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Experimental Investigation of Gauge Widening and Rail Restraint Characteristics

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Development
Washington DC 20590

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16. Abstract

Gauge widening resulting from a loss of adequate rail restraint is one of the major track failure modes and the cause of a large number of derailments. A recent field and laboratory test program conducted by the Transportation Systems Center aimed at the determination of minimum rail strength capacity as influenced by tie and fastener condition resulted in the development of criteria and rail strength capacity limits for the prevention of excessive gauge widening.

One of the major safety issues currently under investigation under this program deals with the problem of gauge widening. The work reported here is part of this investigation dealing with the experimental testing of lateral rail strength for low speed (5-25 mph) track. Tests were conducted using a specially designed track loading fixture for the purpose of simulating actual wheel/rail loads. In addition to these rail restraint tests, experiments were performed to determine spike pull out strength and tie plate vertical and lateral stiffness behavior. This report gives a detailed description of these tests and presents obtained results on gauge widening and rail restraint characteristics.

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PREFACE

The Transportation Systems Center has been conducting research in support of the Federal Railroad Administration's (FRA) Track Safety Research Program to develop the engineering basis for more effective track safety guidelines and specifications. The intent of these specifications is to ensure safe train operations while allowing the industry increased flexibility for cost effective track engineering and maintenance practices.

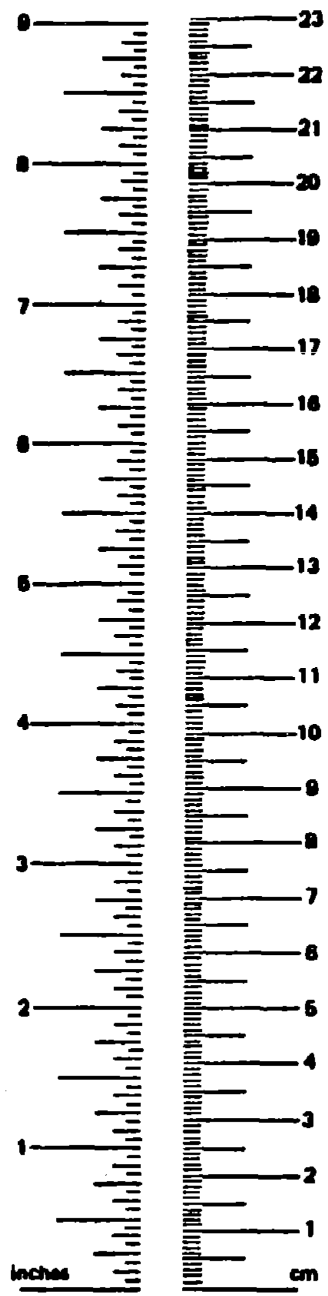
One of the major safety issues currently under investigation in this program deals with the problem of gauge widening. The work reported here is part of this investigation dealing with the experimental testing of lateral rail strength for low speed (5-25 mph) track. Tests were conducted using a specially designed track loading fixture for the purpose of properly simulating actual wheel/rail loads. In addition to these tests, experiments were performed to determine spike pullout strengths and tie plate vertical and lateral stiffness behavior. This report gives a detailed description of these tests, and presents results on gauge widening and rail restraint characteristics.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

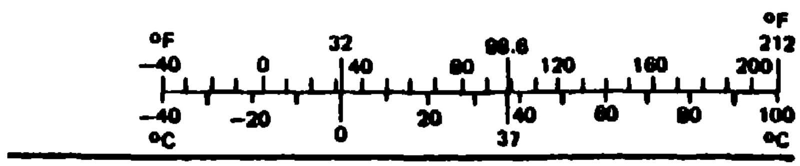
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

Rail restraint failure resulting in excessive gauge widening is one of the major track failure modes, and is responsible for a large number of derailments. In order to improve track safety performance in terms of providing adequate rail restraint, experimental and analytic investigations are being conducted by the Transportation Systems Center (TSC) for the Federal Railroad Administration (FRA). This report discusses the part of this activity which deals with field and laboratory tests on gauge widening and rail restraint characteristics. The analytical part of this investigation is described in a separate report by Jeong and Coltman (10).

The principal purpose of the tests described in this report is to establish minimum rail strength capacities required for providing and maintaining adequate rail lateral restraint for low speed track, and to generate data on rail fastener behavior characteristics for analytic model development and studies. The tests were conducted on the Chessie System's Hocking Division near Logan, Ohio during the summer of 1980, and primarily consisted of evaluating rail restraint behavior in terms of load-deflection characteristics for a variety of tie conditions and loading scenarios.

This report gives a detailed description of these tests, and presents results on rail restraint characteristics as they are influenced by tie/fastener condition, vertical and lateral loads, cyclic loading, and special conditions such as missing ties and weakened joints. Test results on spike pullout strength and tie plate stiffness behavior are also given.

1. INTRODUCTION

The loss of adequate rail lateral restraint, often resulting in gauge widening, is one of the major track failure modes and the cause of a large number of derailments on track in the United States. Accident statistics compiled by the Federal Railroad Administration indicate that about 23 percent of all track related accidents are attributable to rail restraint failure. Furthermore, as shown in Table 1.1, 97 percent of gauge widening induced derailments occur at low speeds or speeds below 25 MPH. The reduction of the number of these accidents through adequate maintenance and better performance standards has been a strong concern to the railroad community.

Present understanding of the problem of gauge widening is that it often results from a combination of rail rotation and rail lateral translation. The factors contributing to this mode of failure have received considerable analytical and experimental treatments through the years. A recent survey by A. Zarembski (1)* reviewed a number of these efforts. More recently, a set of gauge widening tests were performed at the Association of American Railroads' Track Laboratory. A summary of these tests can be found in Table 1.2. In addition, the most applicable measured data currently available for the determination of rail restraint capacity is shown in Table 1.3. This data proved to be extremely useful and important in developing a better understanding of the mechanics of gauge widening and the factors influencing it. However, each of these sets of tests had some unique features, such as the method of load application or artificially degraded track; therefore they are

* numbers in parentheses denote references

TABLE 1.1 - GAUGE WIDENING ACCIDENT SUMMARY

- ACCIDENT OCCURENCE AS FUNCTION OF SPEED:

0--10 MPH	753*	(92%)
10--25 MPH	39	(5%)
25--110 MPH	26	(3%)

- ACCIDENT OCCURENCE AS FUNCTION OF TRACK CAPACITY:

YARD AND SIDING	488	(60%)
MAINLINE	314	(40%)

- ACCIDENT OCCURENCE AS FUNCTION OF HIGH CAPACITY CARS:

70T - 100T OPEN HOPPER	32%
70T - 100T COVERED HOPPER	26%
"JUMBO" TANK CARS	10%
TOTAL	68%

* AVERAGE 1975-78, Based on FRA Accident Statistics

TABLE 1.2 - AAR GAUGE WIDENING TESTS SUMMARY

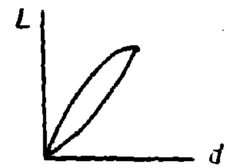
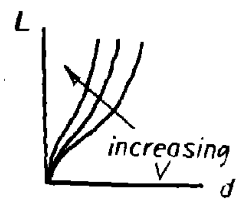
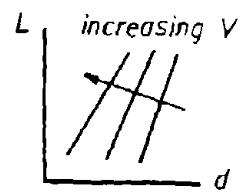
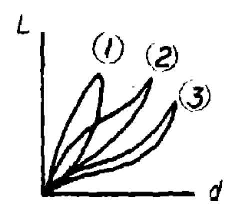
TEST TYPE	OBJECTIVE	TEST DESCRIPTION	TYPICAL RESULT	MAJOR CONCLUSION
BASIC GAUGE WIDENING (G-W)	o predict ultimate strength of track towards failure by gauge widening	o series of 84 tests o lateral loads applied to predetermined g-w limits of 0.25, 0.50, 1.0, 2.0 in. for vertical loads of 0,5,10, 15,20, 30 , 40 kips		o for new track in "good condition, rail head deflections result from rail rotation o lateral load level needed to displace a rail head a certain amount decreases when track has been previously "damaged"
G-W ADJACENT LOADS	o determine the effect of an adjacent set of vertical and lateral loads on g-w of track structure	o series of 15 tests o varying combinations of V and L where maximum lateral railhead deflections = 0.5 in., V_1 = 0 - 40,kips V_2 = 0 - 40 kips, L_1 = varied, L_2 = 0		o adjacent vertical loads increase gauge widening resistance
G-W LONGITUDINAL LOADS (SERIES I)	o determine the effects of longitudinal compressive rail loads on g-w	o series of 12 tests o vertical and axial loads applied first, then lateral load is applied o V=0 - 40 Kips, P = 0-240 Kips, L = 30 kips (constant)		o negligible or minimal effect on gauge widening of track in "good" condition
G-W CYCLIC LOADS	o investigate effects of cyclic loadings on gauge widening	o vertical load of 15 kips o lateral load applied at a rate of 0.75 in/min until rail head was displaced 0.75 in. and released to zero o Procedure conducted for 25 cycles		o load required to displace railhead a certain amount stabilizes after 4 loading cycles o progressive damage occurs in adjacent fasteners with each additional cycle

TABLE 1.3 - RAIL RESTRAINT CAPACITY
AVAILABLE MEASURED DATA

SOURCE	TRACK CONDITION	TEST CONDITIONS	TEST/DATA LIMITATIONS
CN FIELD TEST 1972 (LUNDGREN & SCOTT)	o TANGENT YARD TRACK o GOOD (NEW) TIES o RAIL SIZE: 80, 85, 100, 115 AND 130#	o LOADED CAR INDUCED VERTICAL LOADS (9.4, 17.7, 26.7, 32.6 KIPS) o SPECIAL LATERAL LOADING HEAD	o DID NOT REPRESENT WEAK OR MINIMUM TRACK CONDITION o NON-REALISTIC LOAD APPLICATION RESULTING IN EXCESSIVE OVERTURNING MOMENT
AAR TRACK LAB TESTS (ZAREMBSKI & CHOROS)	o 136# RE RAIL o "NEW" TIES: "DEGRADED" BY SPIKE PULL-OUT	o CONSTRAINED TWO POINT CONTACT o "DAMAGED" TRACK BY CYCLING LOADS AND DEFLECTIONS o "WEAKENED" TRACK AND SPECIAL TESTS (MULTIPLE AND AXIAL LOADS)	o EXCESSIVE OVERTURNING MOMENT DUE TO CONSTANT TWO POINT CONTACT o NEW TIES "DEGRADED" BY SPIKE PULL OUT MAY NOT BE TYPICAL OF MINIMAL TRACK
TTD "DECAROTOR" TESTS ON SR (AAR/TSC/SR)	o 90# RAIL IN YARD o 132# RAIL IN MAINLINE TRACK WITH NEW TIES AND 5 YEAR TIES	o UTILIZES 12" LOAD WHEEL o STATIONARY AND MOVING o VERTICAL LOAD TO 15 KIPS o LATERAL LOAD TO 10 KIPS	o LOADS AND DEFLECTIONS TOO LIMITED FOR RAIL RESTRAINT ANALYSIS o TO DATE, MINIMUM STATIONARY DATA AVAILABLE

not representative of nor can readily be interpreted as characteristic of weak or poor track. Some of the specific limitations of the available test data summarized in Table 1.3, created a need for more testing, especially on low speed track. This report describes the testing conducted on track which is typical of low speed (Class 1 or 2) FRA Track Classifications and presents results on gauge widening and rail restraint characteristics.

Currently, the Transportation Systems Center is conducting research for the FRA which involves the development of data and technical information required for the specification of safety performance limits for rail restraint. In support of this research effort, a series of field tests were performed to address the lack of adequate rail restraint data and the need to focus on rail strength capacity assessment for low speed track. The primary objective of these tests, therefore, was to determine a minimally adequate rail strength capacity against lateral restraint for operating speeds up to 25 MPH. This was accomplished by obtaining lateral load versus rail deflection data for ties with varying degrees of degradation on a low speed track. A characteristic lower bound curve of lateral load versus rail head deflection was found by analysis of the variation in this data. In addition to the rail restraint measurements, resistance characteristics of track components were also examined. Specifically, vertical spike pullout resistance and tie plate lateral resistance were measured. This data was obtained to provide input into an analysis in predicting rail lateral response. The detailed test procedures is described in Reference (2). The purpose of this report is to briefly describe these field test measurements and to summarize the results of the experimental investigation.

