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Research and Test Department

Tie Performance - A Progress Report of the Des Plaines Test Site

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S. M. Chrismer

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This is the eighth of a series of reports on this long term test.

13. ABSTRACT

The report discusses a case study of crosstie performance on a mainline track in the state of Illinois. The site chosen, Des Plaines is the location of a long term test of tie sizes and spacings. The test was installed in 1967 when the entire track section was built. Objective performance measures of tie and track were made. These measurements include gage, cross level, plate cutting, tie moisture content, and tie lateral strength. The results are compared to tie renewals and computer models of tie performance. Ballast sampling showed the variation in ballast condition within the test section. However, no direct correlation between tie condition and ballast condition was found.

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EXECUTIVE SUMMARY

This report discusses recent findings in the long-term tie performance test conducted by AAR in conjunction with the Railway Tie Association (RTA) and the Chicago and North Western Transportation Company (C&NW). Recent performance measurements taken at the Des Plaines site include: tie spacing, plate cutting, moisture content, track gage, track cross level, track lateral strength, and ballast condition.

The field measurements have been supplemented by track elastic layer modeling of the test site. Also, a recent tie renewal by the railroad gives an authoritative evaluation of tie performance to compare to the subjective evaluations made by the researchers involved in the test. The tie renewal also provides a basis for making average tie life projections. While more data is required to provide a solid prediction, the initial results indicate that there are some differences in performance between the eight test sections. All are performing satisfactorily for heavy tonnage tangent track service. The estimated average lives for the eight sections range from 23 to 36 years.

Ballast condition was evaluated in terms of its effort on tie performance. Sampling results showed that the ballast was in good condition; particles are still angular. The ballast gradation still meets the original specification. While conditions varied there was no correlation with tie plate cutting.

ACKNOWLEDGMENT

This project was jointly sponsored by the Association of American Railroads Track Research Division, The Railway Tie Association, and the Chicago and NorthWestern Transportation Company. This is the eighth in a series of progress reports which date back to the installation of the test in 1967.

The results presented in this report were made possible by the considerable efforts of the following C & NW personnel:

D. J. Boger, Chief Engineering Officer
J. R. Wilkins, Assistant Chief Engineer
J. R. Baus, Assistant Roadmaster, Proviso, IL
M. E. Wheeland, Roadmaster, Elk Grove,IL

Mr. John Choros, Manager-Track Engineering, provided invaluable guidance and support for this project. Mr. Victor Shafarenko, Manager Research/Marketing, Gross and Janes; formerly Research Engineer, AAR; provided technical expertise as well as supervising many of the 1986 measurements.

Logistical and technical support was provided by the following AAR personnel:

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J. Choros
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1.0 INTRODUCTION

This is another in the series of progress reports on the AAR - RTA - C&NW test of crosstie size and spacing configurations at Des Plaines, IL. Objective measurements of track and individual tie performance were made during 1986 and 1987. These results provide a more equitable basis for making relative comparisons between the eight tie configurations in the test than the previous subjective evaluations.

Measurements of unloaded track gage and cross level were taken at ten tie intervals. Lateral track strength, gage restraint, was measured at selected locations with a device similar to TSC's Light Track Loading Fixture (LTLF). Tie spacing was measured for each tie in the test section with an AAR designed instrument.

Measurements of individual tie condition were also made at a ten percent sample. Moisture content and plate cutting were measured using portable gages. In addition, ballast samples were taken from beneath eighteen ties. The ties were selected to cover a range of conditions and plate cutting depths.

During 1988 ties were marked by the railroad for renewal. Thus, estimates of tie service life and failed tie clustering tendency were obtained. The condition evaluation given by the renewal marking was compared to the objective measurements taken.

1.1 Background

The Des Plaines test 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 test configurations subjected to actual traffic. The effects of tie cross-section, length and spacing on tie performance will be examined. Exhibit 1 lists the test section configurations. More detailed information on the test site may be found in past progress reports [1]* [2].

Exhibit 1. Test Section Configurations.

Test Section	No. Test Ties	Tie Configuration	Tie Spacing
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	29.3
Seven	321	7 x 12 x 8.5	27.5
Eight	399	7 x 12 x 8.5	23.4

<u>Test Matrix</u>

Exhibit 2 lists the test sections in a test variable matrix. As one can see, the test engineers were judicious in selecting the eight test sections. They chose from amongst all of the possibilities, the most promising in terms of expected cost and ease of manufacture, cost and ease of installation, and likelihood of acceptable performance. In the eight test sections, the three variables of length, cross section and spacing are represented.

---

* Numbers enclosed in brackets refer to the References listed in section 5.0.

The rest of the matrix can be "filled-in" from the relationships developed between the eight actual test sections. Additionally, theoretical models of track are available to compare the likely performance of the non-tested combinations to the tested combinations.

Exhibit 2. Test Variable Matrix.

Tie Length	Cross Section	Tie Spacing/Number of Tie Per 39 foot rail					
		19.5 in (24)	21.3 in (22)	23.4 in (20)	26.0 in (18)	27.5 in (17)	29.3 in (16)
8.5	6 X 8						
	7 X 9	FOUR		FIVE			SIX
	7 X 12			EIGHT		SEVEN	
9.0	6 X 8	ONE					
	7 x 9	THREE					
	7 X 12						
10.0	6 X 8						
	7 x 9	TWO					
	7 X 12						

2.0 PERFORMANCE MEASUREMENTS

To supplement the previously collected visual survey data, several objective measurements of tie/track performance were made over a two year period. The following sections discuss the methods used to measure performance as well as the data collected.

2.1 Tie Spacing

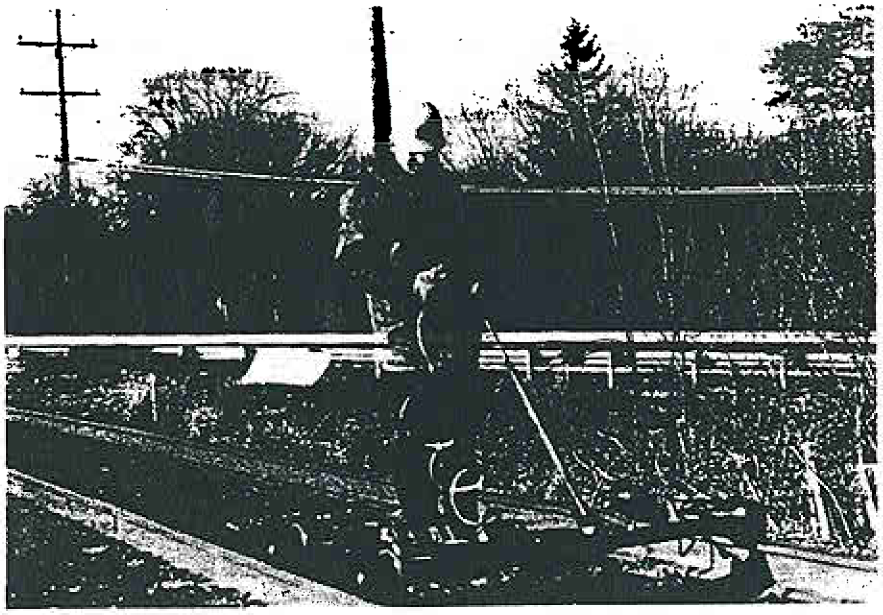
AAR personnel developed a portable tie spacing measurement device for this test. The device consists of a rubber tired wheel and axle rotation counter mounted on a track cart. The cart is insulated electronically and thus can be set on the tracks without affecting train signals. The device and cart, weighing about 100 pounds, can be quickly removed from track. Exhibit 3 shows the device in operation. The device is quite accurate with the practical limit on its accuracy being the operators ability to spot the device over each tie. Accuracies of 0.25 inches are possible under favorable weather conditions.

The device works by counting axle rotations of the rubber tired wheel as the cart moves. Motions as small as 0.05 inch can be detected. The device is also direction sensitive so that if one passes the next tie, one may backup without ruining the measurement. A measurement is made by counting axle rotations from the leading edge of one tie to the leading edge of the next.

Tie spacing is considered to be an important variable in this test. The actual measurement of tie spacing had never been done before; however, the average tie spacing had been verified as being close to the nominal value for each section.

Observers of the original tie installation also report that the ties were installed with an even spacing in each test section. The original test installation involved a complete track rebuilding from the ties up. Thus, the opportunity to accurately space ties was available. Any variation of spacing was unintentional, and, thus assumed to be random.

Exhibit 3. Tie Spacing Measuring Device.



The results of the spacing measurement are presented in Exhibit 4 below. For each test section the nominal and average (as measured) tie spacings are given. In addition, the standard deviation and range of values measured are also given for each test section. Note that section Six has been categorized into two sections: Old Six and New Six. Old six is the original test section consisting of 287 seven by nine inch, eight and one half feet long ties with 13 by 7.5 inch plates on 27.5 inch spacing. New six is a section of newer ties in place of a former crossover which allowed trains in both directions to crossover to the opposite (i.e. "wrong") track. This section consists of 133, 7 by 9 inch, 8.5 feet long ties with 12 by 7.5 inch plates on 20 inch spacing. The new section six ties are relatively new (less than five years old).

Exhibit 5 lists the rail anchor pattern for each section. The rail anchor pattern was generally to "box" (i.e. surround) every other tie. Site characteristics caused the pattern to vary across the test site. In particular, the insulated joints in section two, the railroad overpass of Central Road in section four, and the former crossover in section six have an anchor pattern of "boxing" each tie for a short distance on either side of the above mentioned fixed points in track.

The effects of anchor pattern on tie spacing can be seen in Exhibit 6. Tie spacing is plotted vs Tie Number. Sections five and eight in particular show the two spacing result of the alternate tie anchoring pattern. Evidence indicates that the anchored ties are moving with the rail in the direction of traffic. Traffic on the line is virtually all in one direction for each track. The non-anchored ties are not moving (or at least not moving at the same rate).

The regularity of this pattern (large spacing - small spacing - large spacing - small spacing) can be seen in several test sections. Exhibit 7, showing a trace of tie spacing vs location for section eight, is a good example of the regularity of the spacing variation. Calculation of the spacing changes indicate the spacing dependency on rail anchor pattern. Exhibit 8 lists the number of spacing distance change reversals for each test section by anchor pattern. Sections have reversal rates of 60 to 90+ percent. A rate of 100 percent would be an unvarying long - short - long - short spacing pattern.

Exhibit 4. Tie Spacing Measurement Summary.

Section Number	Count	Average Value	Standard Deviation	Minimum Value	Maximum Value
ONE	478	19.63	1.62	16.14	32.10
TWO	477	19.74	1.75	16.27	32.17
THREE	431	19.88	1.56	16.40	32.17
FOUR	479	20.05	2.26	16.15	32.17
FIVE	393	24.46	2.60	16.46	31.42
SIX	287	27.32	1.35	21.74	33.86
SEVEN	321	29.04	1.86	16.15	33.42
EIGHT	401	24.99	2.27	19.41	29.91

Exhibit 5. Rail Anchoring Pattern.

Section Number	Box Alternate Ties		Box Each Tie		Percent Box Alt. Tie
	Begin	End	Begin	End	
ONE	1001	1478			100
TWO	2001	2245	2246	2477	93.5
THREE	3486	3541	3001	3484	11.0
FOUR	4001 4315	4080 4479	4081	4314	51.4
FIVE	5001	5332	5333	5395	84.2
SIX	6201	6340	6001 6340	6200 6499	9.8
SEVEN	7001 7241	7177 7277	7178 7278	7240 7319	66.4
EIGHT	8011	8401	8001	8010	97.5

Exhibit 6. Tie Spacing vs Tie Number.

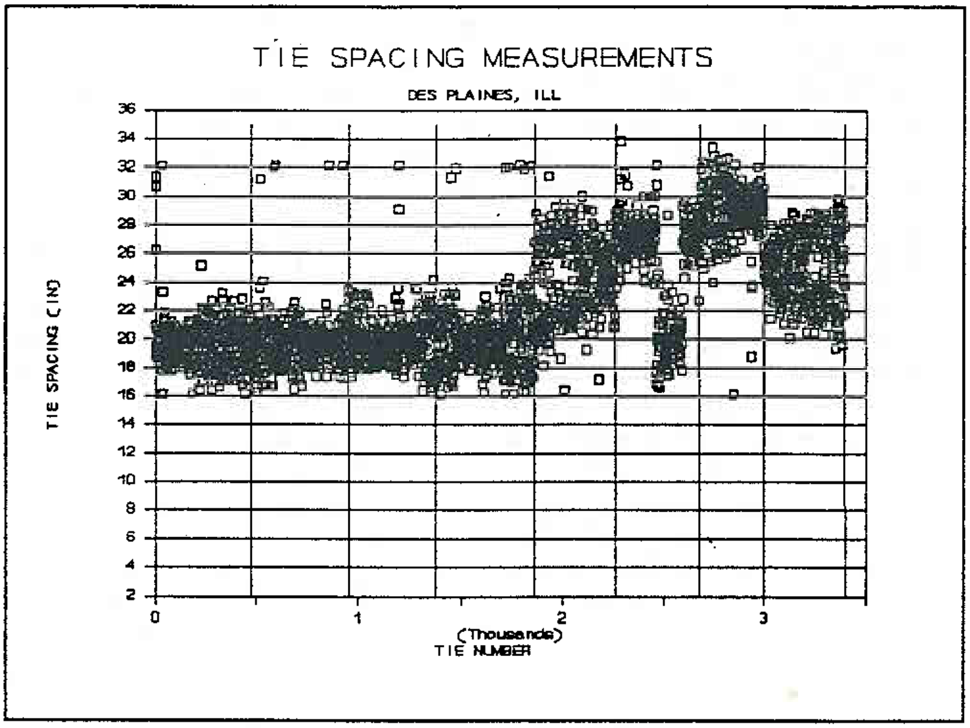


Exhibit 7. Section Eight Tie Spacing vs Tie Number.

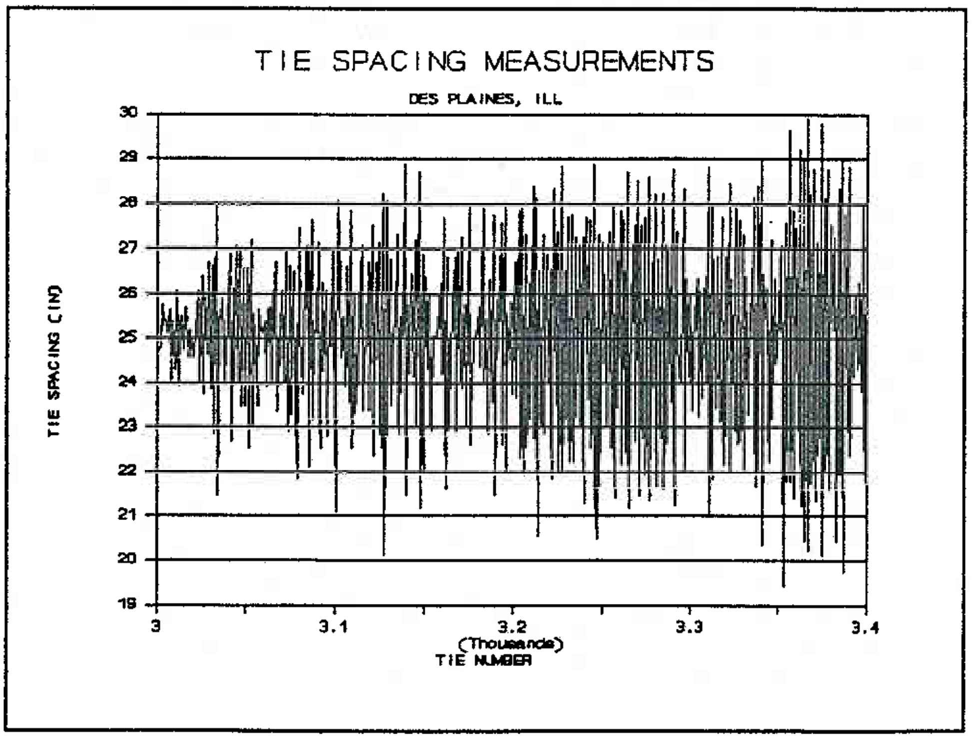


Exhibit 8. Tie Spacing Reversals.

Test Section	No. Test Ties	Spacing Reversals	Percent Reversals
One	480	392	81.7
Two	477	361	75.7
Three	431	316	73.3
Four	479	396	82.7
Five	400	370	92.5
Six	291	211	72.5
Seven	321	259	80.7
Eight	399	355	89.0

2.2. Tie Moisture Content

The moisture content of test ties was measured using a Delmhorst RC-1C moisture meter. The device works by measuring the electrical resistance of the wood between two probes spaced about one inch apart and driven about one inch into the top surface of the tie (see Exhibit 9). Measurements were taken at a spot on the gage side of the north rail tie plate. Measurements were taken on every tenth tie of each test section in 1986. Follow-up measurements in 1987 were made on the first 10 ties that had been measured in each section in 1986.

The results, Exhibit 10, show a wide range of moisture contents in track. Over the entire test site, values as low as 16 percent and as high as 61 percent were measured. The majority of the values fall within the 25 to 35 percent range. The moisture content value histogram (Exhibit 11) for the entire test site shows the shape of the distribution. There is a strong central tendency around 28 - 29 percent. The distribution appears to be non-symmetrical and skewed to the right. The result is the "tail" of high moisture content values. These ties are believed to be ties with decay, surface defects, or incipient decay.

Comparison of the tie moisture contents with the tie renewals showed that moisture content is correlated with tie condition and tie replacement. There are however, some unusual points in this relationship. For example, the newer ties generally have a high moisture content. The older ties with incipient decay also exhibit high moisture contents.

