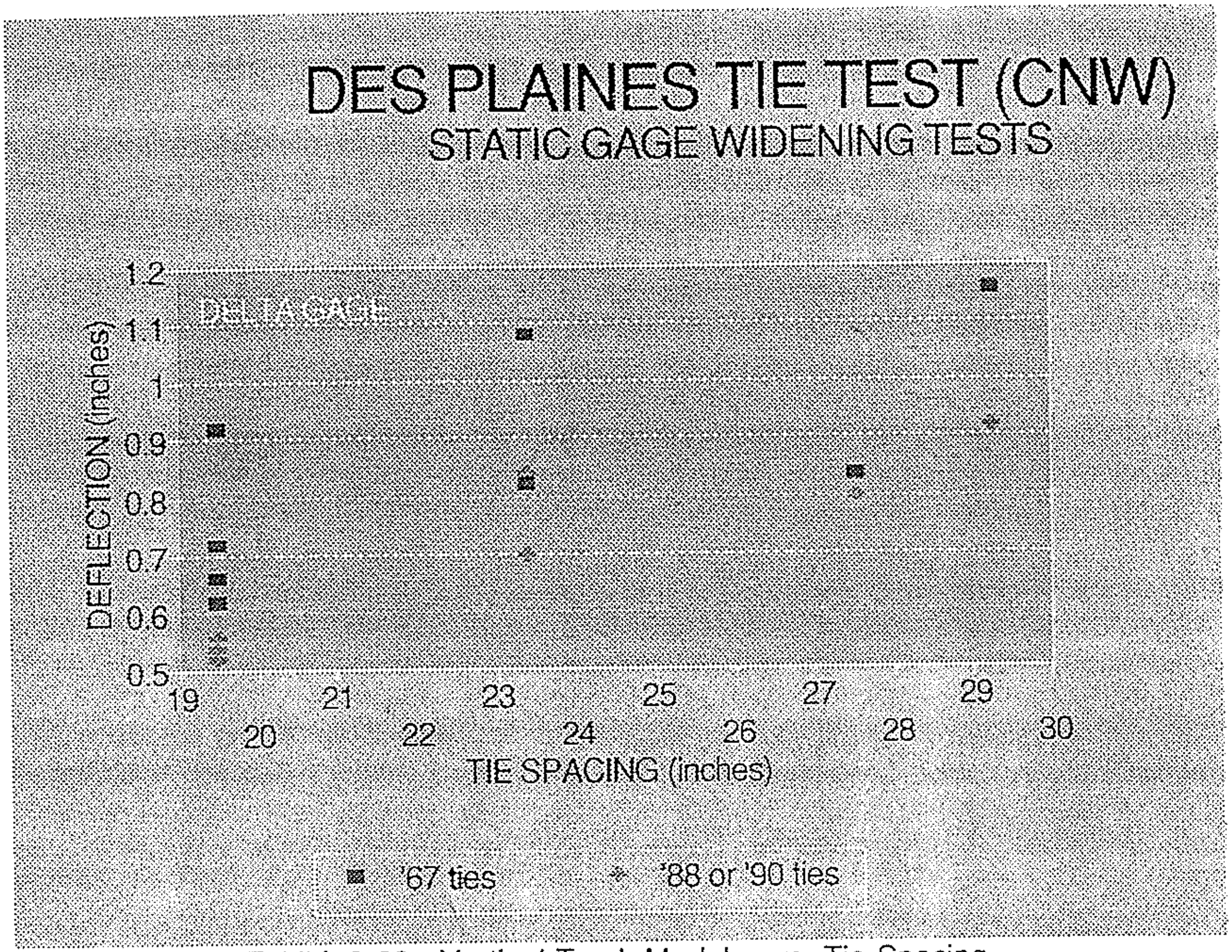

Exhibit 3-28. Vertical Track Modulus vs. Tie Spacing.

Tie Number	Install Date (year)	Tie Spacing (inches)	Comment	Track Modulus (lbs/in/in)	Track Modulus (lbs/in/in)
1340	90	19.5	New		5608
2400	88	19.5	New		4445
3180	90	19.5	New		5985
4200	90	19.5	New		4218
5260	88	23.4	New		3336
6280	88	27.5	New		3647
7240	88	29.25	New		2950
8280	88	23.4	New		4011
1280	67	19.5	Old	5271	
2340	67	19.5	Old	3821	
3120	67	19.5	Old	4011	
4260	67	19.5	Old	3914	
5320	67	23.4	Old	2092	
6160	67	27.5	Old	4218	
7300	67	29.25	Old	2543	
8220	67	23.4	Old	3486	
AVG				3670	4275
STD				926	990

Exhibit 3-29. Vertical Track Modulus By Tie Age Group.

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