2. TEST DESCRIPTION

2.1 TEST SITE

The field tests were conducted from July 7 to July 18, 1980 on the Hocking Division, Pomeroy Subdivision of the Chessie Railroad, near Logan, Ohio. The specific test track segment was located between mile posts 55 and 57, near Union Furnace. The test site characteristics may be summarized as follows:

- General condition: Out of service for 6 previous months, speed limit of 25 MPH (typical speeds of 10 MPH), tangent track, mild (0.3) grade, excellent gauge and alignment
- Rail: 100 lb/yd., not badly worn
- Ties: Wood - Mixture of "good" and "bad", spacing of 20" to 22"
- Plates and Spikes: Single shouldered tie plate two line spikes/plate
- Ballast: Cinder/Gravel

The selection of this segment as the candidate test site was based on the assessment of Chessie/FRA/TSC personnel that it represented a marginally adequate quality of low speed track. This assessment was based primarily on tie condition and the low weight rail. Figures 2.1 to 2.4 show photographs of the test site and typical candidate test ties. The specific test tie locations were chosen in such a manner as to afford an adequate sample of "good," "average", and "poor" ties for a variety of adjacent tie conditions.

2.2 EQUIPMENT AND INSTRUMENTATION

A specially designed track loading fixture (TLF) was employed to provide vertical and lateral loading to the rails. This fixture consists of a pair of clevis pins coupled vertical and lateral jacks which are mounted on the underframe of a loaded hopper car. Figure 2.5 shows the basic layout of the TLF measurements. The loading fixture is powered hydraulically and has a capacity of 50 kips vertical and lateral