Exhibit 9. Moisture Content Measuring Device.

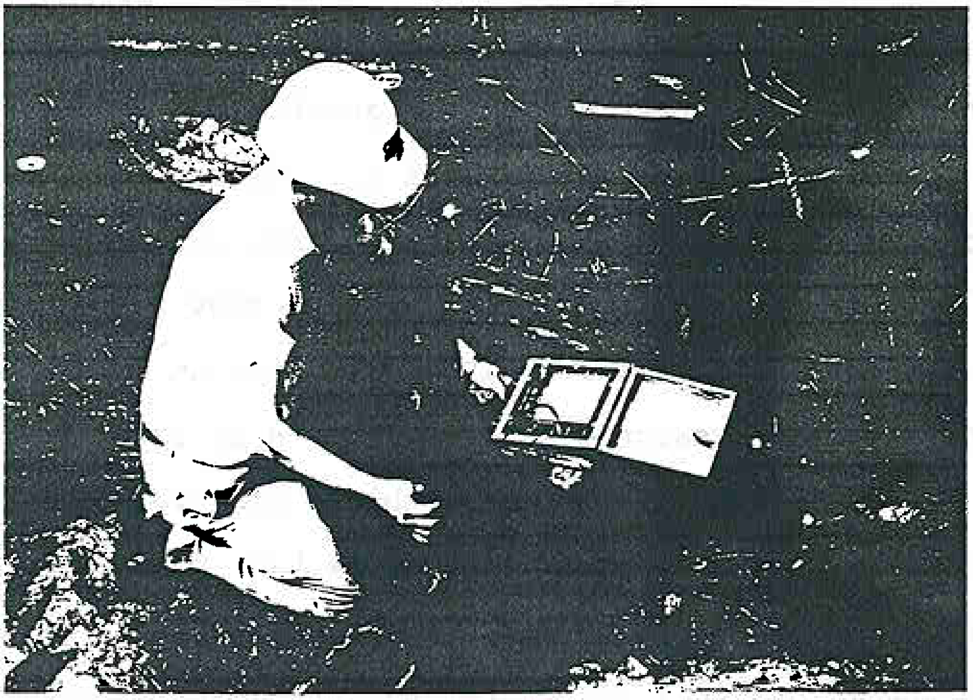
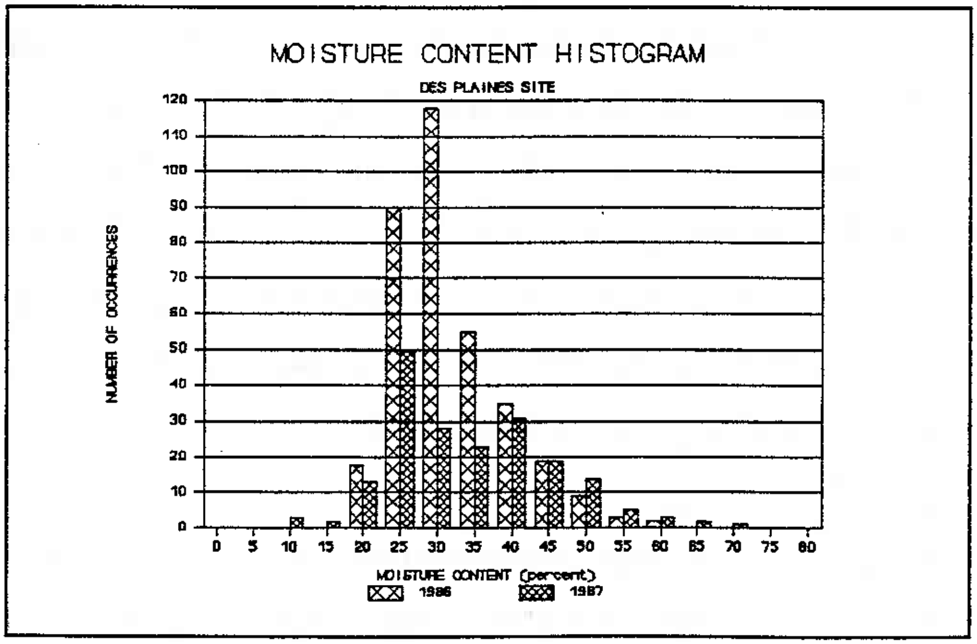


Exhibit 10. Tie Moisture Content Measurement Summary.

DES PLAINES TIE SITE
MOISTURE CONTENT SUMMARY

SECTION NUMBER	1987 NUMBER OF TIES	AVERAGE MC (%)	1986 NUMBER OF TIES	AVERAGE MC (%)
1	49	28.53	49	30.14
2	48	29.17	48	31.17
3	42	36.59	49	30.98
4	11	35.64	49	30.22
5	11	32.36	39	26.74
6	11	32.45	43	29.07
7	11	35.36	33	27.30
8	11	36.36	42	28.36
TOTAL	194	32.11	352	29.42

Exhibit 11. Moisture Content Histogram.



In the 1986 survey of moisture content values the mean value was 29 percent and the mode was 28 percent. The fiber saturation point of wood is considered to be 30 percent. Interestingly, raising moisture contents above this value will have no effect on tie strength. But, lowering moisture contents below this value results in stronger ties. This relationship is valid for whole, intact wood. It would not necessarily apply in cases where decay or other deterioration processes alter the wood structure.

Generally the 1987 survey values are higher than the 1986 values for the same ties. The mean value was 31 percent and the mode was 29 percent. This is most likely due to the weather conditions that occurred during the measurement periods. The smaller number of ties sampled in most sections in 1987 may also contribute to the higher values. In 1986 the weather was warm and dry; however, it was warm and rainy in 1987. The rain is likely to have increased the surface moisture of the ties. Small increases in moisture content can be explained in this way. On the other hand, a large increase in moisture content over a one year interval indicates that a structural problem exists in the tie. Large checks and splits allow moisture and decay fungi to penetrate the tie. Once these substances reach untreated wood, they slowly destroy the tie from inside. Wood undergoing decay generally has a high moisture content.

2.3 Tie Plate Cutting

Plate cutting measurements were taken at the Des Plaines site during the 1986 and 1987 inspections. In both years a 10 percent sample was taken over the entire length of the test site. Every tenth tie in each section was measured in 1986. The same ties were again measured in 1987 so that current and long term plate cutting measurements could be estimated.

In addition, three "clusters" of 50 consecutive ties were measured in 1987. The cluster measurements were taken to study the local effects of plate cutting in three sections.

Measurements were taken using a specially built plate cutting measuring device. This device, shown in Exhibit 12, has electronic transducers and is attached to a datalogger for automatic data storage. The device is merely an updated version of a device developed by AAR in the 1950's and used extensively for 20 years.

The device works by measuring the difference in elevation between the top of the tie plate at a known distance from the edge and the top surface of the tie adjacent to the plate. Factors which can affect the accuracy of the measurement include: plate thickness tolerance, plate slope and warping, tie surface damage, and the presence of debris such as lubricants, oils, sand, etc.

The device is capable of measuring thicknesses as small as 0.001." However, the allowable tolerance in plate thickness as specified by AREA is 1/32"[3]. Thus, the device's practical limit of precision is in the range of 0.1" to 0.01."

The results of the plate cutting measurements are summarized in Exhibit 13. The results suggest that a good correlation between tie spacing and plate cutting exists. Also, the 7 x 12 ties with a larger bearing area, but the same size plate, exhibited more plate cutting than 7 x 9 ties with similar spacing.

Exhibit 12. Plate Cutting Measuring Device.

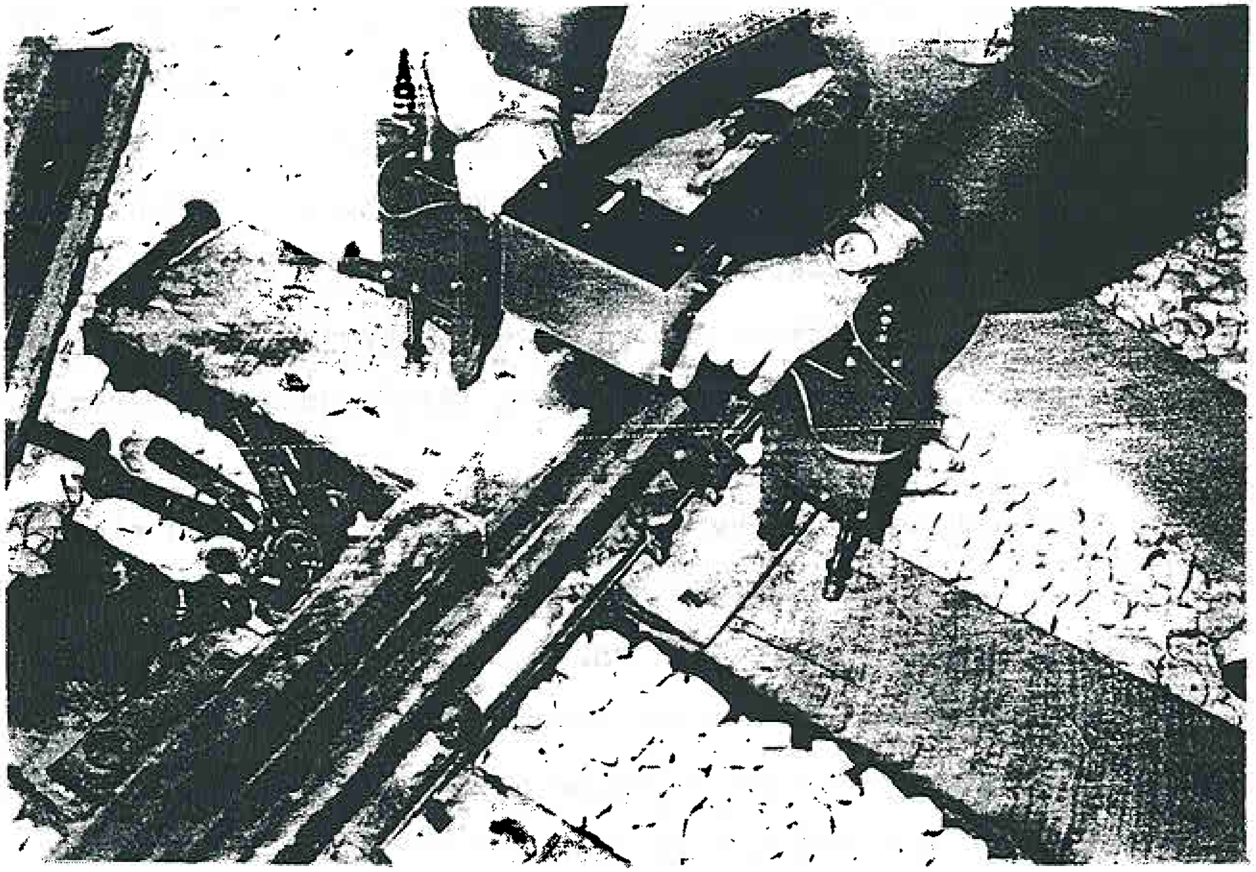


Exhibit 14 is a plot of average plate cutting vs tie number. Also shown is the difference between the cutting of the plates on each tie. The data ranges from 0.2 inches to 1.25 inches with cutting differences ranging from zero to 0.60 inches. Plate cutting has long been used as a criteria for tie renewal marking. Extensive plate cutting is a fairly reliable indicator of overall tie deterioration. Both lateral and vertical support capabilities are affected by plate area deterioration.

Exhibit 13. Plate Cutting Measurement Summary.

Section Number	Tie Configuration	Tie Spacing	Average Plate Cutting (inches)
ONE	6X8X9	19.5	0.54
TWO	7X9X9	19.5	0.49
THREE	7X9X10	19.5	0.45
FOUR	7X9X8.5	19.5	0.34
FIVE	7X9X8.5	23.4	0.39
SIX	7X9X8.5	29.3	0.48
SEVEN	7X12X8.5	27.5	0.85
EIGHT	7X12X8.5	23.4	0.54

Exhibit 14. Tie Plate Cutting vs. Tie Number.

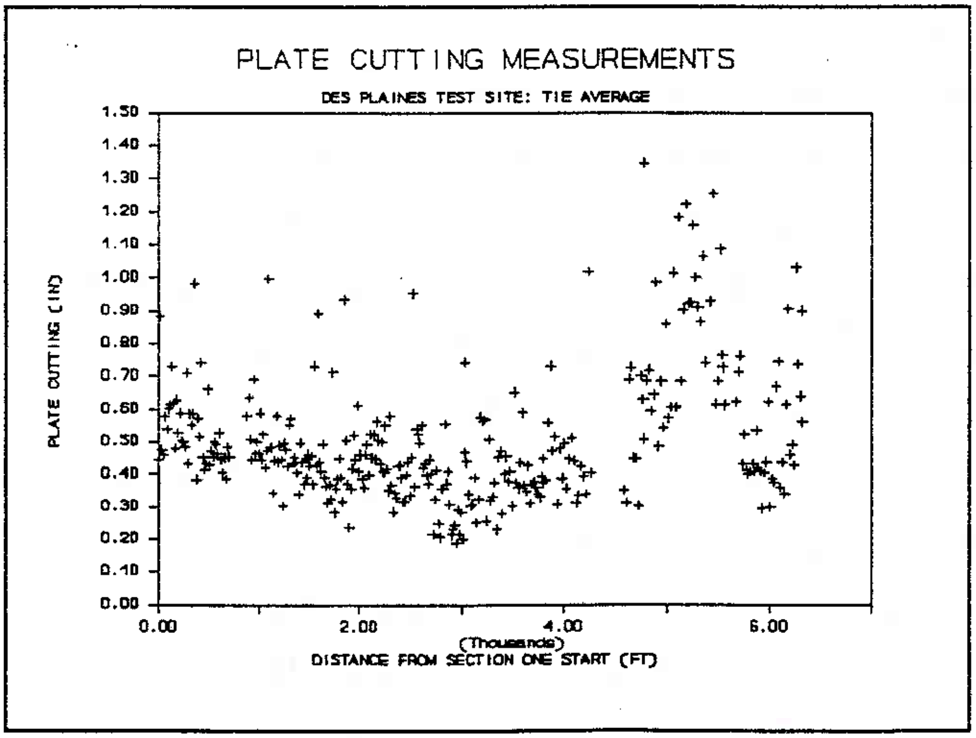


Plate cutting is, largely, a wear process. The tie plate, under the action of traffic, moves relative to the tie while in contact with the tie. The resulting action wears/abrades the wood fibers under the tie plate. In this way, then plate "cuts" through the tie. Chemical reactions between the steel plate and the wooden tie are also believed to contribute to plate area tie deterioration.

New ties resist plate cutting very well. They have sufficient hardness and strength to withstand 400-500 MGT of simulated traffic in laboratory testing with virtually no plate cutting.[4] Over time and with traffic, the tie deteriorates in strength. Weathering alone can reduce wood strength by 50 percent in 20 years of crosstie service.[6] This large strength loss leaves the tie more susceptible to mechanical damage such as spike killing or plate cutting. Subsequently, this mechanical damage opens the tie for bacteriological decay. Thus extensive plate cutting is a good visual indicator that a tie has, at least, lessened capabilities. And, it may likely be internally damaged (i.e. decayed). The use of plate cutting depth for tie marking can be illustrated with an example from the test site. Exhibit 15 is a listing of the ties that were marked for renewal and measured for plate cutting. The accompanying histogram plot (Exhibit 16) shows that specimens with 0.5 inches of cutting or more were prevalent in this group. The average plate cutting values for each group are also shown in Exhibit 17. The marked ties had significantly more plate cutting than the average tie in the test section.

Exhibit 15. Plate Cutting: Ties Marked for Renewal.

BAD TIE NUMBER	1986 P. C. INCHES	1987 P. C. INCHES
1010	0.89	0.84
1070	0.61	0.60
1080	0.86	0.67
1110	0.63	--
1150	0.55	--
1170	0.71	--
1190	0.50	--
1210	0.59	--
1220	0.98	--
1270	0.45	--
1300	0.66	--
1350	0.49	--
1400	0.45	--
1420	0.48	--
2150	0.69	--
2240	1.00	--
2270	0.34	--
2400	0.45	--
2470	0.45	--
2476	0.39	--
3010	0.46	0.48
3030	0.46	0.48
3050	0.73	0.80
3070	0.89	1.04

BAD TIE NUMBER	1986 P. C. INCHES	1987 P. C. INCHES
3080	0.44	0.47
3150	0.32	--
3160	0.71	--
3230	0.93	--
3240	0.50	--
3250	0.37	--
3280	0.42	--
3420	0.41	--
3490	0.52	--
3530	0.56	--
4010	0.46	0.55
4130	0.31	--
4140	0.37	--
4150	0.32	--
4170	0.28	--
4190	0.38	--
4230	0.93	--
4240	0.50	--
4340	0.39	--
4360	0.46	--
4380	0.40	--
4390	0.52	--
4430	0.56	--
4440	0.51	--

Exhibit 15. Plate Cutting: Ties Marked for Renewal (Continuted).