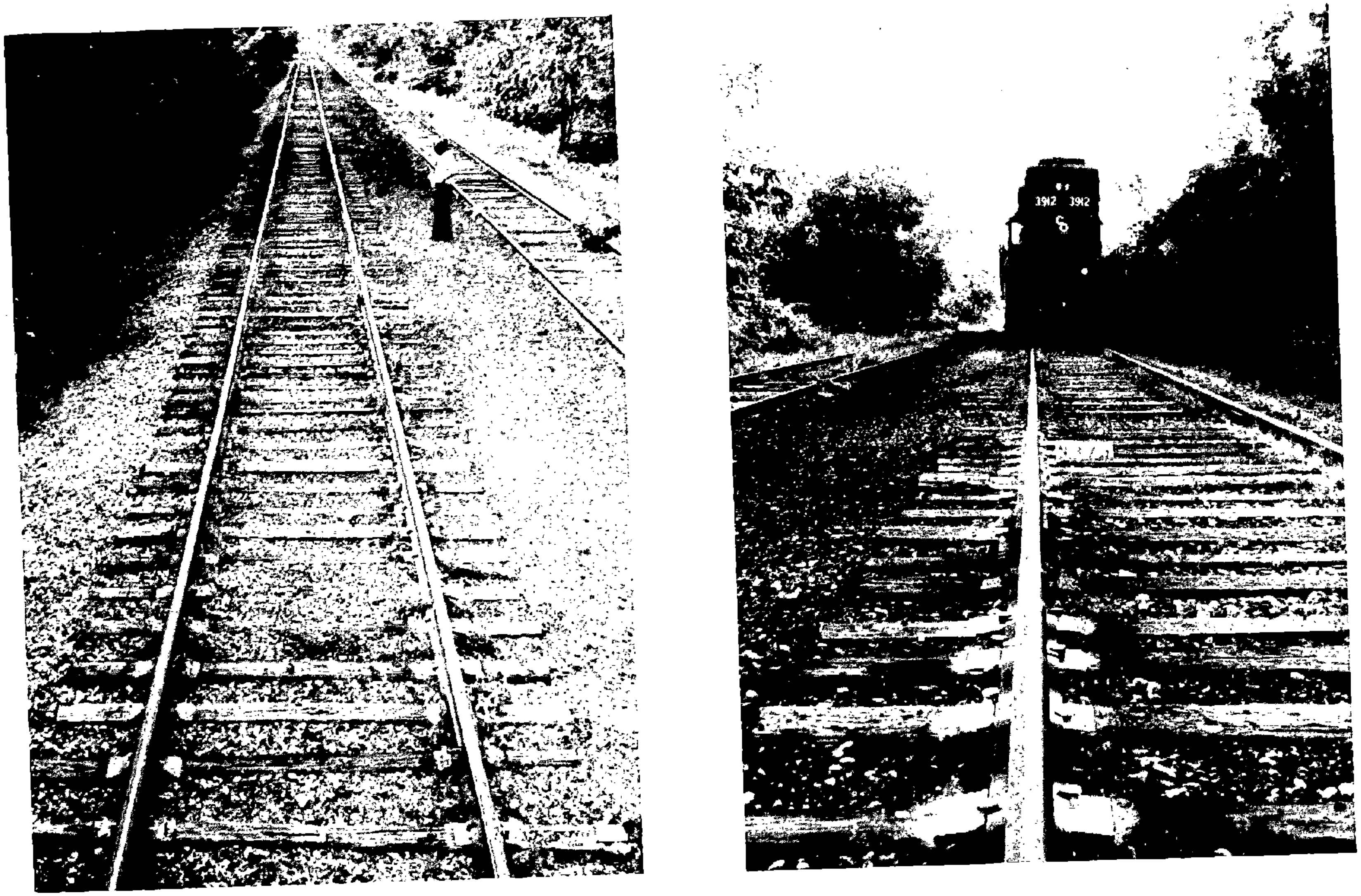


FIGURE 2.1 - LOGAN FIELD TEST SITE

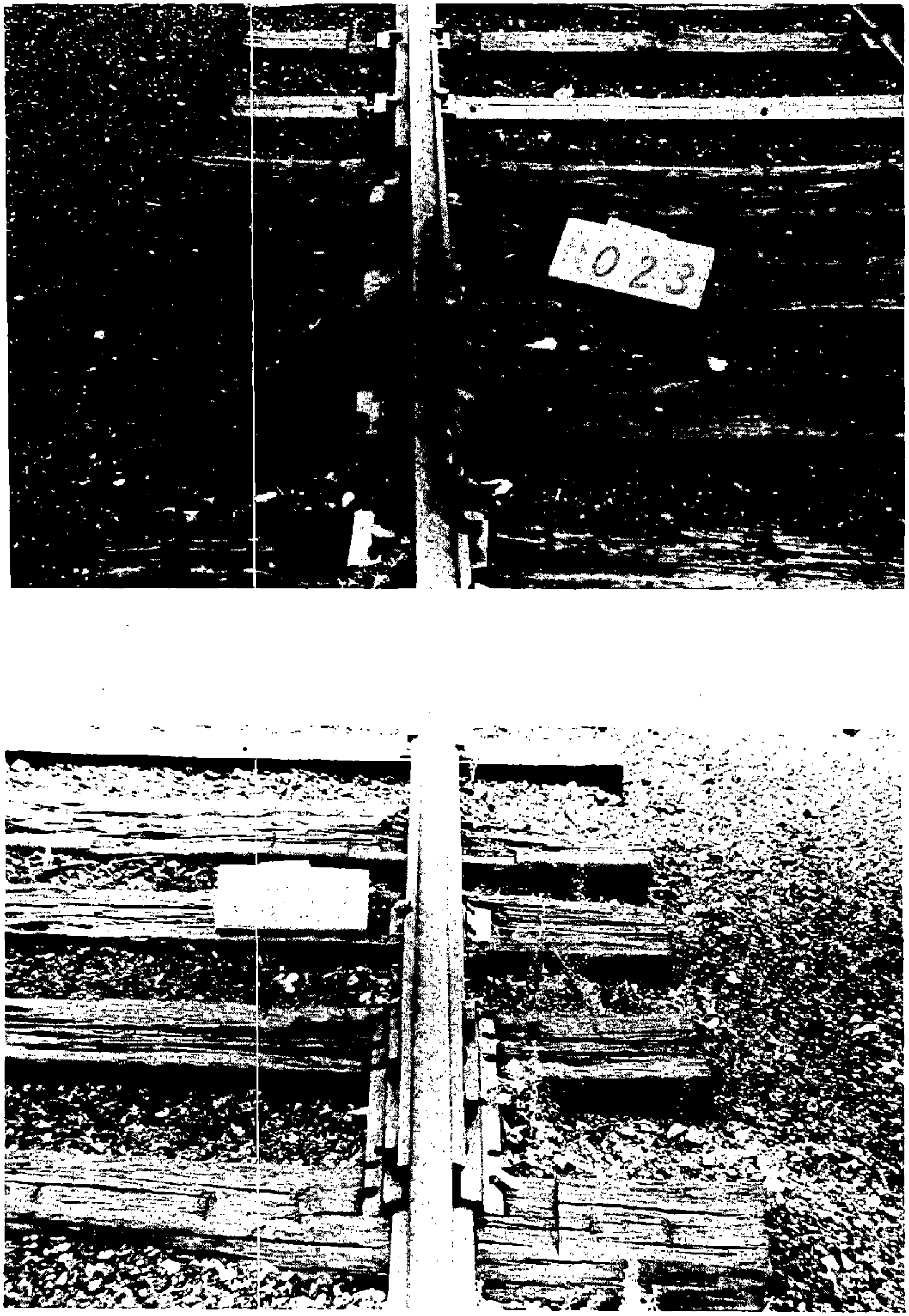


FIGURE 2.2 - TIE #23

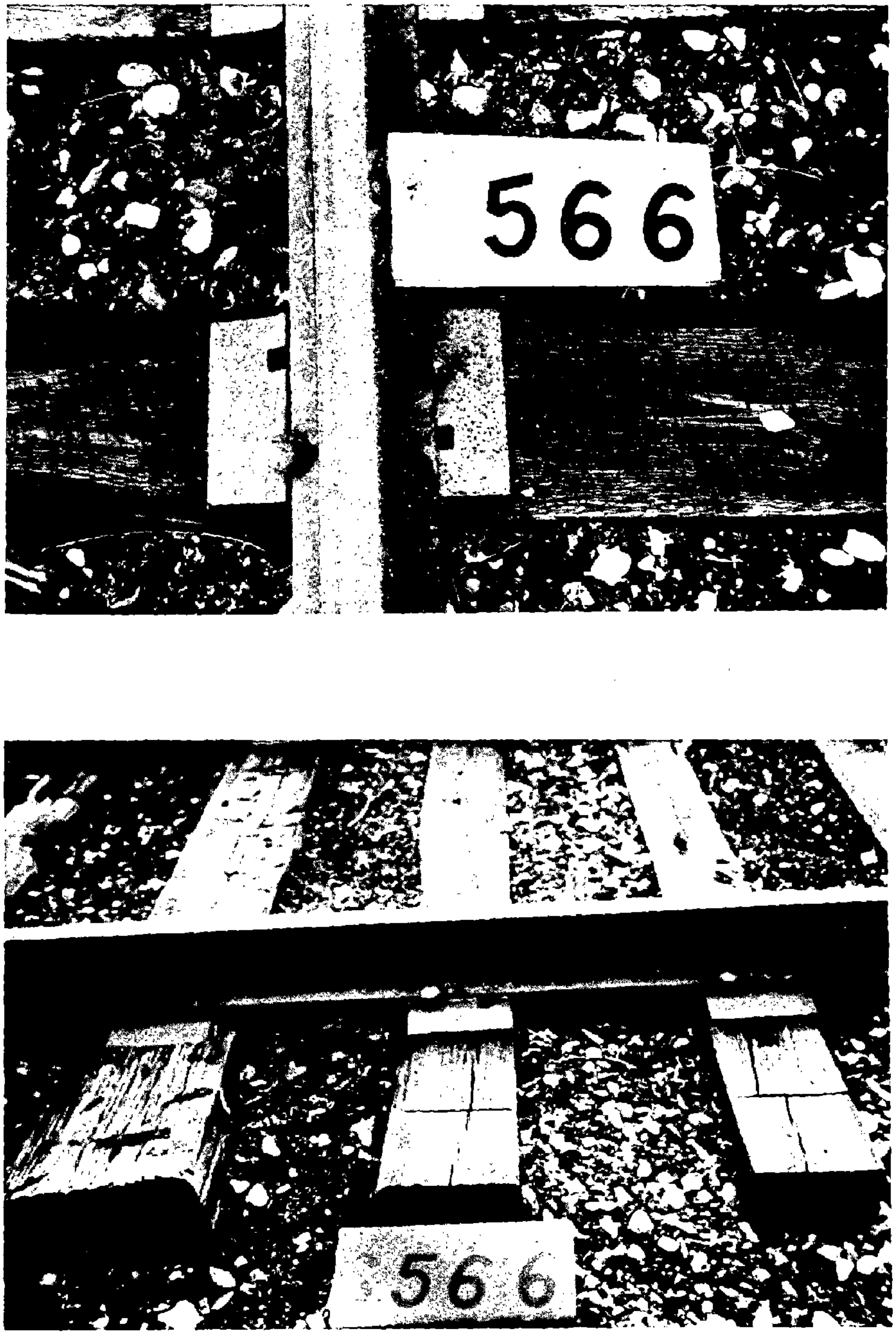


FIGURE 2.3 - TIE #566

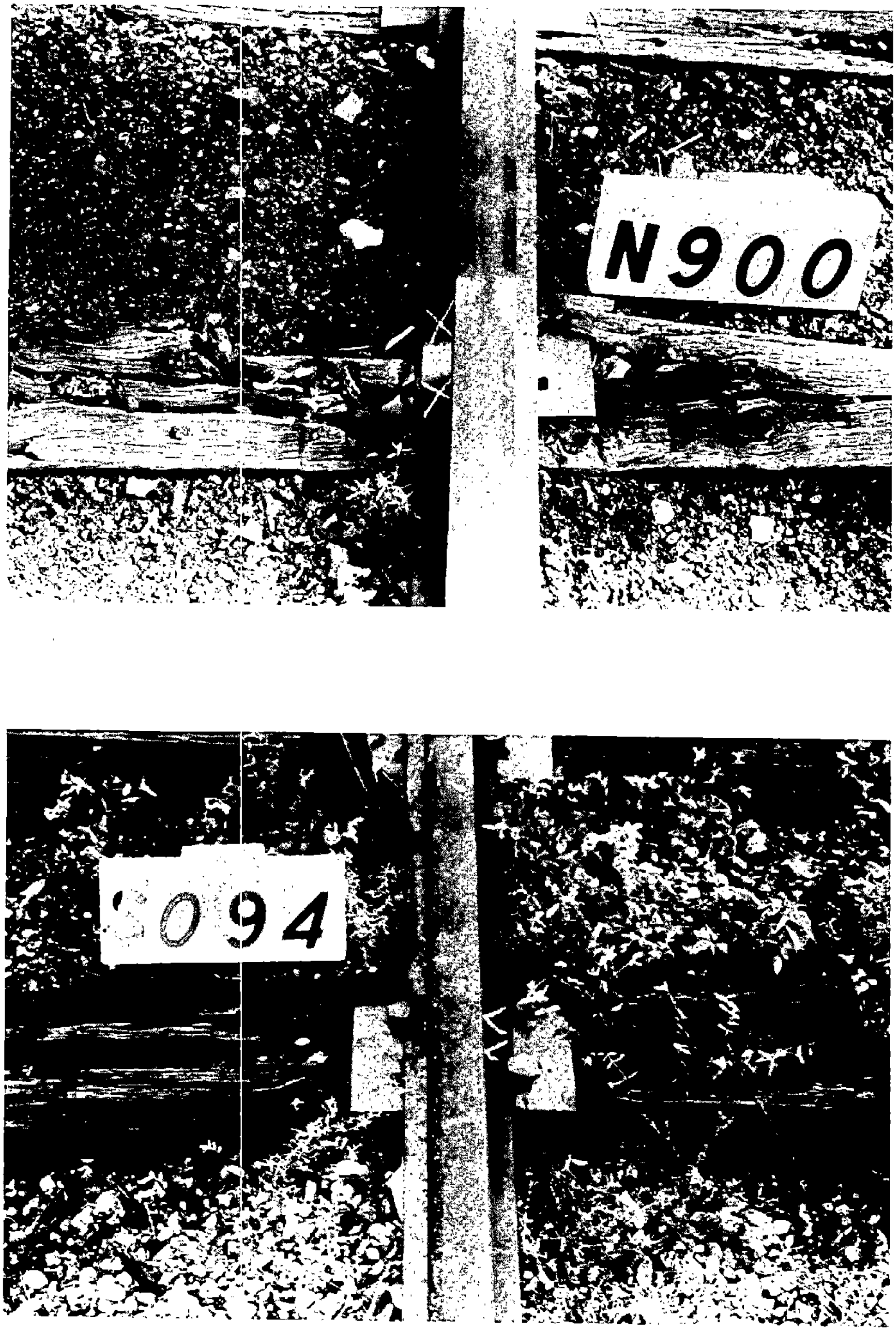


FIGURE 2.4 - TIE #900 NORTH AND TIE #94 SOUTH

load. The actual load transfer to the rails is accomplished through a standard 36 inch diameter AAR wheel profile segment. Therefore, the TLF allows a very close simulation of actual single point wheel rail contact during the loading process. The loads are measured through the pair of clevis pin load cells and are also monitored by a digital readout. The lateral jack was designed to generate large rail lateral deflections; that is, up to 6 inches. The clevis pin load cells allowed for measurements of the total lateral and vertical loads exerted independent of the position of the load cylinders.

The lateral displacements of the rails were measured at the rail head and rail base. These displacements were measured with direct current displacement transducers (DCDT's) capable of measuring up to 3 inches of rail head displacement and 2.5 inches of rail base displacement, see Figure 2.5.

A pair of XYY plotters was used to plot the results for real time analysis. The lateral load was entered into the X channel and the two lateral deflections (rail head and rail base) were entered into the Y channels for a constant vertical load. Figure 2.5 shows the measurement arrangement.

Pre- and post-calibrations of the track loading fixture were done to check sensitivity and cross talk using a standard tensile test machine. These calibration efforts are fully described in Reference (2).

2.3 TEST PROCEDURE

Before testing, each test location was characterized by recording information including tie number, tie condition, adjacent tie condition and track gauge. This information was recorded on a form such as shown in Figure 2.6. Pretest characterization also involved spray painting each rail base/tie plate/tie interface area for subsequent visual assessment of component displacements. Every test tie was also photographed. Several of these photographs are included in this report.

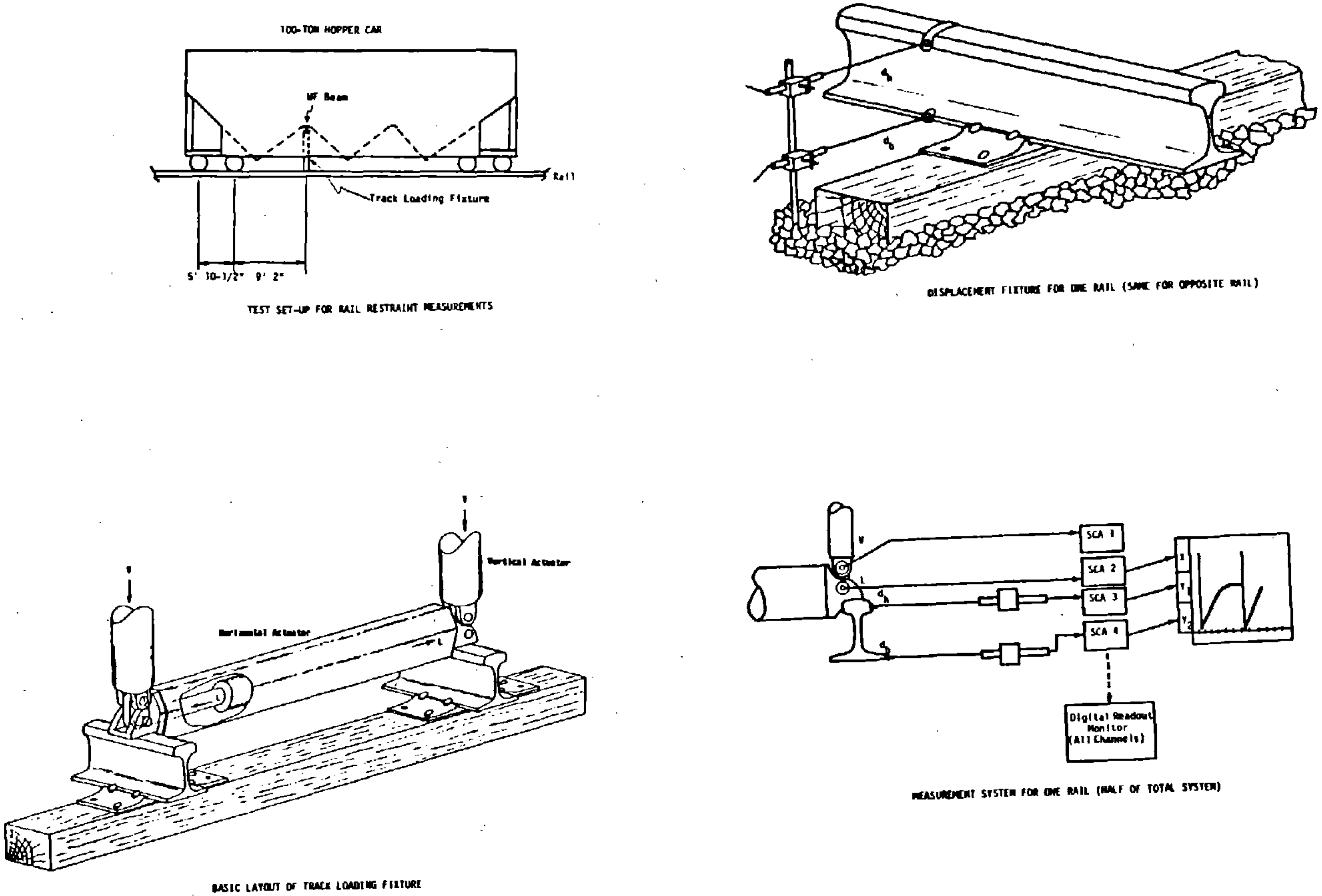


FIGURE 2.5 - TEST SETUP FOR RAIL RESTRAINT MEASUREMENTS

Page TD __ of TD __

Date: ______________________

Zone/Site: ______________________

Track Gage: ______________________

Ballast Type: ______________________

Rail Size: ______________________

Tie Condition: ______________________

Tie Material: ______________________

Tie Size: ______________________

Tie Plate Size: ______________________

Comments:

Tie Plate Cutting:

(a) gage: ______________________

(b) field: ______________________

Spike Size: ______________________

Film Roll # ____________ Photo # ____________

Operator: ______________________

Spiking Pattern (marked with X), Spike Uplift (in inches), and Distance (in inches) between Non-defective Ties (Defective Ties marked with D):

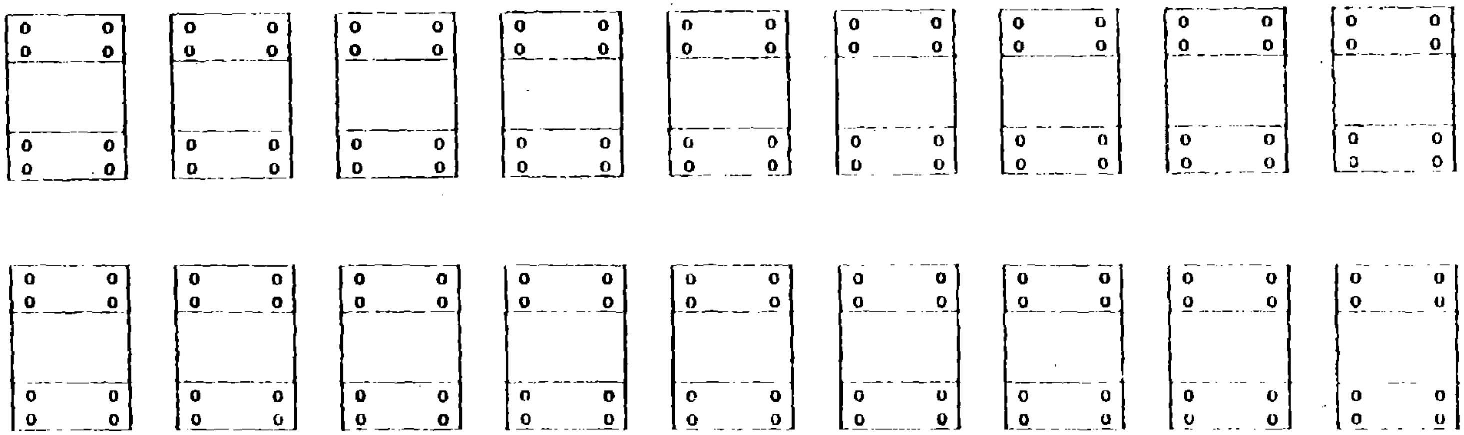


FIGURE 2.6 - GENERAL TRACK DATA FORM

The test conduct proceeded as follows:

- o hopper car and loading fixture positioned over test tie
- o DCDT's mounted
- o track gauge recorded
- o vertical load applied
- o lateral load applied
- o loads and displacements recorded on XYY plotters
- o lateral load was removed, followed by the vertical load.

After completion of each test, the final gauge, the tie plate lateral shift and spike uplift were measured. The tie plate lateral shift and spike uplift were also measured for four ties adjacent to the test tie location. In some cases, the spikes were pulled out to visually compare spike deformation with spikes pulled from non-test zones. Also, for some special cases, the tie plates were removed to assess spike hole elongation and condition.

The field tests consisted of five series which were performed along with several special tests. A test matrix is shown in Table 2.1.

In Test Series 1, a vertical load was applied and the lateral load was increased until the rail head deflection reached 3 inches, or until the lateral/vertical load ratio (L/V) limit was reached. Throughout the test the L/V ratio was limited to 2.8-3.0 to prevent the wheel segment of the track loading fixture from "derailing."

Test Series 2 was similar to series 1, however, two load cycles were run. The first cycle was stopped at a prescribed lateral rail head displacement and the second cycle was stopped at a lateral displacement of 3 inches or the L/V ratio limit.

Test Series 3 was also a 2 cycle test. The first cycle was run under a 5 kip vertical load while the lateral load was increased until the L/V limit was reached. The second cycle was run under a 15 kip or 30 kip vertical load (see test matrix, Table 2.1) with increasing lateral load up to 3 inches of rail head lateral deflection.

Test Series 4 was designed to investigate the significance of the

TABLE 2.1 - RAIL RESTRAINT MEASUREMENT TEST MATRIX

TEST SERIES NUMBER	VERTICAL PRELOAD, V (KIPS)	RAIL HEAD DISPLACEMENT, LIMIT (INCHES)	NUMBER OF LATERAL LOAD CYCLES	NUMBER OF TESTS
1.1	15	3	1	38
1.2	30	3	1	26
2.1	15	1 , 3	2	2
2.2	30	1 , 3	2	2
3.1	5 , 15	1 , 3	2	8
3.2	5 , 30	1 , 3	2	8
4	15, 30, 45	1/2, 1,2	9	4
5.1	15	1	26	2
5.2	30	1	26	2

SPECIAL TESTS:	ADJACENT LOAD INFLUENCE	V = 15, 15, 30
	TWO AND THREE MISSING TIES	V = 15
	WEAKENED TIES, SPIKES REMOVED	V = 15
	WEAKENED JOINT, BOLTS REMOVED	V = 15
	VERTICAL TIE PLATE MODULUS	V VS δ

COMPONENT TESTS: SPIKE PULLOUT CHARACTERIZATION
TIE PLATE LATERAL RESISTANCE

L/V ratio. A 15 kip vertical preload was applied followed by an increasing lateral load up until 0.5 inches of head lateral deflection were reached. Vertical preloads of 30 kips and 45 kips were also applied. The procedure was also repeated for deflection limits of one inch and two inches.

Test Series 5 was a cyclic loading test. Under a specified vertical load (15 or 30 kips) the rail was laterally loaded to 1 inch rail head deflection and then unloaded. The rail was then reloaded and unloaded for a total of 25 cycles. A 26th cycle was run to the L/V limit.

Additionally, a set of special tests were also conducted:

1) Artificially weakened track
In several sections the track was artificially weakened by removing two or three ties, removing spikes or removing the bolts from joints. These sections were then tested under a Test Series 1 procedure with a 15 kip vertical preload.

2) Adjacent load influence
In order to assess the effect of the axle nearest the applied load, the restraining end of the hopper car was lifted before testing.

2.4 COMPONENT TESTS

Another special set of tests were conducted to examine the strength characteristics of rail fastener components. These component tests were performed in the laboratory as well as in the field.

Two special devices designed and built by Battelle's Columbus Laboratories were used to measure the load versus displacement characteristics of these components. Specifically, the Spike Pullout Resistance Device (SPRD) measured the spike vertical pullout force against the spike pullout displacement. The other device, the Tie Plate Lateral Resistance Device (TPLRD) was used to measure the tie plate lateral force versus lateral displacement. These devices are shown in Figure 2.7.

The laboratory tests were carried out on new and used tie/tie

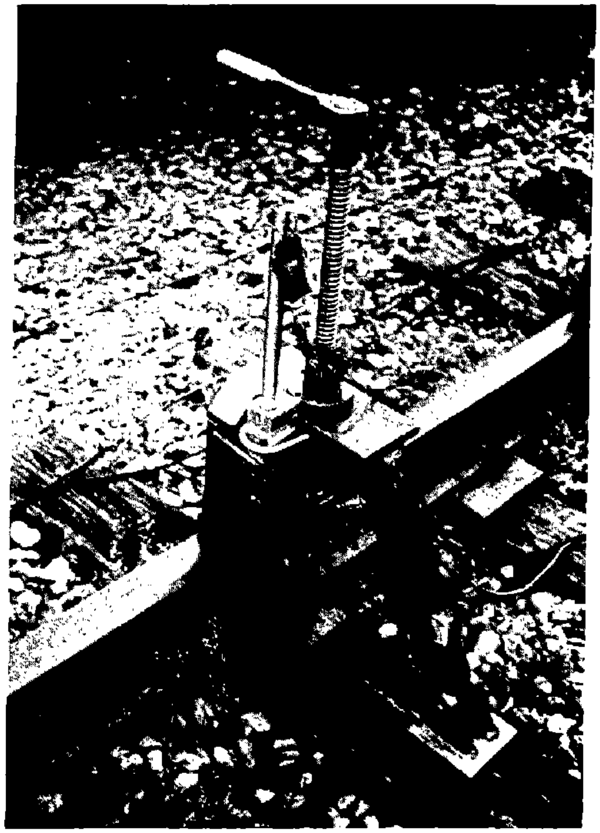


FIGURE 2.7a - SPIKE PULLOUT RESISTANCE DEVICE

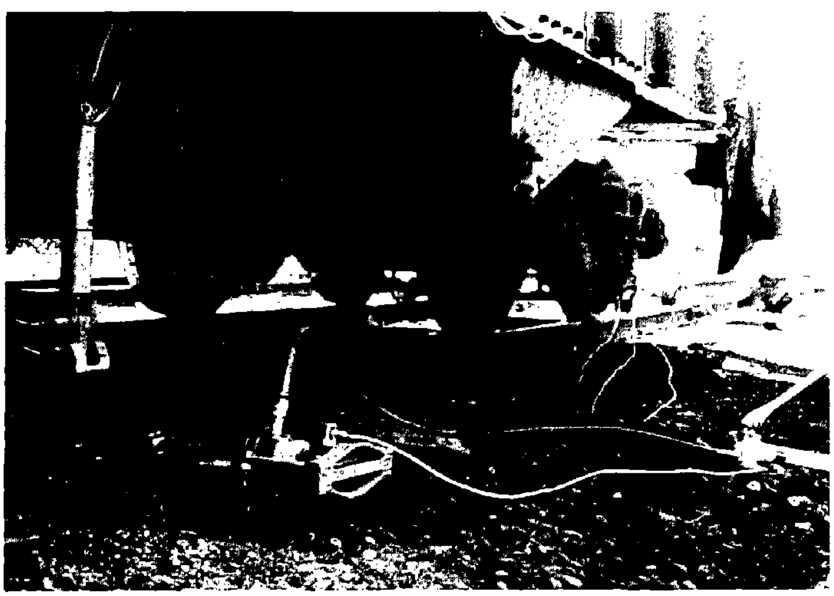


FIGURE 2.7b - TIE PLATE LATERAL RESISTANCE DEVICE

plate/spike configurations. The objectives in the laboratory tests were to develop and demonstrate measurement techniques and to obtain rail restraint data for wood ties. These measurement techniques were then used in the field component tests at Logan. The objectives in these field tests were to obtain measurements of spike pullout resistance and plate lateral resistance at several locations along the track and to evaluate the data to determine the influencing factors of component resistance characteristics.

In the field spike pullout, resistances were measured at 142 locations along the test track for conditions ranging from "poor" to "good". The lengths of the spikes varied from 4.75 to 6.50 inches with embedded lengths varying between 3.6 to 5.6 inches. Spike conditions ranged from straight to severely throat cut and bent.

Tie plate lateral resistances were measured at 11 locations. Again tie conditions ranged between "poor" to "good." To reduce the contribution of adjacent tie plates and spikes on lateral resistance, the tie plates and spikes on the two adjacent ties on both sides of the test tie were removed for all but one of the eleven cases.

For both of these component tests, the locations of the particular tests were chosen in adjoining zones to the rail capacity tests previously described. In this way, the strength characteristics of the components for various track sections were determined without excessively weakening the areas of the rail capacity tests.

In addition to these component tests, another test was performed to determine the load versus deflection behavior of the tie plate loaded vertically. This vertical tie plate modulus test was used to measure vertical displacement of the tie plate into the tie under applied vertical loads. This measurement scheme is shown schematically in Figure 2.8. Adjacent tie plates were removed for three ties in either direction to minimize their influence on the load input.

Further description of the measurement techniques, procedures and test matrices for these component tests may be found in References (2) and (3).

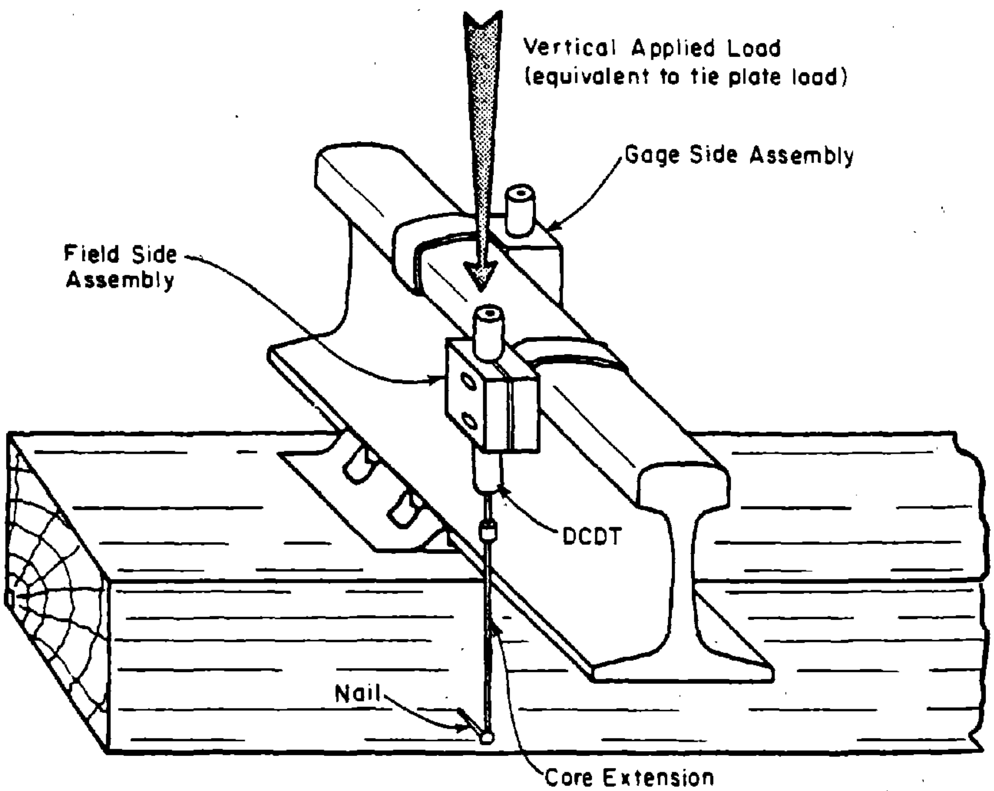


FIGURE 2.8 - TEST CONFIGURATION FOR VERTICAL
TIE PLATE MODULUS

3. TEST RESULTS

3.1 TYPICAL LOAD VERSUS DEFLECTION RESPONSE

Figure 3.1 shows lateral load versus rail head deflection curves for two different tie conditions; a typically "good" versus a typically "bad" tie. The "good" tie, #72, is shown in Figures 3.2 and the adjacent ties were nondefective.* The "bad" tie, #127, shown in Figure 3.3 was defective. At this tie location the north tie plate and spikes were missing while the south plate had sunken into the tie. The ties adjacent to tie #127 were also in "bad" condition. Tie #128 was defective and tie #126 was found moved against tie #125, creating a much larger spacing than usual.