BAD TIE NUMBER	1986 P. C. INCHES	1987 P. C. INCHES
4479	0.41	--
5010	0.44	0.46
5080	0.58	0.51
5090	0.56	--
5110	0.26	--
5120	0.51	--
5130	0.32	--
5140	0.33	--
5150	0.37	--
5180	0.47	--
5200	0.40	--
5210	0.46	--
5230	0.41	--
5260	0.37	--
5270	0.36	--
5290	0.59	--
5310	0.35	--
5330	0.31	--
5350	0.38	--
5370	0.34	--
5380	0.33	--
5390	0.39	--
6010	0.38	0.36
6030	0.73	0.33

BAD TIE NUMBER	1986 P. C. INCHES	1987 P. C. INCHES
6070	0.48	--
6090	0.49	--
6120	0.51	--
6190	1.02	--
6370	0.73	--
6380	0.45	--
6410	0.70	--
6420	0.63	--
7001	0.45	0.48
7020	0.43	0.43
7120	0.37	--
7170	0.28	--
7220	0.29	0.91
7240	0.46	0.98
7250	0.37	--
7270	0.38	--
7280	0.42	--
7290	0.62	--
8090	0.41	0.43
8170	0.28	--
8370	1.03	--
8380	0.74	--

Exhibit 16. Plate Cutting Histogram: Marked Ties.

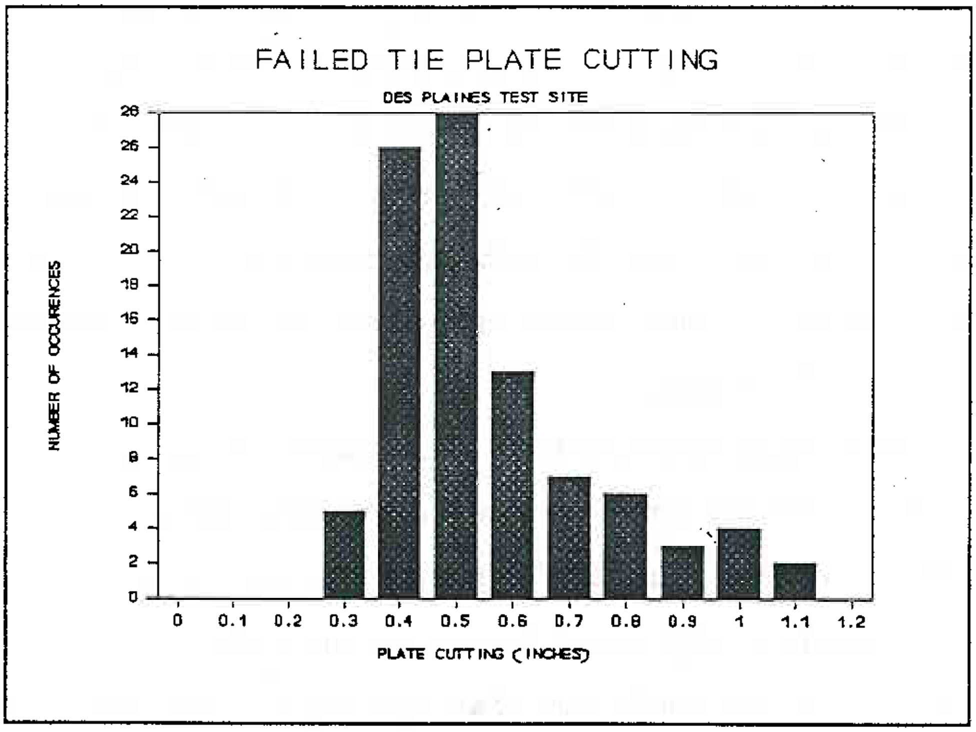


Exhibit 17. Average Plate Cutting - Marked and Unmarked Ties.

Section Number	Tie Configuration	Tie Spacing	Good Tie Average Plate Cutting (inches)	Bad Tie Average Plate Cutting (inches)
ONE	6x8x9	19.5	0.54	0.64
TWO	7x9x9	19.5	0.49	0.55
THREE	7x9x10	19.5	0.45	0.55
FOUR	7x9x8.5	19.5	0.39	0.45
FIVE	7x9x8.5	23.4	0.39	0.41
SIX	7x9x8.5	29.3	0.48	0.61
SEVEN	7x12x8.5	27.5	0.85	0.41
EIGHT	7x12x8.5	23.4	0.54	0.62

2.4 Track Geometry

One of the main functions of a crosstie is to hold the rails in proper alignment. The best measure of horizontal alignment is track gage. A good measure of vertical alignment is cross level. None of the test sponsors was able to provide a geometry car or other automated track performance measuring device for this test. Thus, simple, manual means were used to collect geometry data.

2.4.1 Unloaded Gage

Track gage measurements were made on every tenth tie of each section. The unloaded gage measurements were made with a hand-held gage. Exhibit 18 shows the device in use. The value of an unloaded gage measurement as an indicator of lateral track support or individual bad ties has been questioned. Recent studies have shown that the correlation between loaded and unloaded track gage is not as high as has been commonly assumed.[5] Obviously, loaded track gage is the better measure of track and tie performance. However, due to time and budget constraints, unloaded gage measurements were taken. The unloaded gage measurements were used to compare the relative performance of each tie section. The average and standard deviation of error of gage for each section is listed in Exhibit 19. Exhibit 20 is a plot of gage vs distance from the beginning of the test site (section 1).

It is interesting to note that there were no exceedences of F.R.A. limits for Class V track. There do not appear to be any gage problems in the whole test segment with the possible exception of a short segment at the very end of section Eight. If this segment is removed from the data, section Eight is performing as well as most other sections. However, this does illustrate the idea that there is an added risk when using a wider tie spacing as contained in section Eight. One's margin of safety is reduced since failed tie clusters leave a larger unsupported or poorly supported area in track. Exhibit 21 shows a histogram of the unloaded gage measurements for the entire test segment. Appendix 6.1 contains gage histograms for each test section.

The effect of tie size, spacing, and length on average gage error were negligible. It is assumed that this is due, in part, to the gage measurement being in the unloaded condition. The unloaded position of the rails in the horizontal plane is likely to be different from their loaded positions. However; all sections are performing adequately. This indicates that for tangent track all eight configurations of tie size, spacing, and length are acceptable.

Exhibit 18. Track Gage and Cross Level Measuring Device.

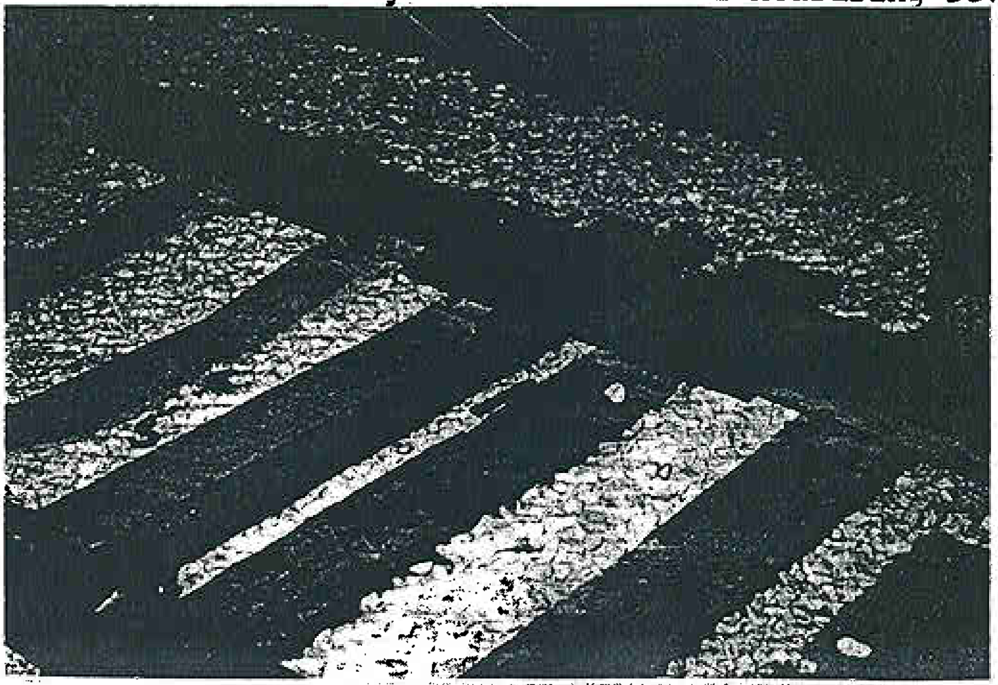


Exhibit 19. Track Gage Measurement Summary.

Section Number	Tie Length (feet)	Cross Section (inxin)	Nominal Spacing (inches)	Gage Mean Error	Gage Std.** Error	Gage Min. Error	Gage Max. Error
ONE*	9	6x8	19.5	0.09	0.10	-0.13	0.30
TWO*	10	7X9	19.5	0.15	0.07	0.00	0.31
THREE	9	7X9	19.5	0.16	0.08	0.00	0.38
FOUR	8.5	7X9	19.5	0.10	0.08	-0.13	0.25
FIVE	8.5	7X9	23.4	0.11	0.07	0.00	0.25
SIX*	8.5	7X9	27.5	0.17	0.08	0.00	0.38
SEVEN	8.5	7X12	29.2	0.11	0.08	0.00	0.31
EIGHT	8.5	7X12	23.4	0.18	0.14	-0.06	0.69

* Bridge section and cross-over replacement ties omitted.
** Std. - standard deviation

Exhibit 20. Track Gage vs Tie Location.

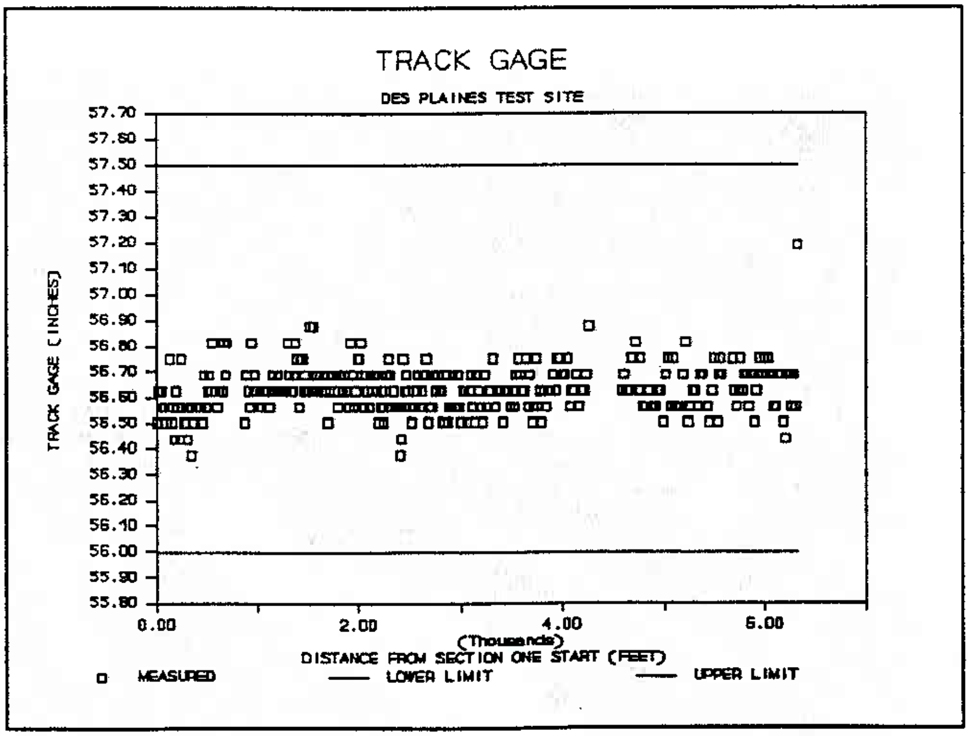
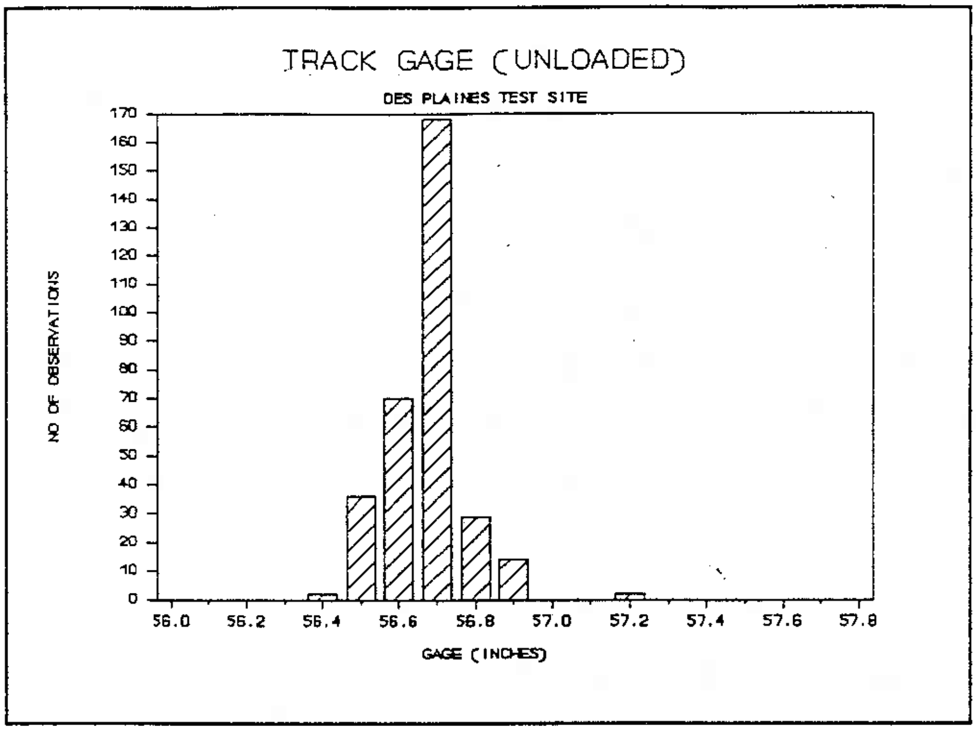


Exhibit 21. Track Gage Histogram.



2.4.2 Unloaded Crosslevel

Cross level* measurements were also made on every tenth tie of each section. Unloaded cross level measurements were made at the same time the gage measurements were made using the same device. The cross level measurements have an accuracy of 0.06 inches.

The value of an unloaded cross level measurement, as with gage, is limited. However; the average and standard deviation of cross level errors do give an indication of the relative performance of the particular section. Exhibit 22 lists the average and standard deviation of cross level error for each section. Exhibit 23 is a plot of cross level vs distance as

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* For this test, cross level was defined as the difference in top of rail elevation of the two rails as a given point in track.

measured from the beginning of the test site (section 1). Exhibits 24 and 25 show histograms of cross level error and absolute cross level error for the entire test section. The distributions are skewed, somewhat, with the south rail being, on the average, higher than the north.

The effects of spacing and tie size on cross level error were un-noticeable in this test. The effect of tie length was noticeable however. The 10 foot long ties (section 2) performed the best (i.e. had the smallest cross level error). In sections one and three the 9 foot long ties also performed well. The 8.5 foot tie sections performed the worst, with the 7x9 inch cross-section ties doing worse than the 7x12 inch ties. Exhibit 26 illustrates these points.

Exhibit 22. Track Cross Level Measurement Summary.

Section Number	Tie Length (feet)	Cross Section (inxin)	Tie Spacing (inches)	Cross Level (nominal value)		Cross Level (absolute value)	
				Mean**	Std***	Mean	Std
ONE*	9	6x8	19.5	-0.14	0.14	0.16	0.11
TWO*	10	7X9	19.5	-0.03	0.09	0.08	0.05
THREE	9	7X9	19.5	0.10	0.16	0.15	0.16
FOUR	8.5	7X9	19.5	0.37	0.23	0.37	0.23
FIVE	8.5	7X9	23.4	0.07	0.32	0.27	0.32
SIX*	8.5	7X9	27.5	0.10	0.21	0.18	0.21
SEVEN	8.5	7X12	29.2	0.14	0.15	0.23	0.11
EIGHT*	8.5	7X12	23.4	0.23	0.11	0.23	0.11

* Bridge section and cross-over replacement ties omitted.
** Mean - average value
*** Std. - standard deviation

Exhibit 23. Track Cross Level vs Tie Location.

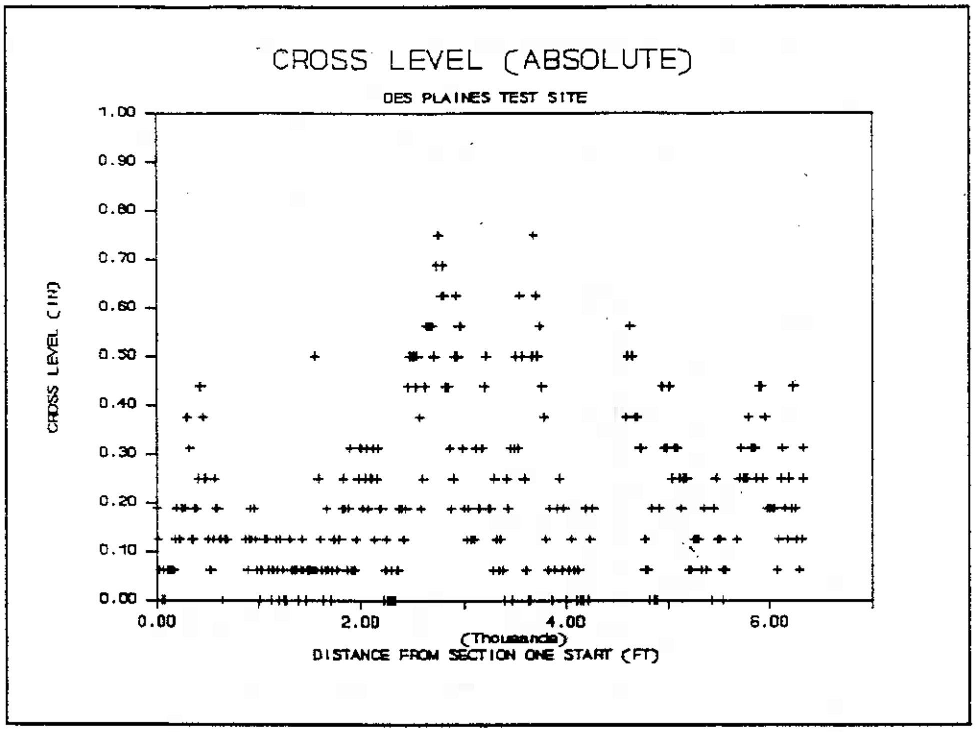


Exhibit 24. Track Cross Level Histogram (Actual Values).

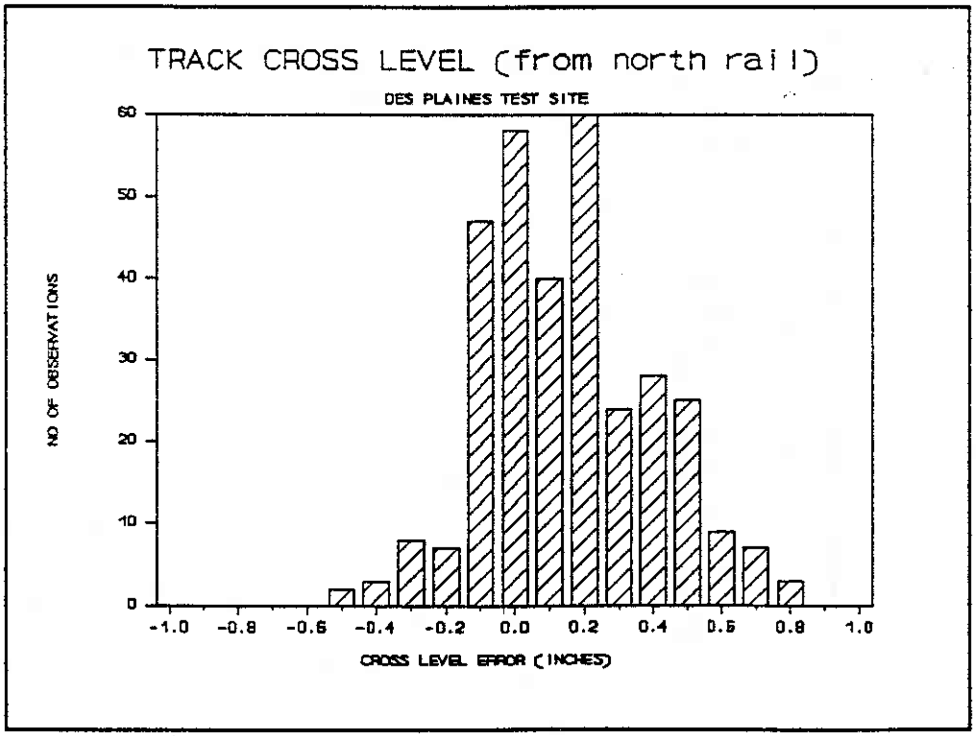


Exhibit 25. Track Cross Level Histogram (Absolute Values).

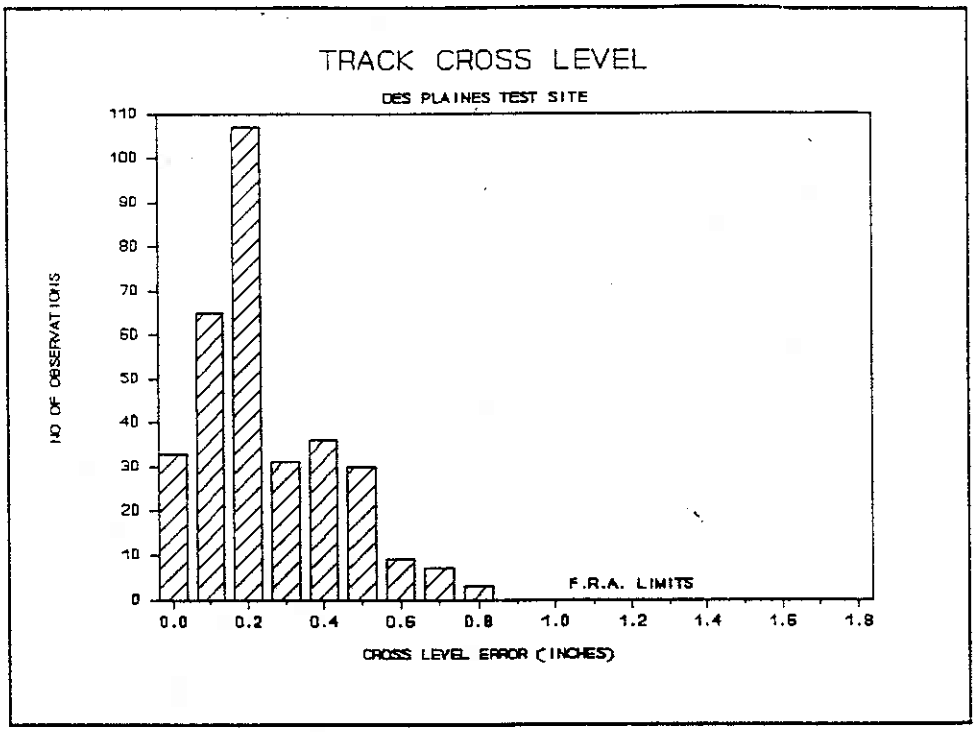
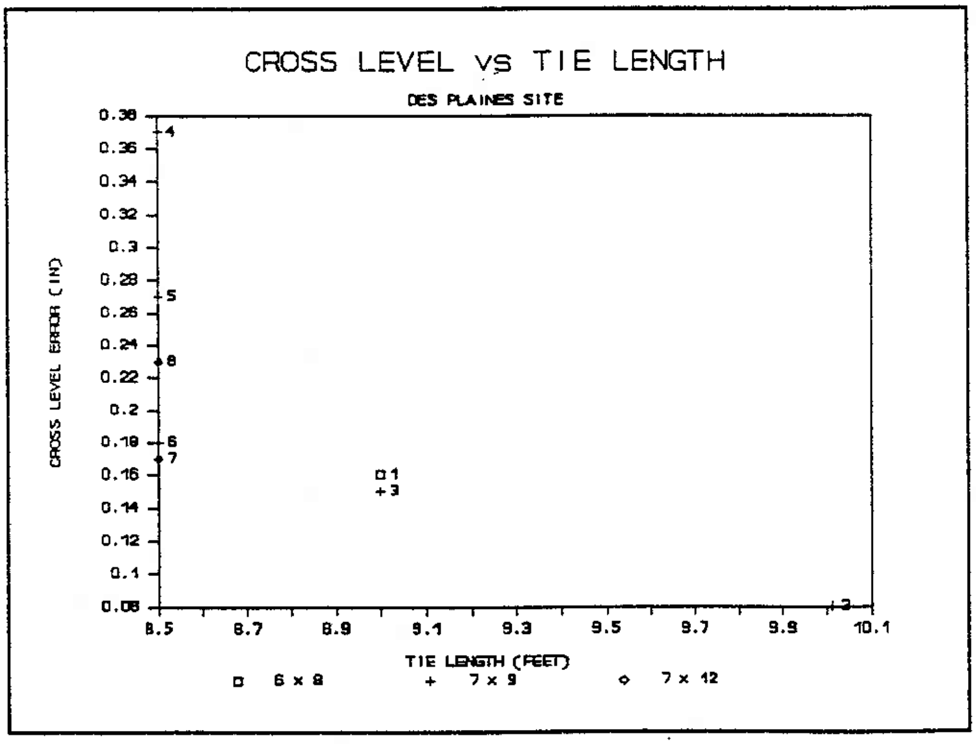


Exhibit 26. Track Cross Level vs Tie Length.



2.5 Track Lateral Strength

Tests of track/tie gage resistance were conducted for a small sample of ties in each section. These non-destructive tests were conducted in-track using an "LTLF" device. AAR's device was built from plans of the Transportation Systems Center's Light Weight Track Loading Fixture (LTLF)[7]. Exhibit 27 shows the device in action. The LTLF operates by a hydraulic cylinder which applies lateral (outward) force to the web of each rail. By measuring the resultant deflection for a sequence of applied loads, one can determine the lateral resistance characteristics, such as lateral stiffness or Gage Restraint Index (GRI), for each site. This measurement is a good proxy for loaded gage.

Lateral strength tests were conducted on 80 sites within the test sections. These sites were selected based on test section and tie condition as determined by visual survey[6]. Exhibit 28 lists the selected sites.

The test sequence consisted of an initial gage measurement, a measurement at 1,000 pounds lateral load applied, a measurement at 4,000 pounds, and (if within safety limits) a measurement at 6,000 pounds. Modulus values were calculated for the 6,000 pound load and the 4,000 pound load as follows:

$$\text{STIFFNESS} = \frac{\text{LOAD1}-\text{LOAD2}}{(\text{DEFL1}-\text{DEFL2})}$$

where: LOAD1 = test load
LOAD2 = 1000 lb. pre-load
DEFL1 = deflection at test load
DEFL2 = deflection at pre-load

Exhibit 29 lists the LTLF results for each location tested. The crosstie condition evaluation was derived from the 1988 tie renewal marking made by the division engineer using the normal railroad criteria. As can be seen in Exhibit 30 , a plot of the test results, the lateral stiffness data falls into discrete categories or levels. This is of course due to the precision of the measurements and the small lateral movements being measured. The precision of the device is 1/16 inch.

The stiffness values at 6,000 pounds are generally higher than those at 4,000 pounds due to the rigidity of the track structure. As more deflection is accumulated more ties and a longer section of rail become involved in resisting the load applied. Also, the initial "slop" or free space in the system of rail, plate, spike and tie may not be used up in the initial 1000 pound seating pre-load. Any remaining slop will reduce the 4000 pound stiffness proportionately more than it will the 6000 pound stiffness.

The stiffness vs tie condition relationship is plotted in Exhibit 31 . This relationship is complicated by the types of tie failures seen and by the different spacings used in the test section.

Exhibit 27. "LTLF" Device in Operation.

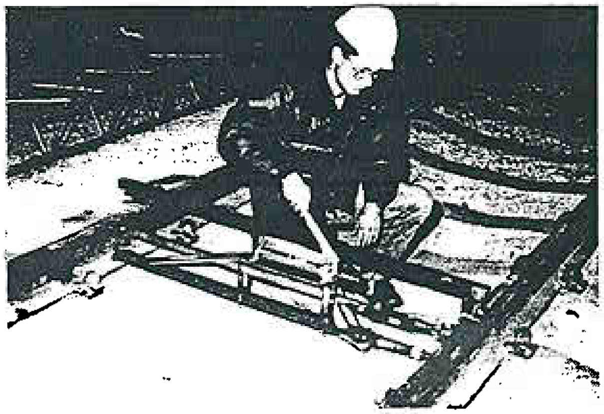


Exhibit 28. Lateral Restraint Test Ties.

TIE NUMBER	SECTION NUMBER	NOMINAL SPACING	ACTUAL SPACING
1012	1	19.5	19.01
1110	1	19.5	20.27
1113	1	19.5	19.73
1190	1	19.5	18.98
1270	1	19.5	19.76
1440	1	19.5	19.92
1456	1	19.5	18.85
1465	1	19.5	19.85
1467	1	19.5	18.38
1479	1	19.5	19.07
2044	2	19.5	27.46
2050	2	19.5	19.42
2100	2	19.5	19.26
2294	2	19.5	19.73
2320	2	19.5	18.72
3031	3	19.5	21.90
3050	3	19.5	19.98
3060	3	19.5	19.57
3097	3	19.5	20.86
3211	3	19.5	19.70
3398	3	19.5	20.52
4336	4	19.5	20.58
4396	4	19.5	20.01
5055	5	23.375	23.19

TIE NUMBER	SECTION NUMBER	NOMINAL SPACING	ACTUAL SPACING
5072	5	23.375	22.21
5090	5	23.375	24.66
6168	6	27.5	27.71
6211	6	27.5	20.04
6370	6	27.5	27.62
7011	7	29.25	29.31
7168	7	29.25	29.56
7278	7	29.25	29.54
8062	8	23.375	25.26
8125	8	23.375	25.60
8312	8	23.375	24.92

Exhibit 29. Lateral Restraint Test Results.

TIE NUMBER	SECTION NUMBER	NOMINAL SPACING	ACTUAL SPACING	STIFFNESS AT 6000 LBS	STIFFNESS AT 4000 LBS
1012	1	19.5	19.01	40000	48000
1110	1	19.5	20.27	20000	24000
1113	1	19.5	19.73	26667	24000
1190	1	19.5	18.98	20000	24000
1270	1	19.5	19.76	26667	24000
1440	1	19.5	19.92	16000	16000
1456	1	19.5	18.85	20000	24000
1465	1	19.5	19.85	16000	16000
1467	1	19.5	18.38	20000	24000
1479	1	19.5	19.07	20000	24000
2044	2	19.5	27.46	26667	24000
2050	2	19.5	19.42	26667	48000
2100	2	19.5	19.26	26667	48000
2294	2	19.5	19.73	26667	24000
2320	2	19.5	18.72	26667	24000
3031	3	19.5	21.90	20000	24000
3050	3	19.5	19.98	20000	24000
3060	3	19.5	19.57	20000	24000
3097	3	19.5	20.86	26667	48000
3211	3	19.5	19.70	26667	48000
3398	3	19.5	20.52	20000	24000
4336	4	19.5	20.58	20000	16000
4396	4	19.5	20.01	20000	24000
5055	5	23.375	23.19	20000	24000
5072	5	23.375	22.21	20000	24000
5090	5	23.375	24.66	16000	16000
6168	6	27.5	27.71	26667	24000
6211	6	27.5	20.04	26667	24000
6370	6	27.5	27.62	16000	16000
7011	7	29.25	29.31	13333	16000
7168	7	29.25	29.56	11429	12000
7278	7	29.25	29.54	13333	12000
8062	8	23.375	25.26	26667	48000
8125	8	23.375	25.60	20000	24000
8312	8	23.375	24.92	26667	48000

Exhibit 30. Track Lateral Stiffness vs Tie Spacing.

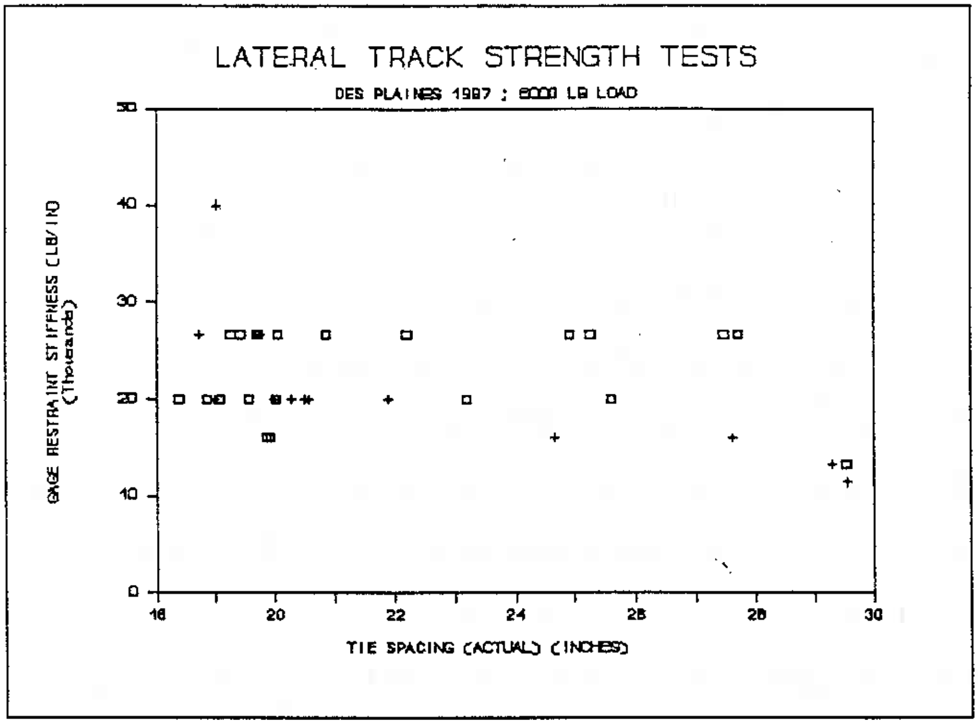
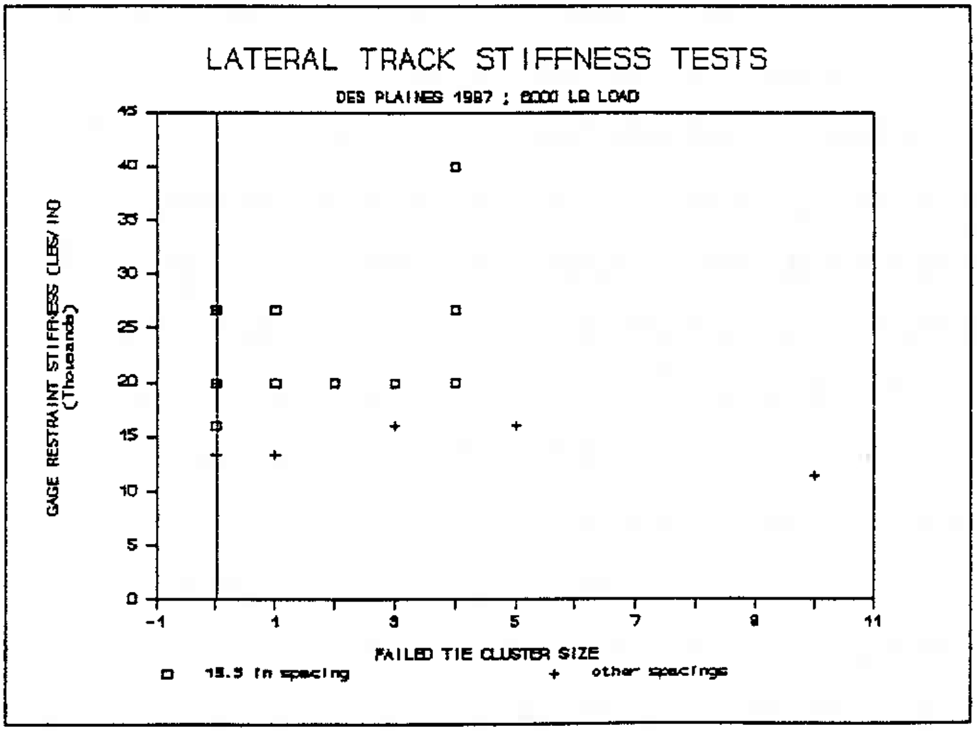


Exhibit 31. Track Lateral Stiffness vs Tie Cluster Size.