A vertical load of 15 kips was applied to both ties #72 and #127 while lateral load was applied. As can be seen in Figure 3.1 the "bad" tie, #127, was found to be weaker, with a 32 percent reduction in lateral load capacity at 1 inch lateral rail head deflection.

The lateral load versus deflection behavior generally appears to be bilinear for strong ties and nonlinear for weak ties. The latter response, however, was found to be the more typical of the ties tested.

One other important feature of the load deflection behavior is that in the small displacement regime (that is, up to railhead displacement of 0.25 inches) there are very few differences between "good" and "bad" tie conditions. For example, the difference in displacements at a lateral load of 10 kips is about 12 percent. Hence, using small deflection data as an indicator of rail restraint capacity at higher

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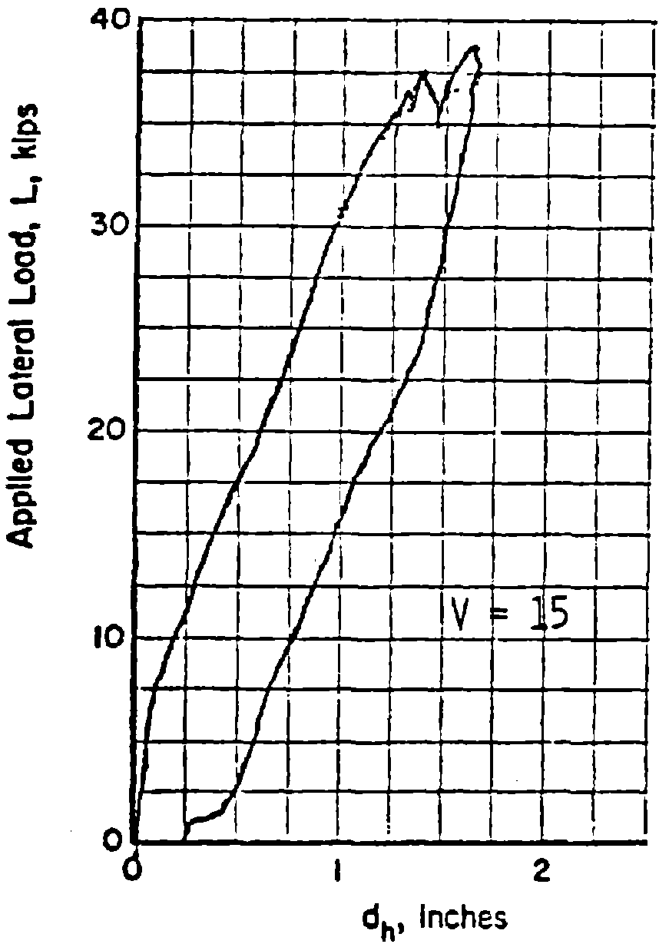
*A timber crosstie is considered to be defective in line with reference (4) when it is: 1) broken through, 2) split or otherwise impaired so that it will not hold spikes or will allow the ballast to work through, 3) so deteriorated that the tie plate or rail base can move laterally more than 1/2" relative to the crosstie, 4) cut by the tie plate through more than 40 percent of its thickness, 5) not spiked with at least 1 field and 1 gauge spike per rail per tie.

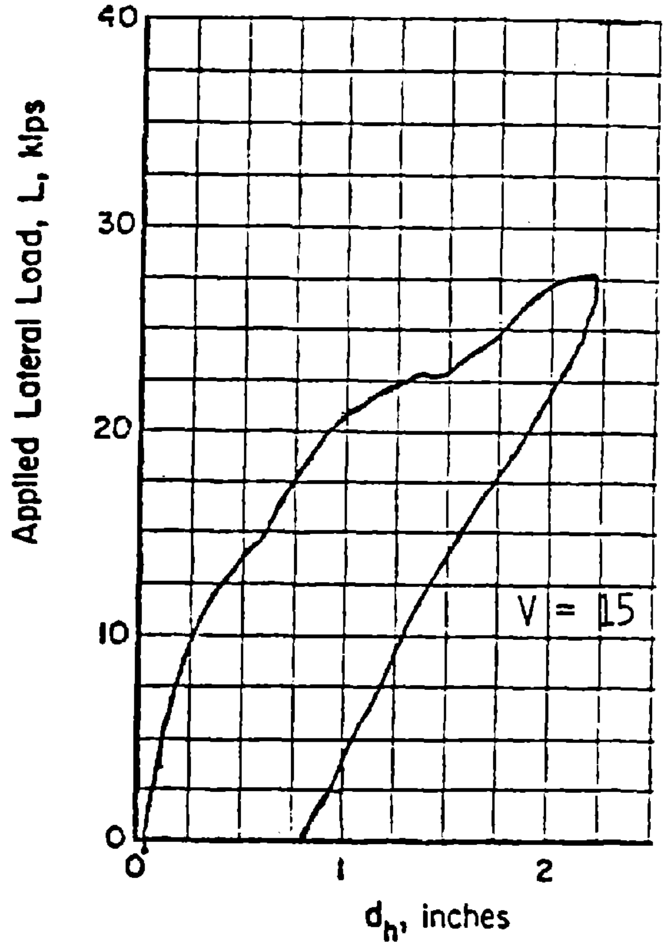
TIE 72S



SITE DESCRIPTION

GOOD, NONDEFECTIVE TIE
ADJACENT TIES IN GOOD CONDITION

TIE 127N



SITE DESCRIPTION

BAD, DEFECTIVE TIE
TIE 126 MOVED AGAINST TIE 125

FIGURE 3.1 - TYPICAL "GOOD" VERSUS "BAD" TIE LOAD- DEFLECTION BEHAVIOR

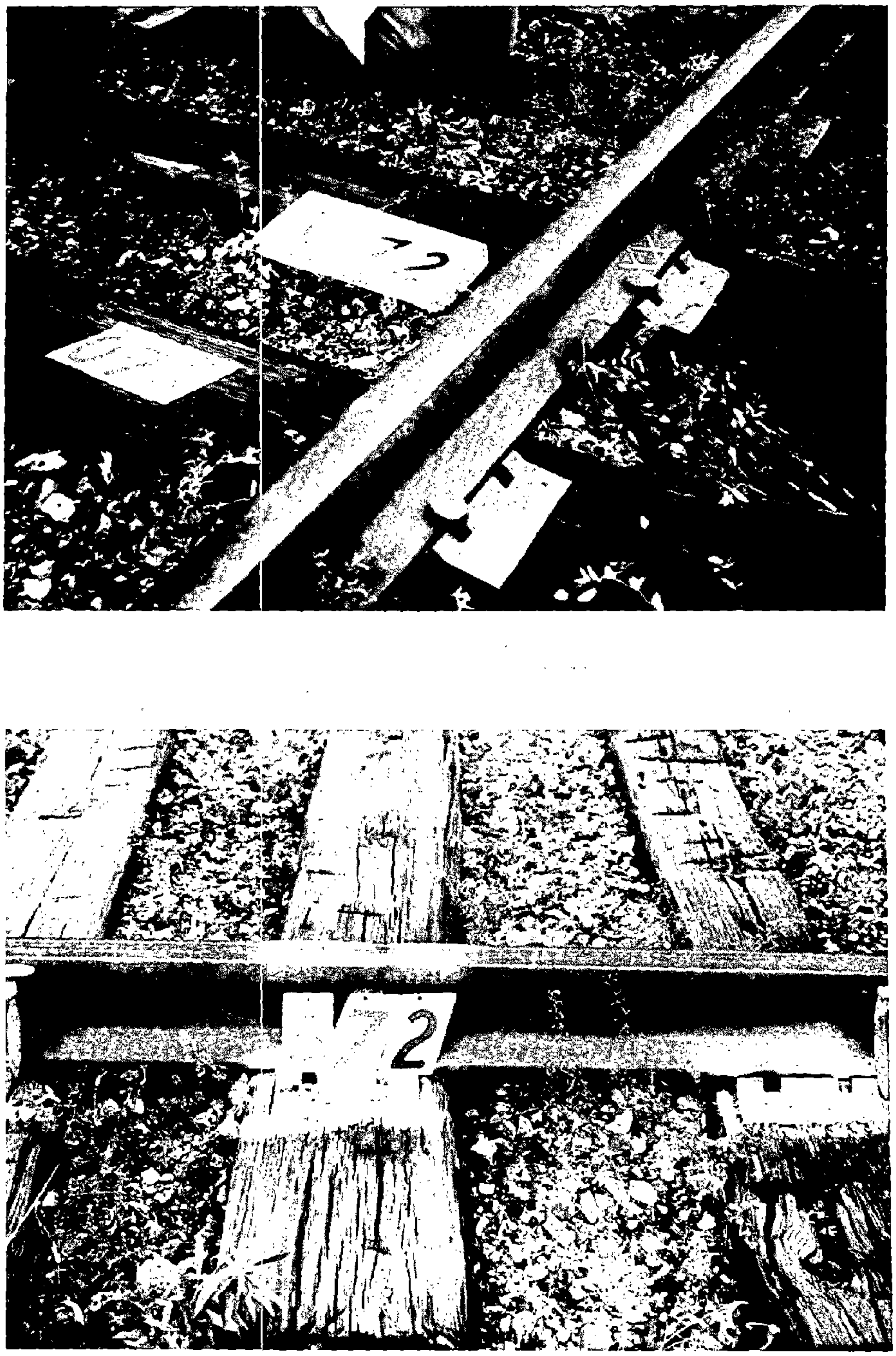


FIGURE 3.2 - "GOOD" TIE #72

FIGURE 3.3 - "BAD" TIE #127

load levels is inadmissible, based on the type of load application device used in these tests.

A comparison of rail head and rail base deflection for the same ties is shown in Figure 3.4. As can be seen from the figure, the difference between rail base and rail head deflections ranges from 0.5 inches to 0.9 inches depending on the lateral load level.

Examination of other data indicated that rail base displacements were generally much larger in this series of tests than those observed in AAR tests (6). This difference is explained in the next section.

Typical deflection responses under lateral load for expectedly weak conditions are shown in Figure 3.5. It can be seen that tie #1077N exhibited the lowest strength for deflections below 1.5 inches.

Figure 3.6 shows the strengthening effect of vertical load. For two ties of similar tie condition, the one under a higher vertical load appears to yield a higher lateral load capacity. Interestingly, the difference in lateral load capacity between good and bad tie conditions appears to be independent of vertical load. It can be seen from Figure 3.6 that there is approximately a 40 percent decrease in capacity at rail head deflections of 1 inch between "good" and "bad" ties under 15 kip vertical loads as well as under 30 kip vertical loads.