As one can see from the plot, the key factors are tie spacing and tie condition or failed tie cluster size.

2.6 Ballast Condition

In order to study the relationship between tie plate cutting and ballast condition, a ballast sampling program was conducted. To minimize test variables, ties were chosen from sections Three and Four. These sections are "standard" sections of 7"x9"x8.5' and 7"x9"x9.0' ties on 19.5" spacings. The ties were selected based on location and amount of plate cutting. Locations had to be within sections Three and Four, away from joints, and away from special structures (turnouts, open deck bridges, etc). A variety of plate cutting values were selected ranging from 0.2 inches to 0.9 inches. Also selected for evaluation were three ties which showed a large difference in plate cutting between the two plates. These specimens showed unusually large plate cutting on one side and typical performance on the other side. With the track being tangent and track surface good, the differences in plate cutting noted may be due to wood property variations or tie support variations. Large differences in plate cutting of a tie were rare, but differences up to 0.25 inches were typical. For the three differential cutting specimens two ballast samples were taken: one from under each rail seat/tie plate area. Exhibit 32 lists the ballast sample ties.

The ballast was a quartzite from Baraboo, WI and is known to be a strong ballast. The ballast sampling procedure consisted of obtaining one 50-80 pound sample of ballast material from beneath one of the rail/tie interface areas of the tie. The sample is obtained by:

1) completely removing the crib ballast from both sides of the tie to a depth equal to the bottom of the tie

2) removing the tie

3) "sinking" the ballast sampling box into the ballast by digging around the box (see Exhibit 33)

4) removing the ballast sample from within the box; making sure to collect the fine material

With this method, good samples of the ballast materials under the tie are collected. It is very important to obtain samples from the tie-ballast interface area, since this is the ballast supporting the track. Care was taken to include in the sample the ballast in the tamping zone as well. Ballast taken from the crib area (i.e. between the ties) is often not representative of the ballast in the section because it is subjected to little or no vertical loading. Crib ballast is often the newest, biggest, cleanest ballast in the section.

The samples collected were examined for gradation, particle shape and fines content. The results of each are discussed in detail below.

2.6.1 Gradation Analysis

The ballast samples were tested for gradation using a standard sieve analysis (ASTM D421-58 and D422-63). The results of the sieve analysis are presented in Exhibit 34. The samples show a range of gradations around the nominal AREA #4 gradation. If one assumes the gradation when the ballast was new to have been mid-point AREA #4 gradation, then an estimate of ballast life may be made.

Using the criteria that ballast life is over when twenty percent of the material passes the Number four sieve, the average

Exhibit 32. Ballast Sample Ties.

Plate Cutting			
Tie Number	South Rail (inches)	North Rail (inches)	Difference (inches)
3050*	0.54	0.92	0.38
3070	0.88	0.90	0.02
3160	0.63	0.79	0.16
3170	0.28	0.28	0.00
3230	0.89	0.98	0.09
3240	0.55	0.46	0.09
3260	0.23	0.25	0.02
3280	0.42	0.42	0.00
3310*	0.79	0.43	0.36
4030	0.52	0.64	0.12
4110	0.31	0.32	0.01
4170*	1.25	0.66	0.59
4200	0.48	0.56	0.08
4310	0.41	0.41	0.00
4330	0.21	0.20	0.01
4479	0.77	0.72	0.05

* Samples taken from under both tie plate areas

Exhibit 33. Ballast Sampling Procedure.

degree of breakdown is just past the halfway point. with 600 MGT accumulated, the ballast is projected to require replacement after about 500 more MGT.

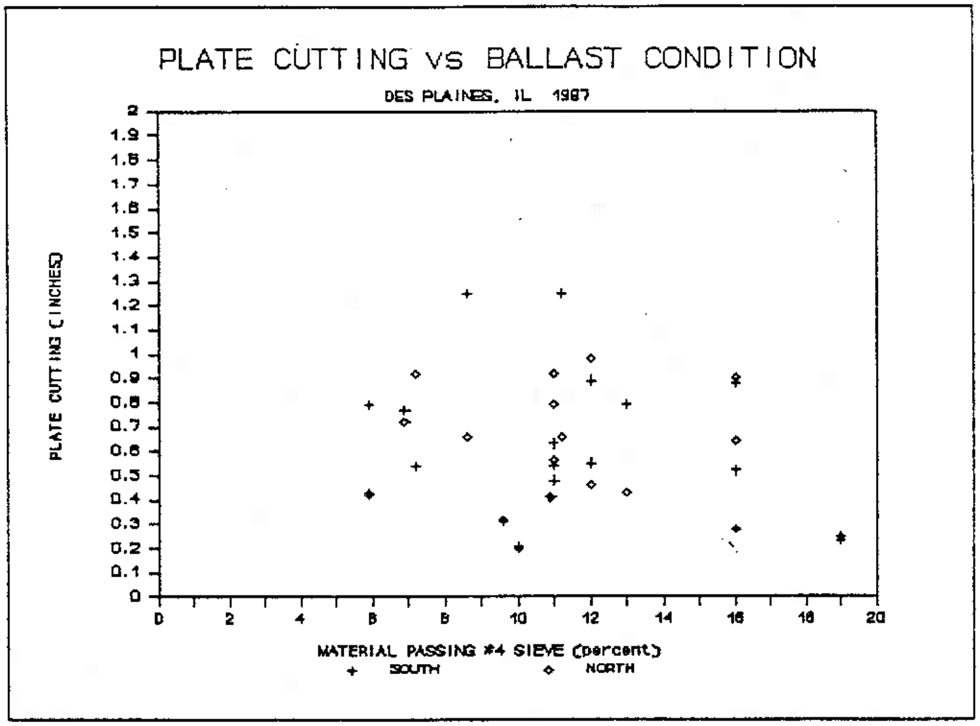
The breakdown of the ballast did not correlate with the observed plate cutting, as Exhibit shows. The thought was that perhaps ties with more plate cutting received greater loads and therefore more ballast breakdown would result. But the two phenomena appear to be fairly independent. In addition, the three ties which had different amounts of plate cutting under each rail did show differing amounts of ballast breakdown. The side with more plate cutting had less ballast breakdown (as indicated by the percentage of material passing a number 4 sieve).

The fines were judged to be derived mostly from ballast degradation because a layer of broadly graded subballast was found underneath the ballast which should have prevented any subgrade intrusion. Also, even after this much time and traffic, the particle shape was not rounded as expected, but sharp and angular. It appears that even though ballast degrades, it may still retain its angular shape.

Exhibit 34. Gradation Analysis Summary.

TIE NUMBER	PERCENT PASS #4	COEFF. UNIFORMITY
3050	11.0	7.4
3050	7.2	3.1
3070	16.0	23.5
3160	11.0	7.1
3170	16.0	11.5
3230	12.0	10.1
3240	12.0	13.6
3260	19.0	22.6
3280	5.9	2.3
3310	5.9	2.2
3310	13.0	10.1
4030	16.0	16.5
4110	9.6	2.9
4170	11.2	2.8
4170	8.6	12.5
4200	11.0	8.5
4310	10.9	8.0
4330	10.0	6.1
4480	6.9	2.4

Exhibit 35. Plate Cutting vs Ballast Condition.



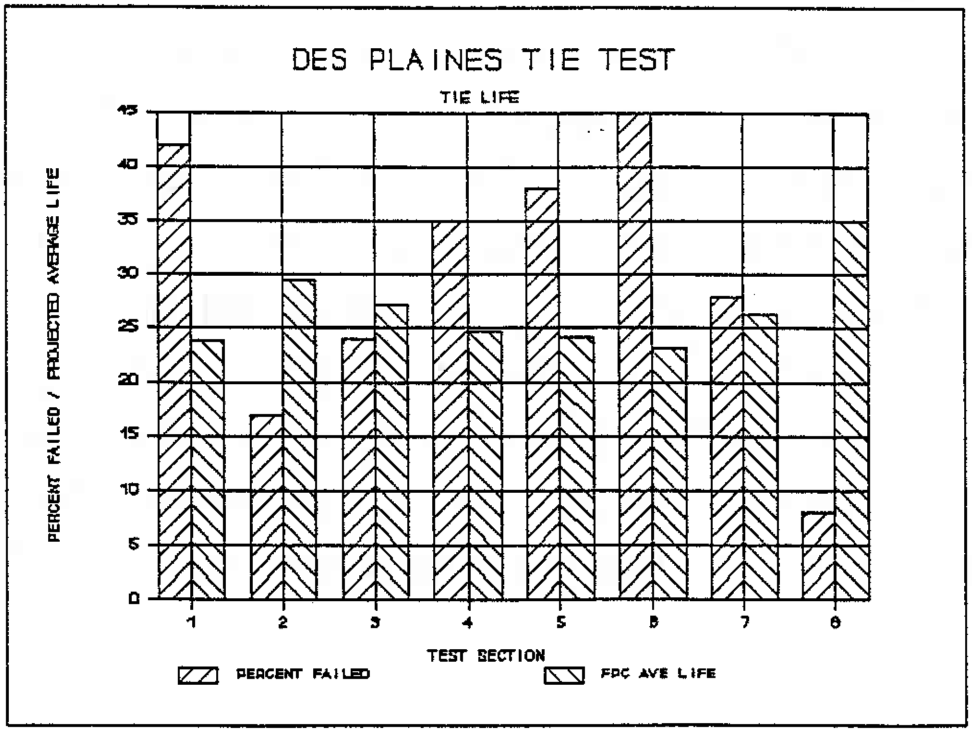
2.7 Tie Renewal

In 1988 the railroad provided an independent and practical evaluation of tie performance by replacing ties in the test section. This was the first large scale replacement of ties in the history of the test; with only the spot replacement of four ties over a collapsed culvert in 1986 preceding it. A total of 941 ties were replaced in the test sections. Through the generosity of the RTA, ties of the same configurations as the originals were provided for use as replacements. Exhibit 36 lists the number of ties replaced in each test section by the railroad in 1988.

Exhibit 36. 1988 Tie Replacement Summary.

NUMBER OF TIES	SECTION NUMBER	NUMBER FAILED	PERCENT FAILED	PERCENT AVE LIFE	F.P.C. PROJECTED AVE LIFE	LINEAR PROJECTED AVE LIFE
435	1	182	42	88	24	25
377	2	63	17	71	30	62
477	3	116	24	77	27	44
479	4	166	35	85	25	30
396	5	152	38	87	24	28
322	6	146	45	91	23	23
319	7	89	28	80	26	38
351	8	27	8	60	35	131
3156	ALL	941	30	81	26	35

Exhibit 37. Average Life Projections.



Also listed are the percentage of test ties replaced and, based on that, estimates of average tie life. Average tie life was estimated by two separate methods. The first is the U.S.D.A. Forest Products Curve[9] method. This method uses an empirically derived relationship between the cumulative number of tie replacements and the average tie life to predict average tie life. An estimate of the average life of a group of ties can be made at any time after a sufficient failure history is known. The Forest Products Lab suggests that projections should be based on a minimum of 20 percent failures. The second method is a simple linear extrapolation of average life based on the current percentage of failures.

Results of the projections (plotted in Exhibit 37) show the life estimates of 23 to 35 years (by the first method) and 23 to 131 years (by the second method). There is a decrease in tie life associated with wider tie spacing, shorter tie length and smaller cross-section. The dowel-laminated ties performed well in most respects. The dowels (fluted rods which hold the two 6 x 7 pieces together) performed very well: with but a handful of failures. The dowel-laminated also showed very few large checks or splits. Whether this is due to the smaller dimensions of the wood pieces or compression forces imposed by the dowel is not known. Most of the other sections with the solid sawn, one piece ties had the splitting, checking, weathering, decay-associated defects that are typical with oak species crossties. The dowel-laminated ties, by reducing checking and splitting, also appear to have reduced the surface decay sometimes seen in oak ties. This better surface appearance leads to fewer ties being marked for replacement; since tie marking is usually based on a cursory visual inspection.

The most prevalent problem encountered with the 7 x 12 dowel-laminated ties is plate cutting. Standard 7.75 x 13 inch tie plates were used on all eight test sections. Thus the dowel-laminated ties had the smallest plate area to tie bearing area ratio. This parameter was shown to be highly correlated with tie performance in a previous progress report[2]. This is the most probable explanation for the difference in performance between the two dowel-laminated sections. Section Eight is arguably the best section in the test. It has the lowest percentage of replacements (8 percent). The ties are spaced 23.375 inches on average. Section Seven is performing well also; ranking fourth in the percentage of replacements (28 percent). The ties are spaced 27.5 inches apart on average. The results show both the large effect of tie spacing on tie performance and the superior performance of the dowel-laminated ties on both sections as compared to standard 7 x 9 ties.

3.0 GEOTRACK STUDY RESULTS

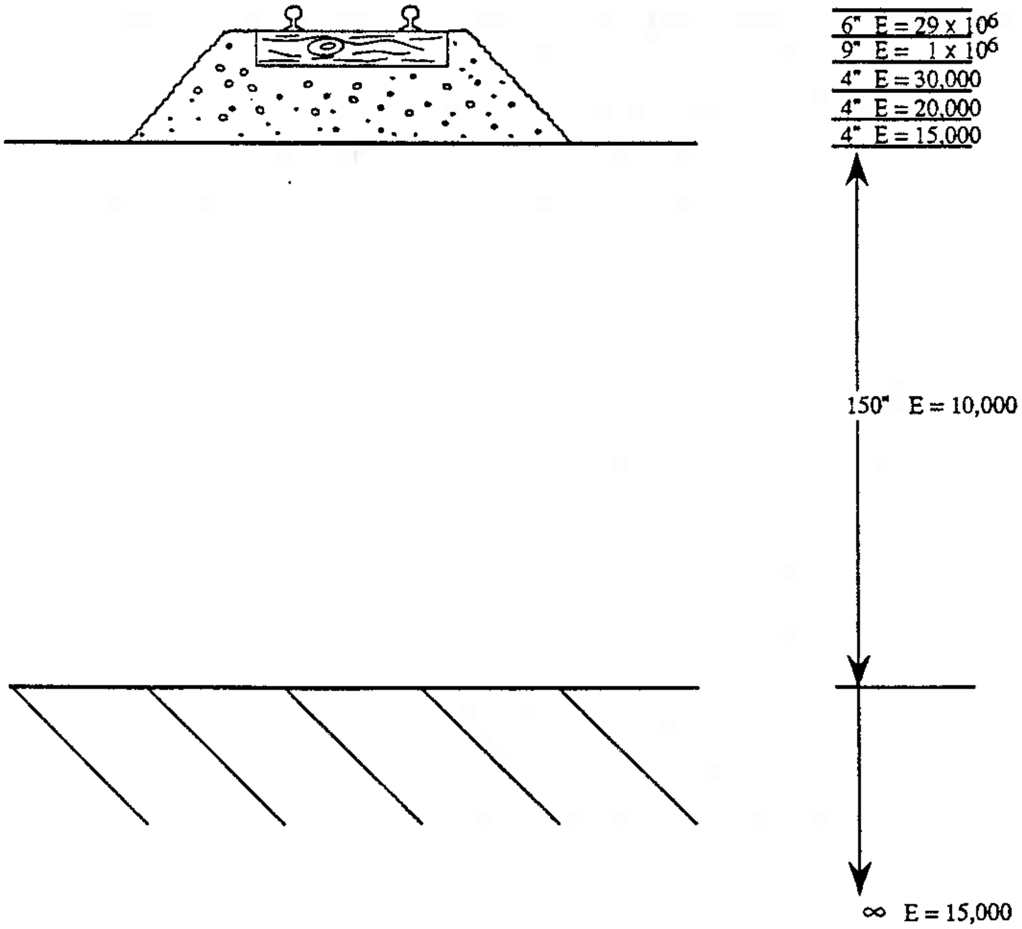
A parametric study of tie cross-section, length, and spacing was conducted for the support conditions representing the Des Plaines site. GEOTRACK[8] is an elastic layer model of the track structure. It was developed for ballast and geotechnical related work. The model has some limitations in the tie area; such as, the inability to vary strength properties amongst the ties. These shortcomings do not diminish the models's usefulness in performing the comparison of tie loads and deflections for the nominal track configurations and traffic representing the Des

Plaines site.

The track structure representation used in the GEOTRACK study is shown in Exhibit 38. This represents the as-built structure of the test site in 1967. The site is built largely on a fill which tapers off into a cut at test section eight. The track structure is very stable; with the local track forces commenting that this test section is one of the most trouble-free locations on the line.

Use of this structure in the model resulted in a stiff track. Modulus values of 5,000 to 6,000 psi were calculated for the various configurations. This result is considered to be in the typical range for good undisturbed mainline wooden tie track.

Exhibit 38. GEOTRACK Study Track Structure.



The results of the GEOTRACK study are shown in Exhibits 39-42 (the 9 foot ties) and in Appendix 6.2 (All others). A nominal 100 ton car loading (33 kips static axle loads) was used for all cases. As Exhibits 40-45 show the main factor affecting tie (vertical) reaction load is tie spacing. The patterns are similar for all tie cross-sections and lengths.

Both tie rail seat and tie center bending moment values are dependent on the tie cross-section dimensions (i.e. the vertical moment of inertia). Both the length of the tie and the tie spacing also have a smaller effect; with longer ties and closer spacing reducing the bending stresses.

Exhibit 39. GEOTRACK Study of The Effect of Tie Spacing on Tie Reaction Load.

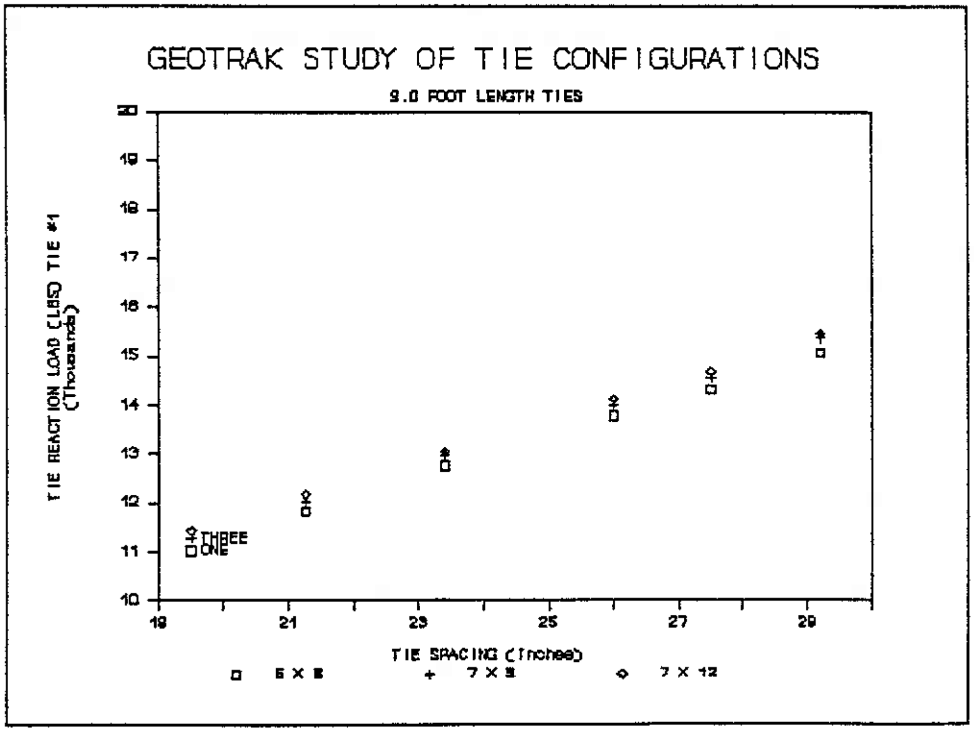


Exhibit 40. GEOTRACK Study on the Effect of Tie Spacing on Tie Deflection.

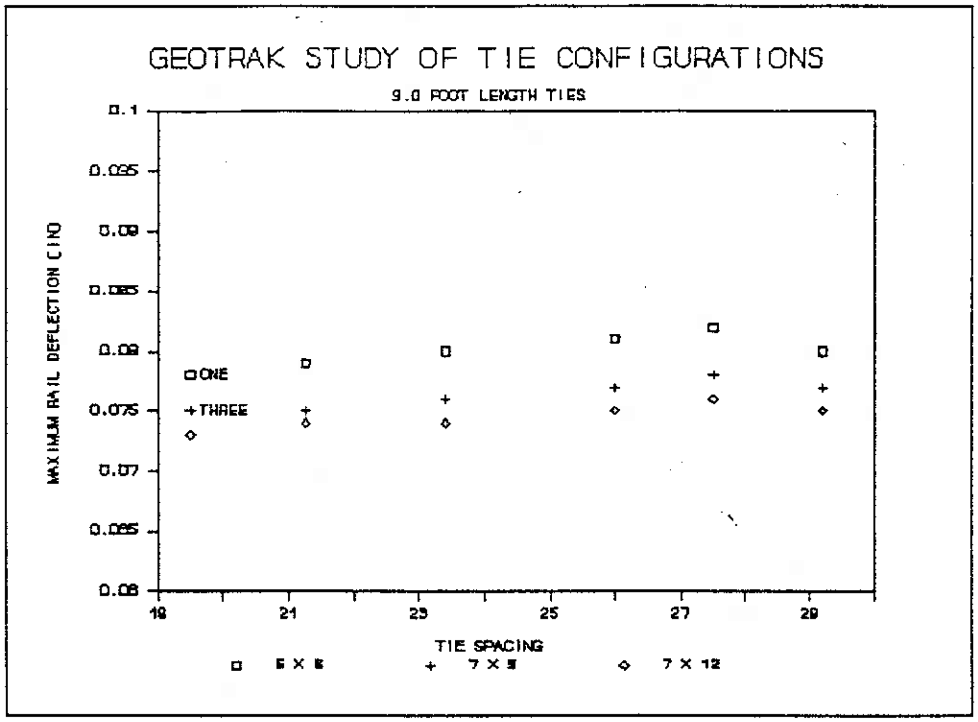


Exhibit 41. GEOTRACK Study on the Effect of Tie Spacing on Rail Seat Bending Load.

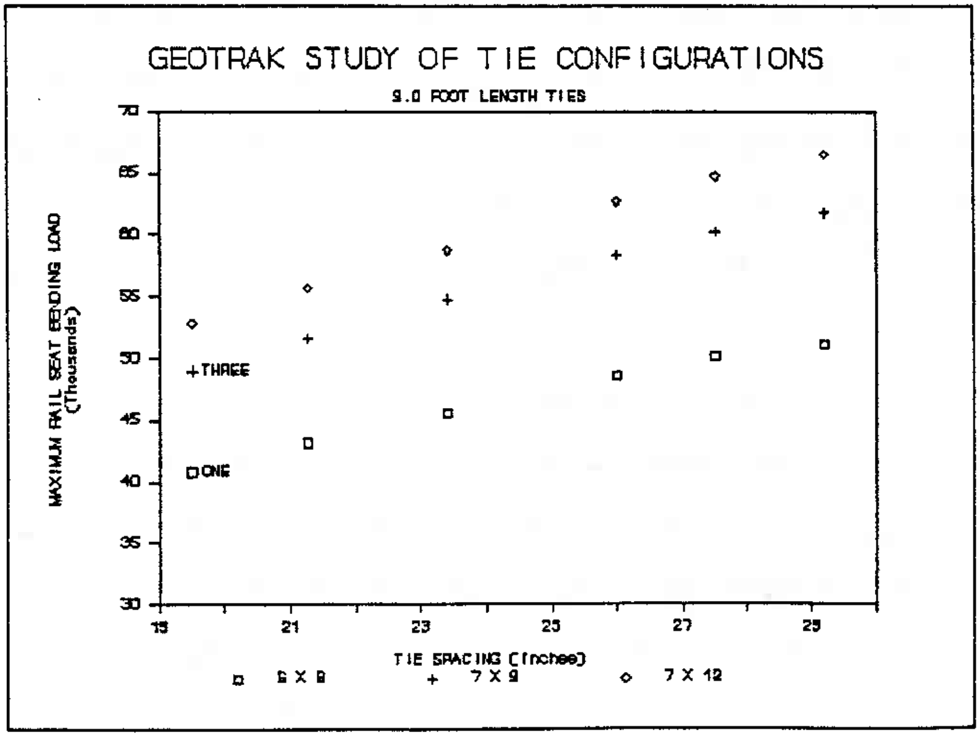
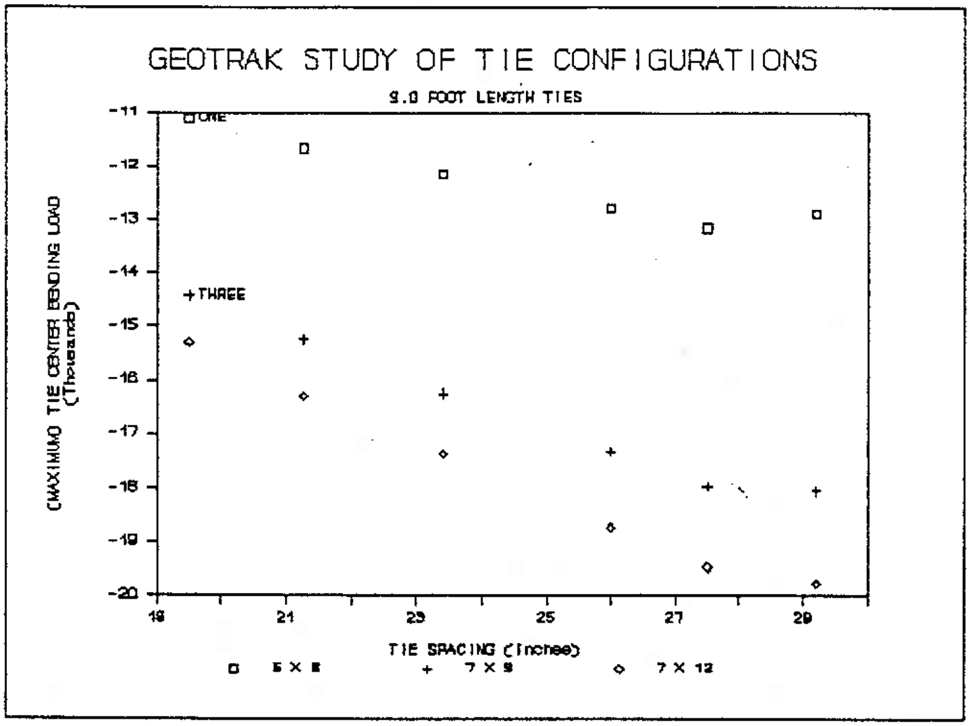


Exhibit 42. GEOTRACK Study on the Effect of Tie Spacing on Tie Center Bending Load.



The GEOTRACK study results show some interesting predictions of test section performance. Exhibit 43 lists predicted values of maximum tie deflection, tie load, and both tie center bending and rail seat bending stresses. The track modulus value is also listed. These values were calculated for 33 kip wheel loads (static) in typical 100 ton nominal capacity car configurations of axle spacings.

From the results one may conclude that the track modeled is stiff. The track modulus values and tie deflections are representative of good wooden tie track. This does indeed represent the test location, where drainage is good and the ballast is a strong material in a deep section.

Exhibit 43. GEOTRACK Study Results.

WHEEL LOAD	TIE CROSS SECTION (INXIN)	TIE LENGTH (FT)	TIE SPACING (IN)	TRACK MODULUS (PSI)	MAX TIE DEFLEC-TION (IN)	MAX. TIE LOAD (LBS)	MAX. TIE CENTER BENDING (PSI)	MAX. TIE SEAT BENDING (PSI)	TEST SECTION
33	6 x 8	8.5	19.5	5567	0.078	11007	-11276	42240	
33	6 x 8	8.5	21.3	5491	0.079	11007	-11823	44764	
33	6 x 8	8.5	23.4	5345	0.080	12754	-12285	47428	
33	6 x 8	8.5	26.0	5328	0.081	13780	-12976	50557	
33	6 x 8	8.5	27.5	5263	0.082	14323	-13379	52246	
33	6 x 8	8.5	29.2	5357	0.081	15127	-13154	53554	
33	7 x 9	8.5	19.5	5896	0.075	11254	-14641	49650	FOUR
33	7 x 9	8.5	21.3	5841	0.076	12067	-15320	51748	
33	7 x 9	8.5	23.4	5777	0.076	12985	-16399	55725	FIVE
33	7 x 9	8.5	26.0	5673	0.077	14022	-17551	59461	
33	7 x 9	8.5	27.5	5611	0.078	14569	-18183	61457	
33	7 x 9	8.5	29.2	5712	0.077	15378	-18240	62263	SIX
33	7 x 12	8.5	19.5	6079	0.073	11408	-15619	53192	
33	7 x 12	8.5	21.3	6025	0.074	12160	-16580	56053	
33	7 x 12	8.5	23.4	5981	0.074	13087	-17661	59454	EIGHT
33	7 x 12	8.5	26.0	5885	0.075	14120	-19010	63410	
33	7 x 12	8.5	27.5	5827	0.076	14670	-19751	65543	SEVEN
33	7 x 12	8.5	29.2	5943	0.075	15450	-19980	67498	
33	6 x 8	9	19.5	5573	0.078	11016	-11112	40790	ONE
33	6 x 8	9	21.3	5499	0.079	11825	-11664	43158	
33	6 x 8	9	23.4	5445	0.080	12754	-12145	45644	
33	6 x 8	9	26.0	5339	0.081	13779	-12769	48558	
33	6 x 8	9	27.5	5276	0.082	14319	-13156	50158	
33	6 x 8	9	29.2	5382	0.080	15066	-12889	51079	

Exhibit 43. GEOTRACK Study Results (Continued).

WHEEL LOAD	TIE CROSS SECTION (INXIN)	TIE LENGTH (FT)	TIE SPACING (IN)	TRACK MODULUS (PSI)	MAX TIE DEFLECTION (IN)	MAX. TIE LOAD (LBS)	MAX. TIE CENTER BENDING (PSI)	MAX. TIE SEAT BENDING (PSI)	TEST SECTION
33	7 x 9	9	19.5	5904	0.075	11263	-14429	48976	THREE
33	7 x 9	9	21.3	5860	0.075	12024	-15248	51555	
33	7 x 9	9	23.4	5787	0.076	12987	-16241	54777	
33	7 x 9	9	26.0	5685	0.077	14012	-17337	58284	
33	7 x 9	9	27.5	5625	0.078	14556	-17966	60202	
33	7 x 9	9	29.2	5720	0.077	15358	-18050	61735	
33	7 x 12	9	19.5	6096	0.073	11413	-15302	52874	
33	7 x 12	9	21.3	6040	0.074	12170	-16306	55681	
33	7 x 12	9	23.4	6008	0.074	13049	-17353	58740	
33	7 x 12	9	26.0	5903	0.075	14108	-18729	62664	
33	7 x 12	9	27.5	5847	0.076	14655	-19467	64716	
33	7 x 12	9	29.2	5944	0.075	15461	-19782	66516	
33	6 x 8	10	19.5	5540	0.079	10982	-11445	34094	
33	6 x 8	10	21.3	5473	0.079	11748	-11953	35750	
33	6 x 8	10	23.4	5412	0.080	12698	-12468	37618	
33	6 x 8	10	26.0	5307	0.081	13715	-13122	39932	
33	6 x 8	10	27.5	5241	0.082	14258	-13514	41160	
33	6 x 8	10	29.3	5351	0.081	14991	-13205	41355	
33	7 x 9	10	19.5	5875	0.075	11221	-14590	43500	TWO
33	7 x 9	10	21.3	5812	0.076	11979	-15459	45630	
33	7 x 9	10	23.4	5777	0.076	12838	-16304	47794	
33	7 x 9	10	26.0	5692	0.077	13816	-17370	50474	
33	7 x 9	10	27.5	5656	0.077	14307	-17927	51807	

Exhibit 43. GEOTRACK Study Results (Continued).

WHEEL LOAD	TIE CROSS SECTION (INXIN)	TIE LENGTH (FT)	TIE SPACING (IN)	TRACK MODULUS (PSI)	MAX TIE DEFLECTION (IN)	MAX. TIE LOAD (LBS)	MAX. TIE CENTER BENDING (PSI)	MAX. TIE SEAT BENDING (PSI)	TEST SECTION
33	7 x 9	10	29.3	5711	0.077	15206	-18133	52863	
33	7 x 12	10	19.5	6069	0.073	11370	-15277	47986	
33	7 x 12	10	21.3	6012	0.074	12117	-16297	50292	
33	7 x 12	10	23.4	5974	0.074	13003	-17403	52806	
33	7 x 12	10	26.0	5910	0.075	13948	-18661	55650	
33	7 x 12	10	27.5	5821	0.076	14568	-19500	57636	
33	7 x 12	10	29.3	5904	0.075	15407	-19875	58748	

Exhibit 44. Test Section Performance vs GEOTRACK Prediction.

	Percent Increase over Standard* Section				
	Tie Defl.	Tie Load	Center Bending	Rail Seat Bending	Ties Replaced
ONE	4	(2)	(24)	(18)	20
TWO	0	0	0	(12)	(62)
THREE	0	0	(1)	(1)	(30)
FOUR	0	0	0	0	0
FIVE	11	51	2	12	11
SIX	33	72	5	25	31
SEVEN	13	03	5	32	(20)
EIGHT	(1)	16	21	20	(78)

* Standard Section is defined as 7"x9" ties of 8.5' length on 19.5" spacing (as represented by section 4).

The results show the spacing dependence of the ties on the theoretical stresses in the ties. For tie reaction forces, the tie spacing is the main variable. The tie reaction load varies from 11 kips to 15 kips (~30 %) among the spacings tested. The effect is especially pronounced on a stiff track such as this test site; where the proportion of total deflection taken by the tie is larger than it is on soft track. The effects of tie cross section or tie length on tie reaction force are both minimal. The tie/rail deflection results indicate a dependence on tie cross section and tie spacing. The effect of tie length appears to be minimal. Cross section appears to be the main factor with an approximate spread of 10 percent between the three cross sections.