3.2 MODES OF FAILURE

Gauge widening typically occurs due to a combination of severe train loads and degraded tie conditions. The typical mode of failure observed in the field tests described here was a combination of rail rotation and simultaneous rail lateral shift. Upon application of a lateral load, the rail head began moving outward more rapidly than the rail base, causing the rail to rotate about its field side corner while also translating laterally. As the lateral load was increased, incurring larger displacements, the tie plate began rotating (sometimes together with rail base tilt). With a further increase in lateral load the tilted tie plate was driven into the tie at an angle. Almost all of the

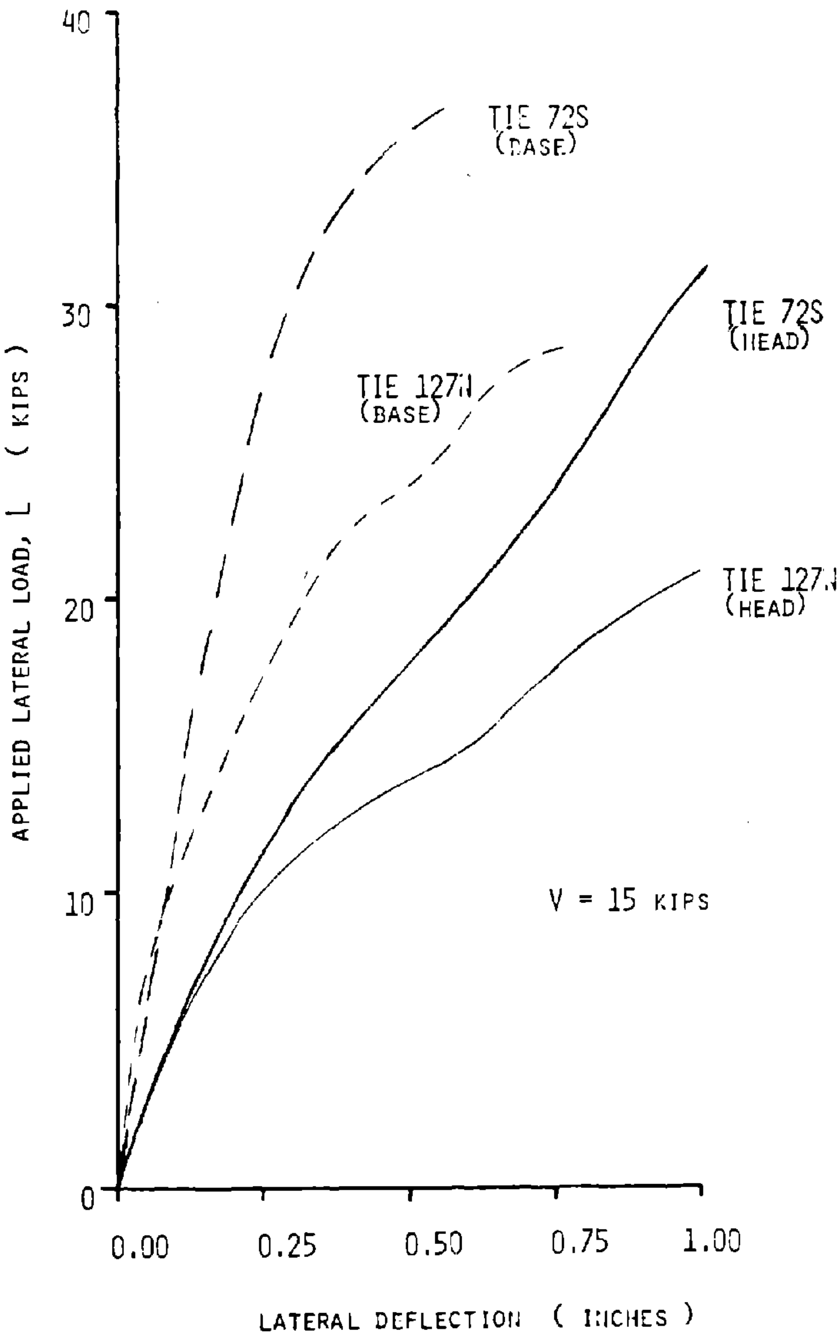
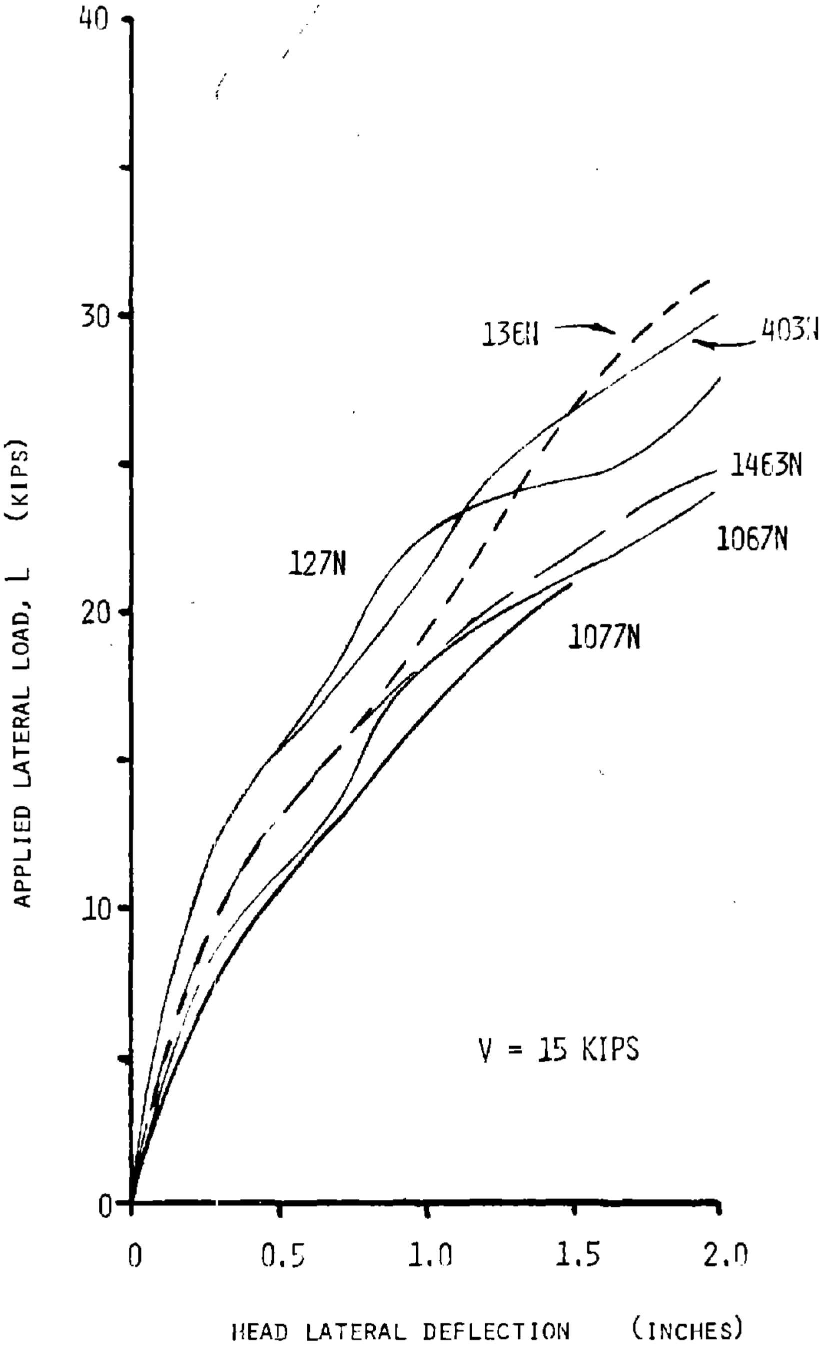


FIGURE 3.4 - RAIL HEAD AND BASE LATERAL DEFLECTIONS



TIE DESCRIPTION

127: DEFECTIVE TIE; ADJACENT TIE DEFECTIVE; TIE #126 MOVED AGAINST TIE #125
136: BAD NONDEFECTIVE TIE; ADJACENT TIES NONDEFECTIVE; AFTER 1st CYCLE WITH V = 5 KIPS
403: DEFECTIVE TIE; ADJACENT TIES DEFECTIVE
1067: TIE #1066, #1067, AND #1068 REMOVED
1077: TIE #1077 AND #1078 REMOVED
1463: GOOD TIE; JOINT BOLTS REMOVED

FIGURE 3.5 - RAIL RESTRAINT LOWER BOUND SUMMARY

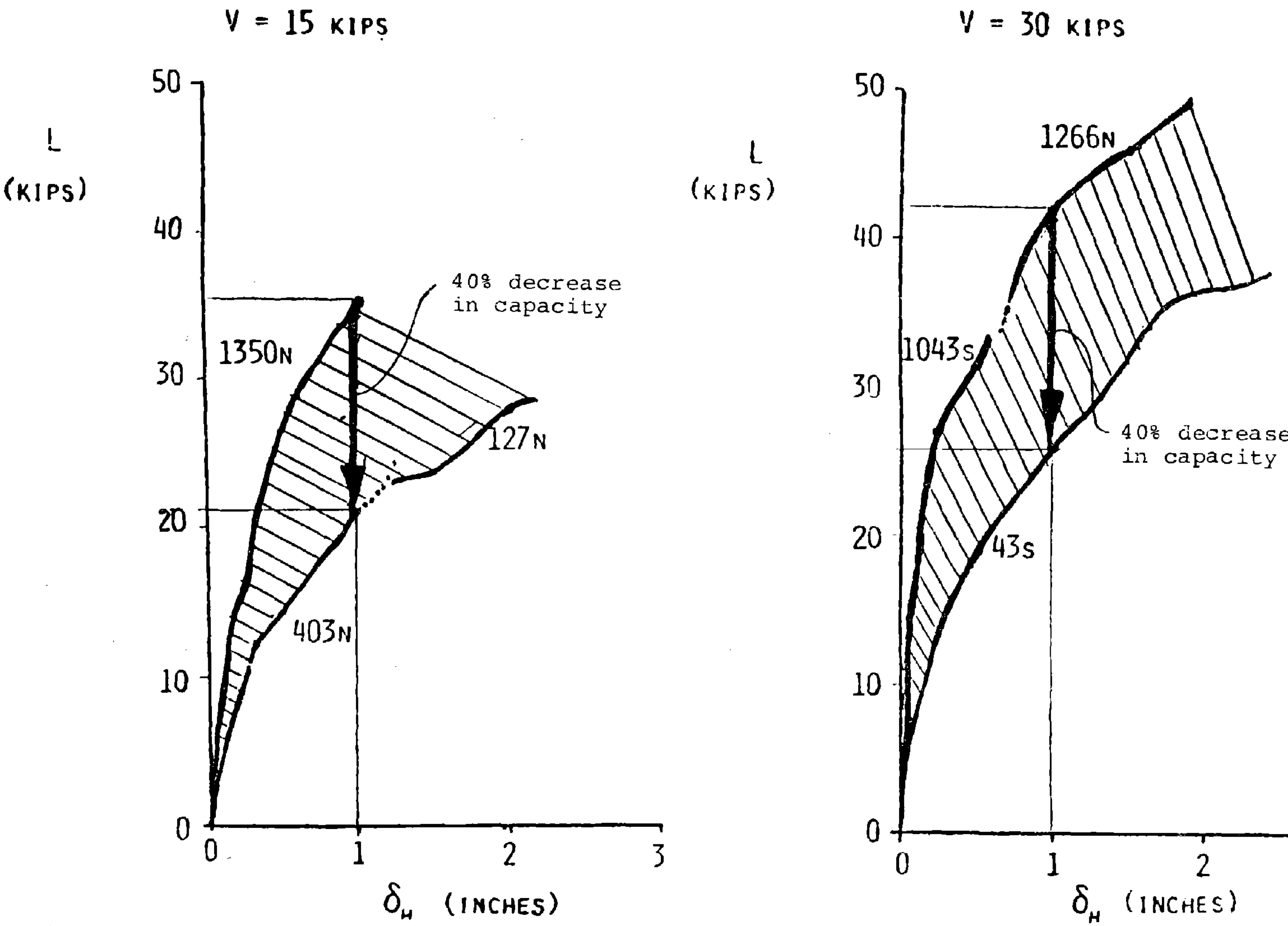


FIGURE 3.6 - LATERAL LOAD VERSUS RAIL HEAD LATERAL DEFLECTION SUMMARY

tests revealed this rotation of the tie plate into the tie, in some cases inducing crushing of the tie on the field side (see Figures 3.7a and 3.7b).