The key factor in both the rail seat bending and tie center bending results is cross section. Of particular importance is the depth (i.e. vertical height) of the tie in resisting vertically applied loads. The spread of values for the three cross sections is about 30 percent at nominal tie spacing and 50 percent at 29 inch spacing. The effect of tie spacing is also significant; with a 10 percent range for 6 by 8 ties and a 25 percent range for 7 by 9 and 7 by 12 ties.

A comparison of GEOTRACK tie stress and deflection calculations and actual test tie performance (as indicated by tie replacements) is shown in Exhibit 44. The GEOTRACK results agree with the field performance for most test sections.

The most notable "exceptions" are sections One and Eight. Except for tie deflection, the GEOTRACK stresses in the section One ties are lower than the standard section. However, the reduction in tie depth from 7 to 6 inches reduces the bending strength of the tie by about 34 percent. While the stresses imposed are 20-25 percent less, the net effect is a tie loaded more closely to its capacity.

Similarly, sections Seven and Eight have higher stresses (20-30 percent) and higher strength (33 percent) due to their larger cross sections. Thus, the better than standard section performance is also explainable.

Section Three performed better than GEOTRACK predicted (in comparison to section Four). The difference in performance is not likely attributable to differences in tie stresses.

4.0 CONCLUSIONS

The performance of the ties in all eight configurations of tie cross-section, length, and spacings has been acceptable for high tonnage tangent track operation. Over 21 years of service the test section has seen 600-700 MGT of traffic. During that time loaded coal unit trains have become a larger portion of the total traffic. Thus the ties have been subjected to the most demanding structural loads required of ties in tangent track.

Average tie life projections of 23 to 35+ years have been made for the eight test sections. There have been differences in performance between the test sections. However these differences in tie performance were not significant enough in effect on track performance to cause any change in maintenance policy. It may be that the sections are too small to make a discernible difference to the track maintenance forces. The railroad reports that the test site is relatively problem-free and that all sections have received the same maintenance.

Generally, decreases in performance were noted in sections where a smaller cross-section (One) or a wider spacing (Five,Six,Seven) was used. Sections with longer tie length (Two,Three) performed better than the standard section. The dowel-laminated ties of 7 x 9 cross-section performed very well in most respects compared to the standard section. These ties had good dimensional stability (i.e. split resistance). The most prevalent cause of failure amongst these ties was plate cutting or plate area deterioration. The wider tie spacing, large tie bearing area, and standard size plates all contribute to the high plate area forces at work on these ties. These effects are seen in the different levels of performance exhibited by the two dowel-laminated sections.

The relationship between tie plate cutting and ballast condition was investigated; however no definite conclusions can be reached. The condition of the ballast through the site is good. The material is still angular. The gradation samples taken indicate that the material is still largely within the original specification. Projections of ballast life suggest that the material has another 500 MGT before requiring replacement.

5.0 REFERENCES

1. Somogy, C., Sixth Progress Report of Cooperative Research on Wood Ties of the Railway Tie Association and Association of American Railroads Research and Test Department, Report Number R-111, Association of American Railroads, December 1971.

2. Davis, D. D. and Shafarenko, V. M., Tie Condition at Des Plaines - A Progress Report, Report Number WP-131, Association of American Railroads, 1988.

3. American Railway Engineering Association, Manual for Railway Engineering, Volume 1, Chapter 5, p. 5-1-3.

4. Davis, D. D., "Tie Wear Machine Progress Report", presented to the AAR Tie Working Group, September 21, 1988.

5. McCown, R., "Initial Results of the FRA Split-Axle Device Field Tests", presentation to the AAR Tie Working Group, May 14, 1987.

6. Davis, D. D., Tie Condition Inspection - A Case Study of Tie Failure Rate, Modes, and Clustering, Report Number R-714, Association of American Railroads, 1989.

7 Coltman, M., "Rail Restraint" presentation to AREA Committe on Track Safety Standards, May 28, 1987.

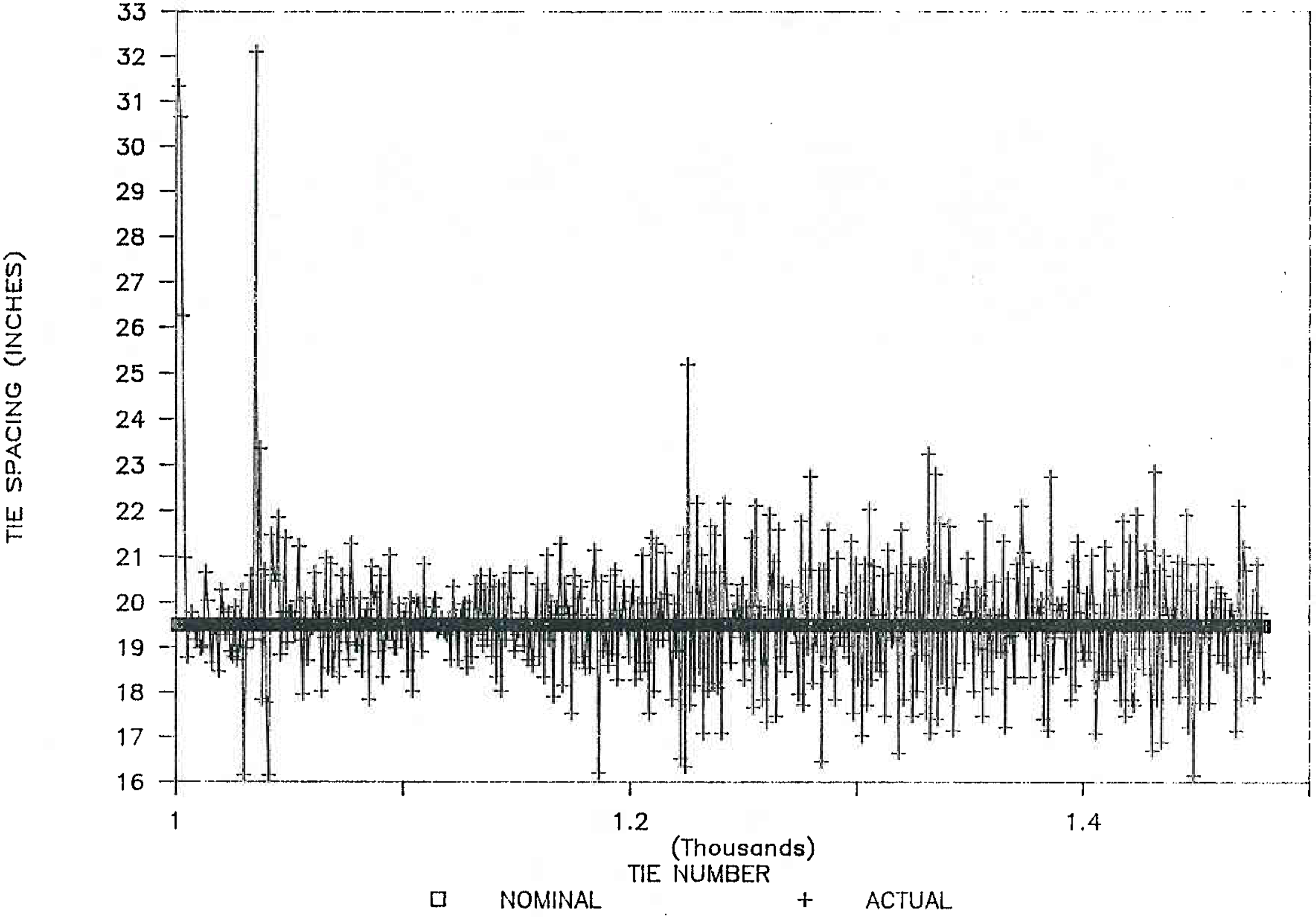
8. Yeh M. and Stewart, H., User's Manual for GEOTRACK Computer Program, Report Number AAR84-202R, University of South Carolina, 1984.

6.0 APPENDIX

6.1 Tie Performance Measurements

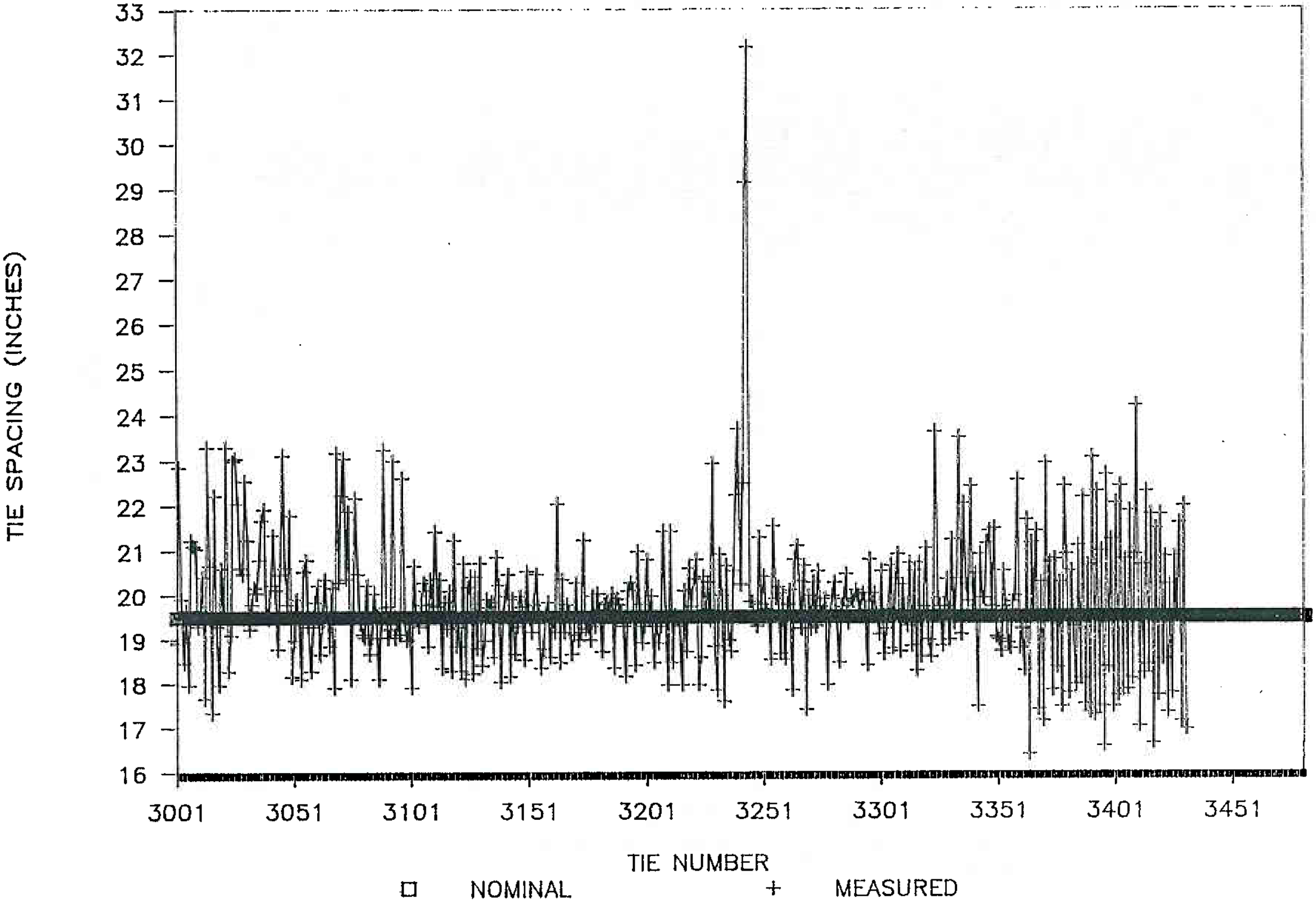
MEASURED TIE SPACING

SECTION ONE; DES PLAINES



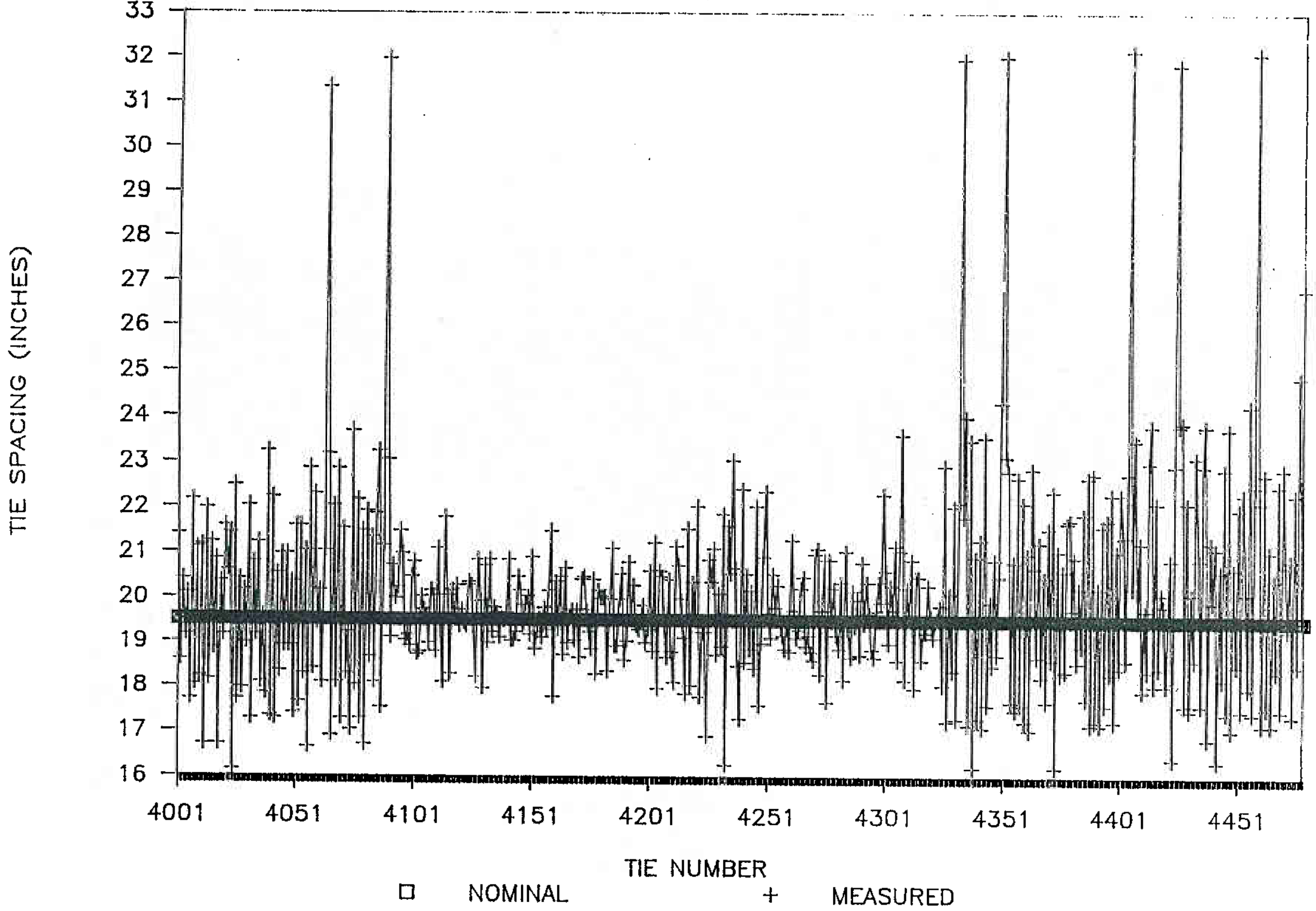
MEASURED TIE SPACING

SECTION THREE; DES PLAINES



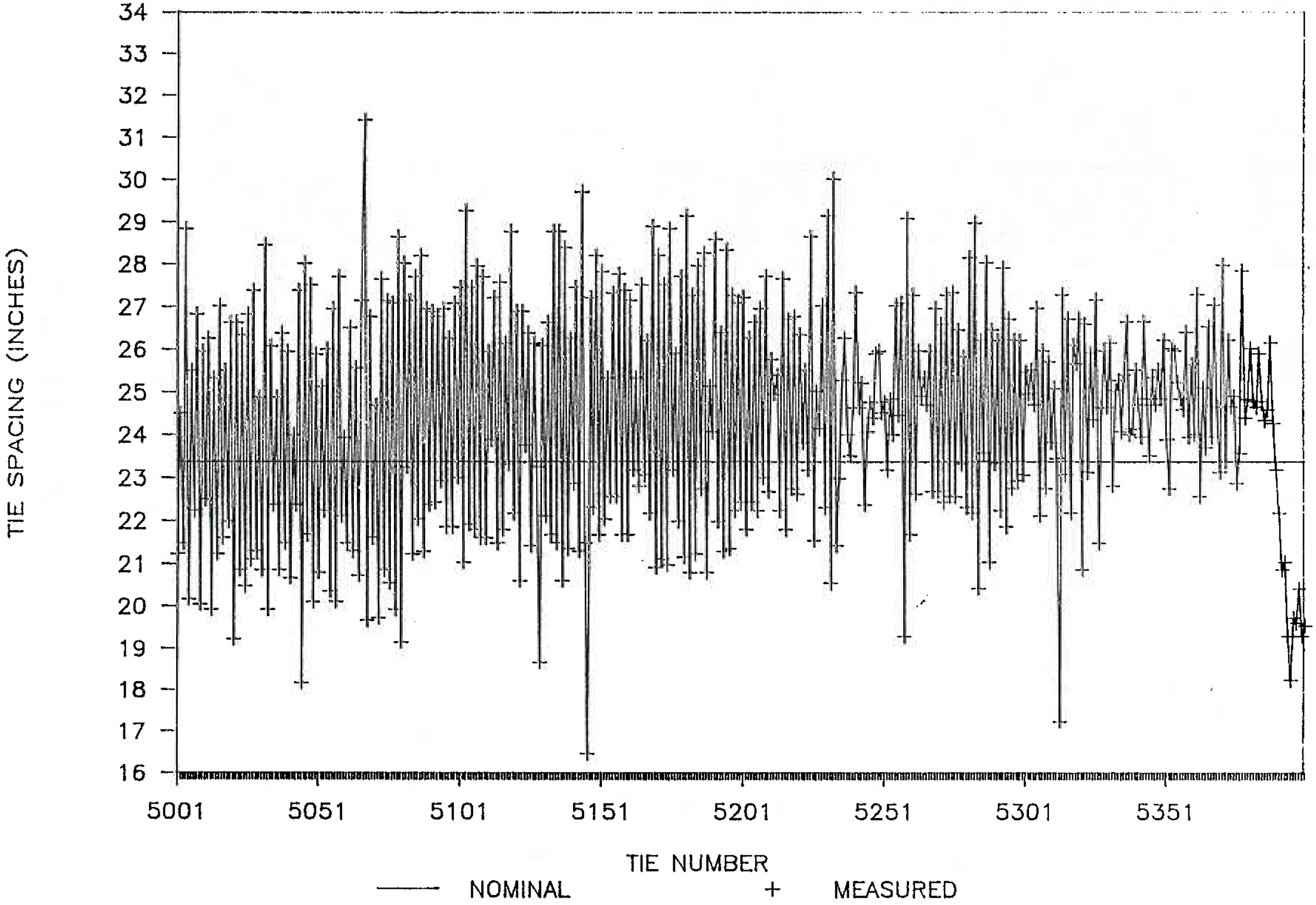
MEASURED TIE SPACING

SECTION FOUR; DES PLAINES



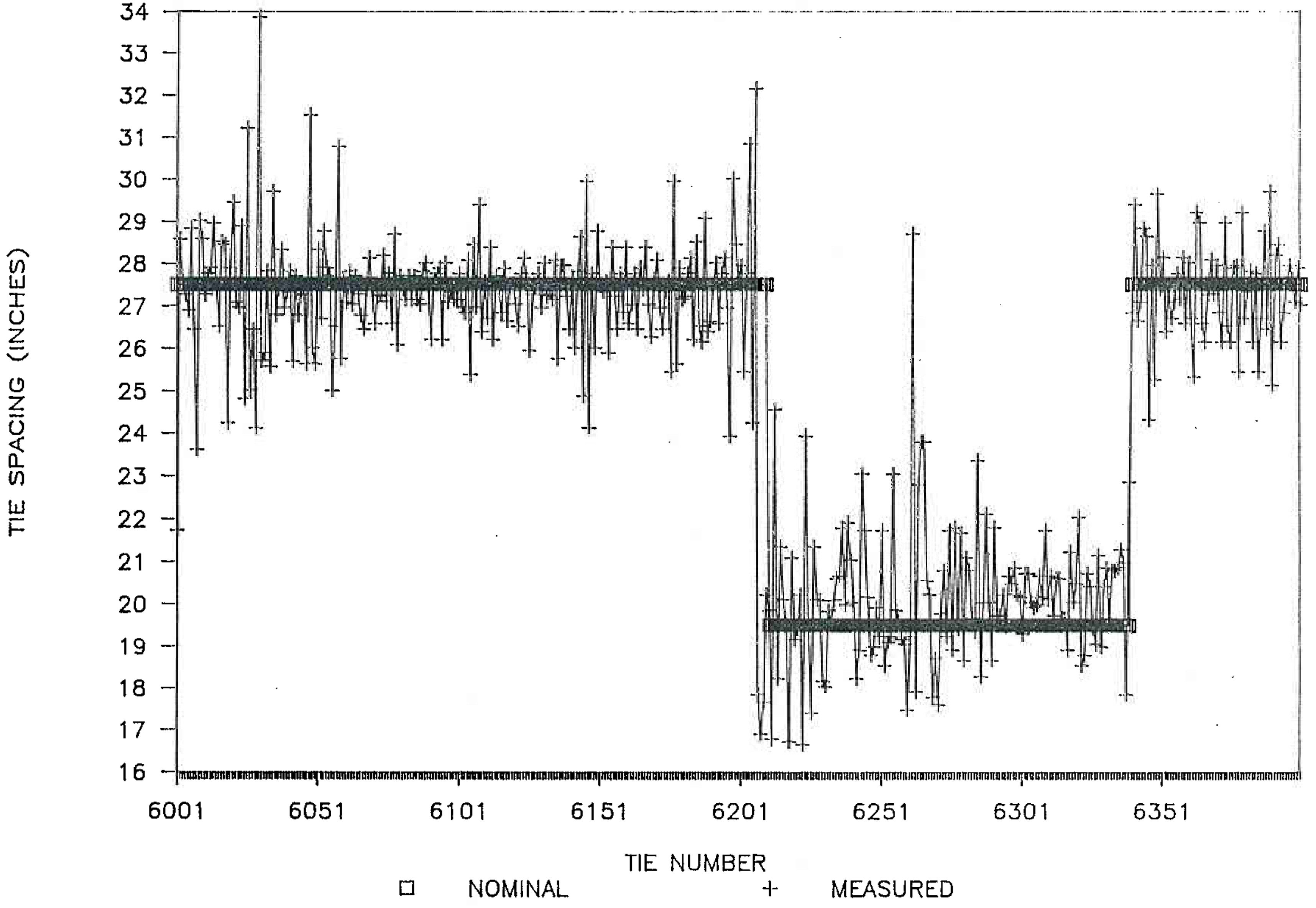
MEASURED TIE SPACING

SECTION FIVE; DES PLAINES

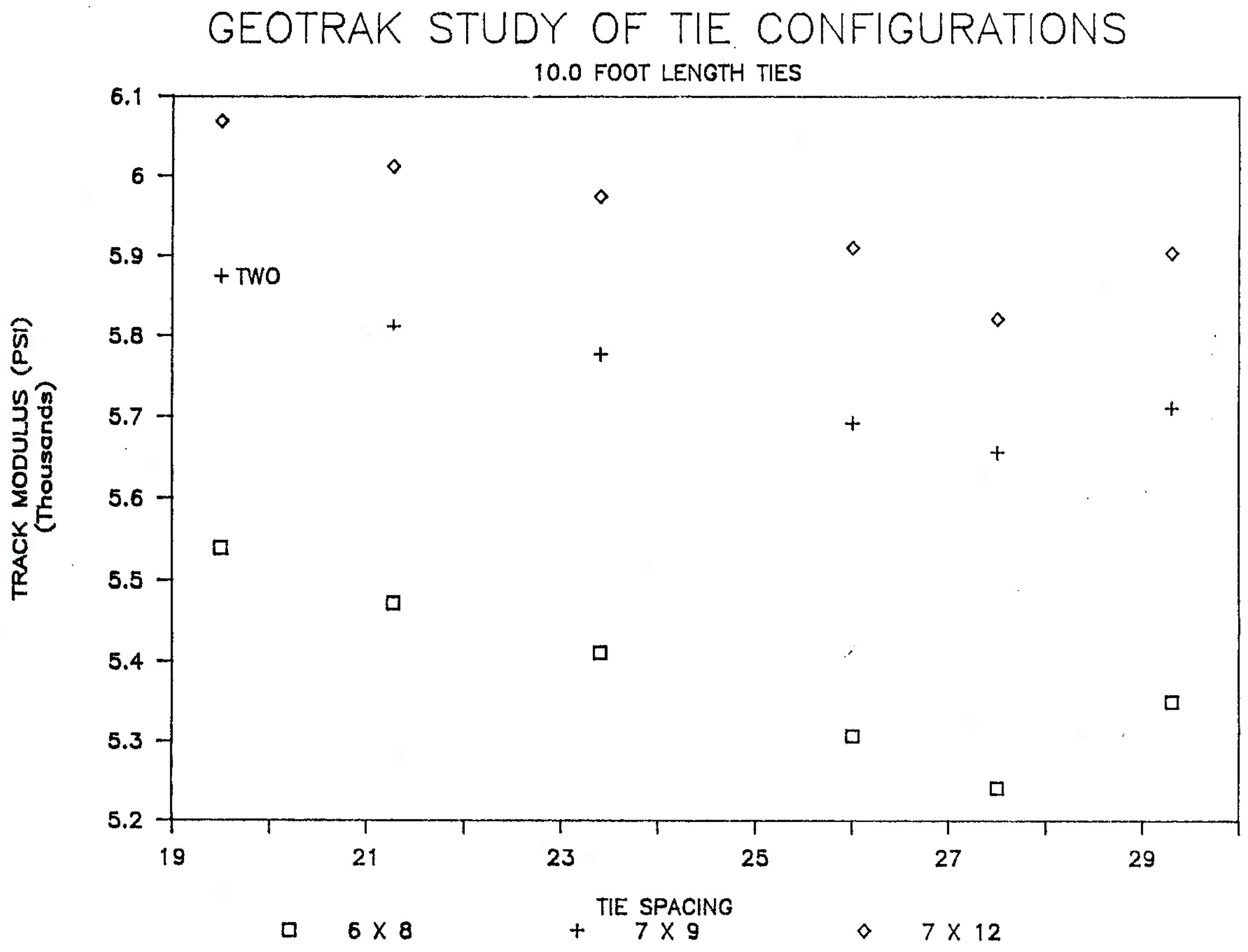


MEASURED TIE SPACING

SECTION SIX; DES PLAINES

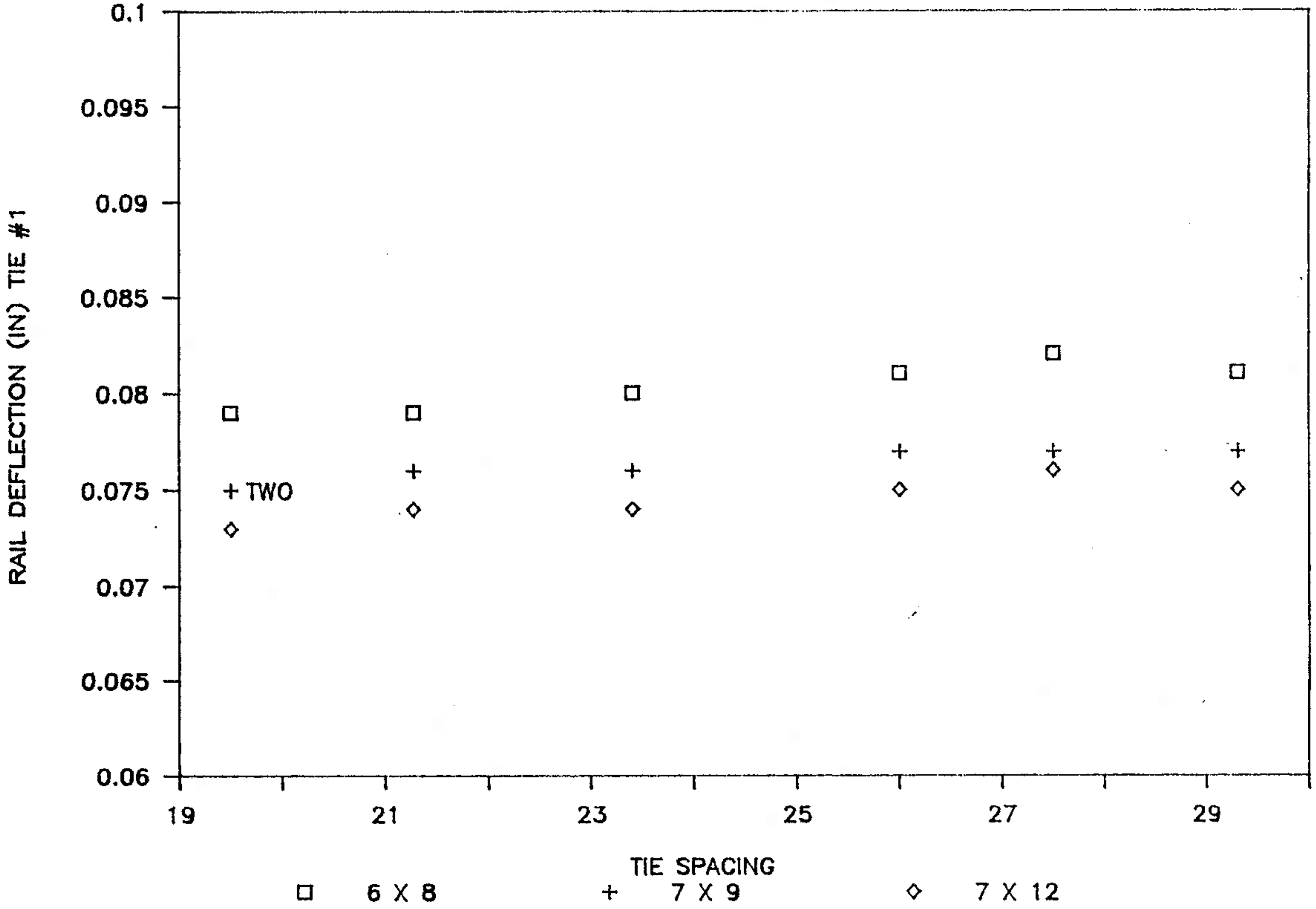


6.2 GEOTRACK Study Results


GEOTRAK STUDY OF TIE CONFIGURATIONS
10.0 FOOT LENGTH TIES
TRACK MODULUS (PSI)
(Thousands)
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
19
21
23
25
27
29
TIE SPACING
+ TWO
□ 6 X 8
+ 7 X 9
◇ 7 X 12

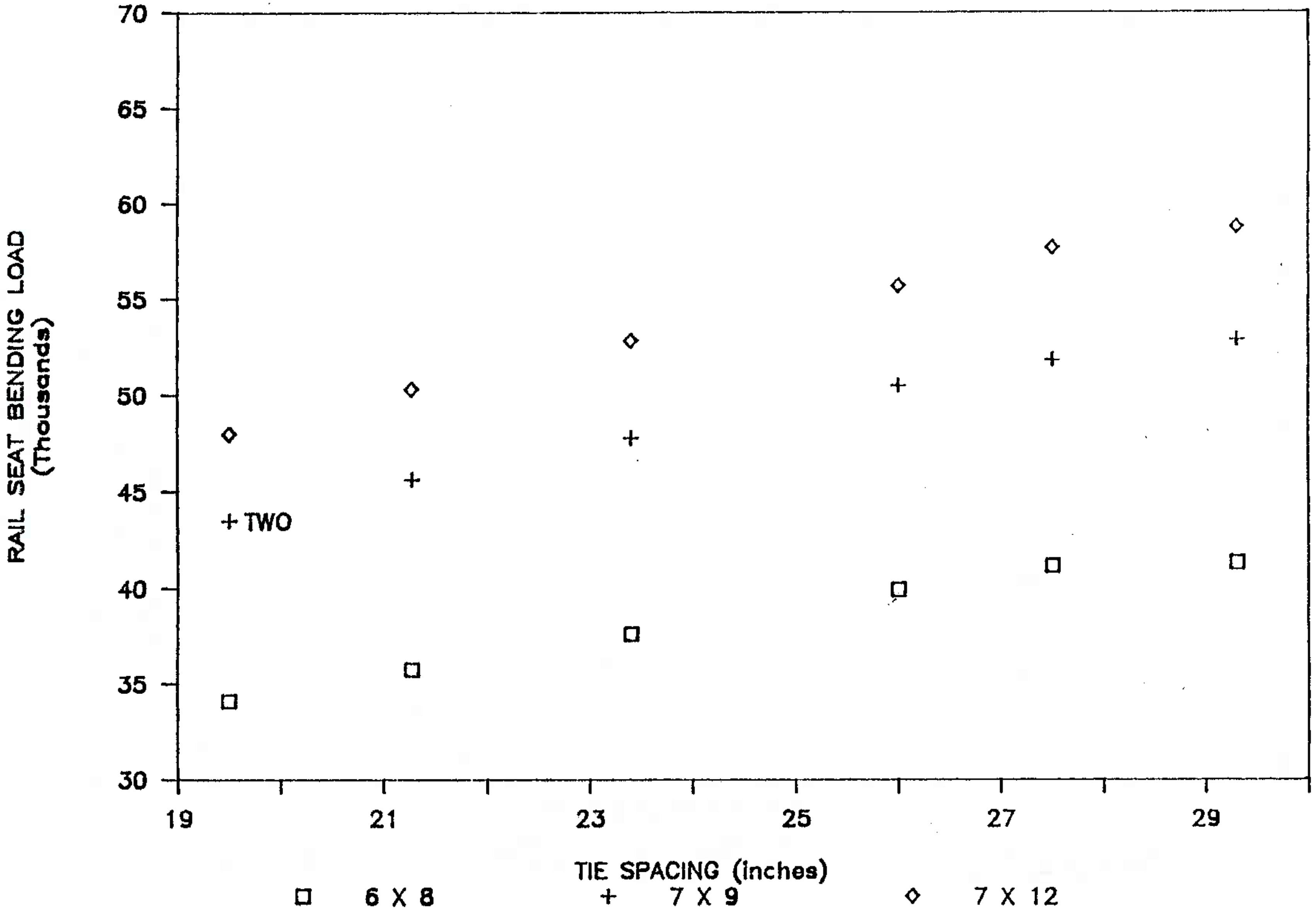
GEOTRAK STUDY OF TIE CONFIGURATIONS

10.0 FOOT LENGTH TIES



GEOTRAK STUDY OF TIE CONFIGURATIONS

10.0 FOOT LENGTH TIES



GEOTRAK STUDY OF TIE CONFIGURATIONS

10.0 FOOT LENGTH TIES