An estimate of the amount of rail rotation relative to simple lateral shifts can be found by comparing the lateral displacements of the rail base with those of the rail head. For high lateral loads (35 kips) the rail base deflections were 30-50 percent of the value for rail head deflections. For intermediate lateral loads (25 kips) rail base deflections were 50-70 percent of rail head deflections. For low lateral loads (15 kips) rail base deflections were 70-90 percent rail head deflections. Thus, at lower lateral load levels the rail base moves almost as much as the rail head, indicating mainly a lateral shift with a small amount of rotation. Higher lateral loads seem to indicate considerable rail rotation. All lateral loads, however, produced some degree of both rotation and translation.

These estimates appear to support the Canadian National (CN) gauge widening tests (5), in which three distinct modes of failure were apparent:

A. Rail Rotation - rail twists and lifts upward pulling gauge spikes, little plate shifting or cutting

B. Rail Rotation and Translation - rail twists and gauge spikes are pulled, some plate shifting with bending of spikes

C. Rail Translation - limited rail lift, considerable plate shifting and bending of spikes, some plate cutting of tie.

The obtained data seemed to point out that the observed modes are highly vertical load dependent in as much as mode A was most likely to occur under smaller vertical loads, and mode C occurred most often under larger vertical loads. Although distinct modes were not found in the field tests presented here, similar tendencies to the CN tests were observed. Specifically, trends toward translation under low lateral force levels and toward rotation under higher lateral loads were noted.

In AAR investigations of gauge widening (6), the mode of failure was

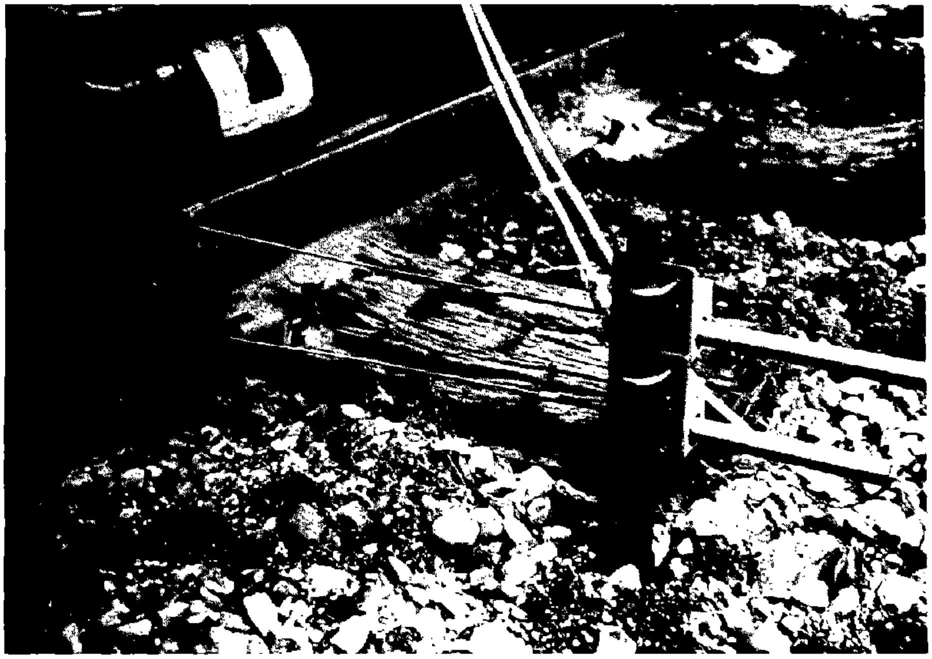


FIGURE 3.7a - INSTRUMENTED RAIL DURING TESTING: TIE PLATE ROTATION INTO TIE AND TIE CRUSHING

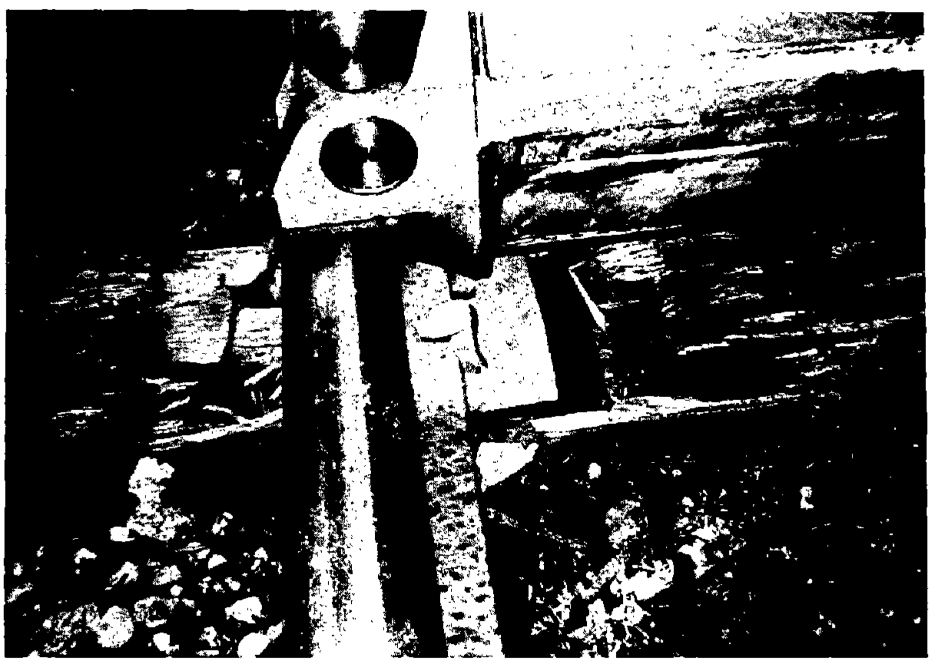


FIGURE 3.7b - TRACK LOADING FIXTURE: TIE PLATE ROTATION INTO TIE

found to be almost exclusively rail rotation (that is, very little rail base displacement). This occurrence may be attributed to a combination of test conditions and also the loading fixture which was utilized. The AAR tests were conducted on new ties with spikes fully driven, resulting in a high tie plate lateral resistance and, consequently, little rail base translation. Furthermore, the loading fixture employed in these tests imposed loads on the rail through a fixed two-point contact which resulted in generating larger overturning moments than would be generated by a single wheel/rail contact.

In the Logan field tests, gauge widening resulted from a combination of rail translation and rotation. The number of ties in the vicinity of the test tie which showed spike pullout or tie plate shift varied with tie condition. This influence zone was found to be 6-7 ties for a "good" tie test zone and 10-12 tie for a substantially degraded zone. For a typical test tie, extraction of the gauge spikes ranged between 1/2 inch to 3/4 inch. Little or no extraction was found on spikes 5-6 ties away. The removal of spikes in the test zone after the test revealed some bending (1/8 to 1/4 inch) in the spikes (see Figures 3.8a and 3.8b). However, inspecting spikes removed from a nontest zone revealed similar service bending. Because of this similarity, determination of the extent of spike bending due to the testing loads may be difficult.

After the test tie plate, lateral displacements varied from 1/4 to 3/4 inch on or near the test tie with little tie plate shift 5-6 ties away. Removal of the tie plates in the test zone after the test revealed typical spike hole elongation of 1/4 to 1/2 inches indicating substantial spike rotation during deformation.

The mean pretest gauge was 56.46" and the mean post-test gauge was 57.26", with only one test location exceeding 57.5". This indicates the important fact that in spite of the excessively large gauge widening induced during the tests (in some cases as much as 5.5 inches), there is a substantial recovery of gauge as evidenced by a resulting average permanent set of 0.8 inches.

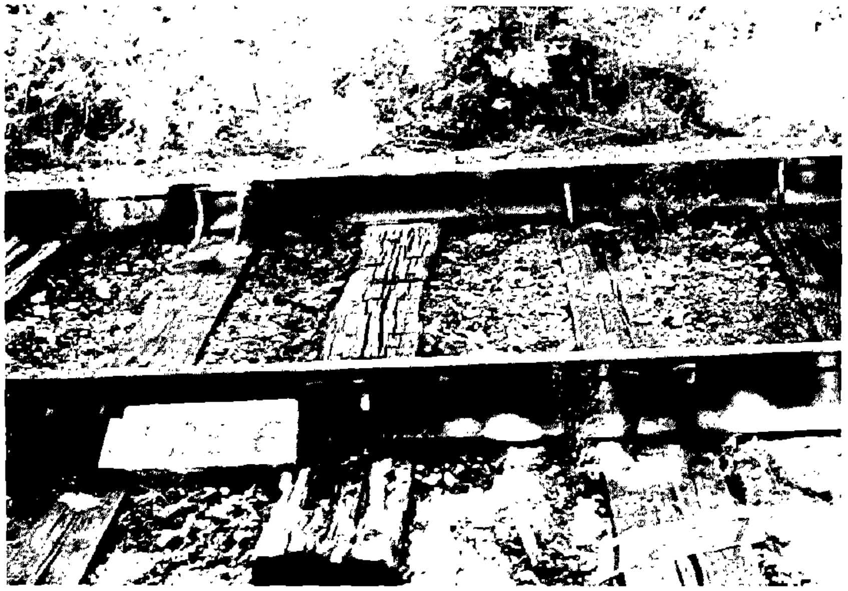


FIGURE 3.8a - SPIKES REMOVED AFTER TESTING TO OBSERVE BENDING

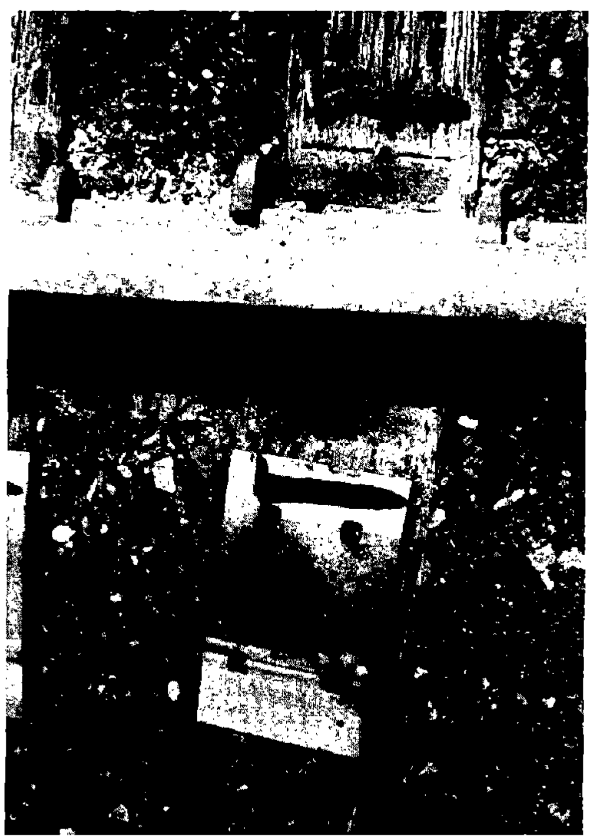


FIGURE 3.8b - BENT SPIKES AFTER TESTING

Laboratory investigations of gauge widening conducted by the Association of American Railroads (AAR) (6, 7, 8, 9) have led to a relationship between gauge widening and the lateral to vertical load ratio. The data from these AAR tests has shown that lines of constant gauge widening in lateral versus vertical load coordinates are straight and parallel. It is also believed that the shift between these lines may be explained by the amount of damage on the track. Data appear to show that increased track damage causes these straight and parallel lines to shift downward, indicating that loss of a lateral load is required to reach the same lateral railhead displacement at the same vertical load level.

Data from the present test series were used to show the relationship between lateral and vertical loads for constant gauge widening. Two different tie conditions were compared: "good" tie #1237 and "bad" tie #1202, see Figures 3.9 and 3.10. Lines of constant gauge widening for railhead deflections of 0.5, 1, and 2 inches are shown in Figure 3.11 for both of these ties. As seen from this plot, the lines are straight and, with the exception of the railhead displacement of 2 inches for the bad tie condition, of constant slope. Figure 3.12 compares lines of constant gauge widening for "good" tie #1237 and "bad" tie #1202 to a mean line of constant gauge widening for all test data. This mean line was acquired through a least squares curve fit. It is interesting to note that in the two cases shown in the figure for constant deflections of 0.5 inches and 1 inch, that the mean is found in region bounded above by the "good" tie case and bounded below by the "bad" tie case.

3.3 CYCLIC LOADING INFLUENCE

A series of cyclic loading tests were performed to determine the extent and nature of rail restraint "damage" caused by repetition of applied loads. The cyclic tests consisted of applying a lateral load to a vertically preloaded track and increasing the lateral load until a rail head deflection of 1 inch was reached. The lateral load was then removed and reapplied for a total of 26 times to the same deflection limit.

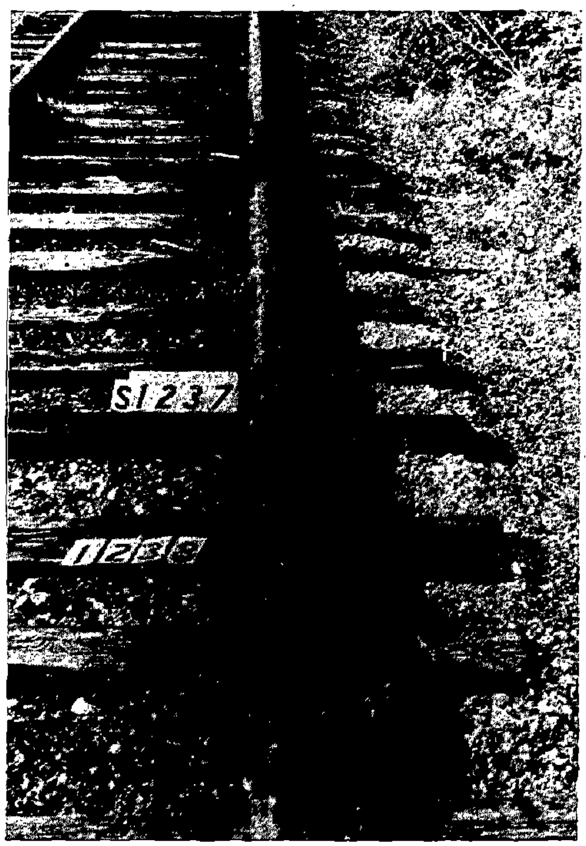


FIGURE 3.9 - TIE #1237: SOUTH RAIL

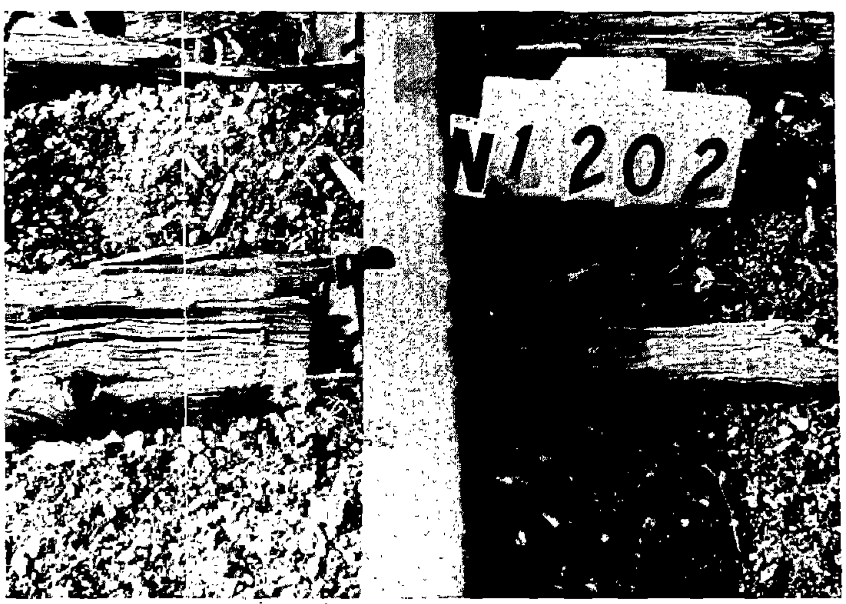


FIGURE 3.10 - TIE #1202: NORTH RAIL

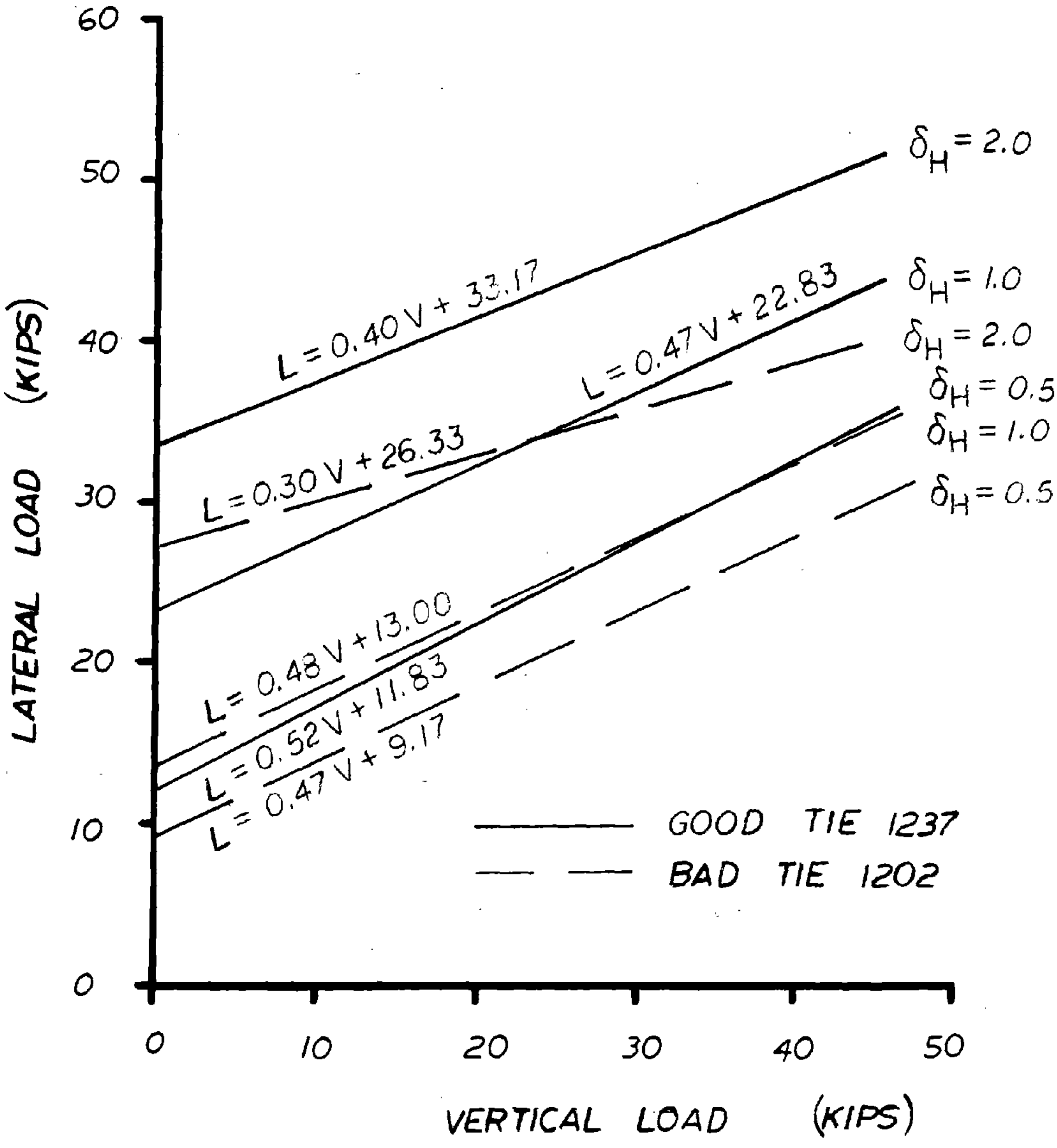


FIGURE 3.11 - LATERAL LOAD VERSUS VERTICAL LOAD FOR VARYING LATERAL RAIL HEAD DEFLECTIONS

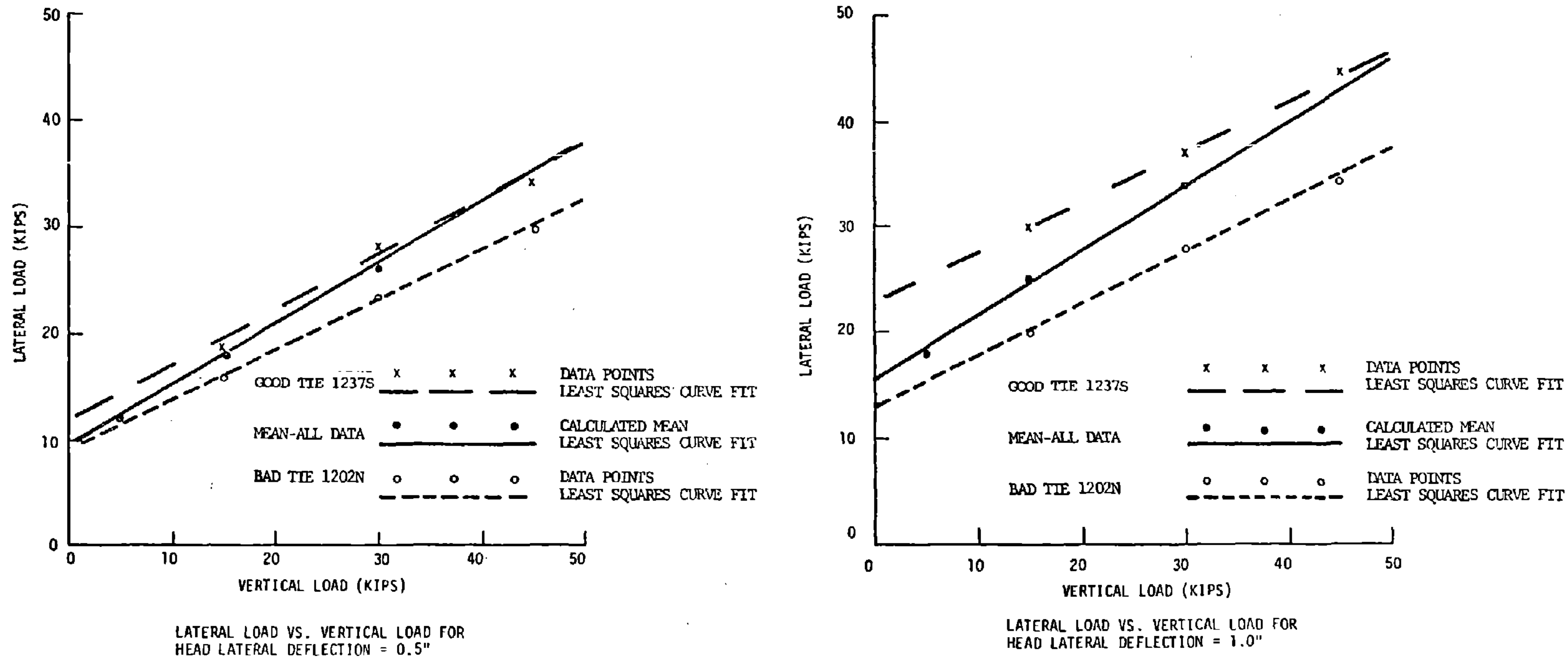


FIGURE 3.12 - RAIL CAPACITY FIELD TEST RESULTS:
L, V COMPARISONS

Cyclic load tests were conducted on ties #1120 and #1154 (see Figures 3.13 and 3.14). Tie #1120 was tested under a vertical load of 15 kips. This tie was considered a poor, defective tie with good non-defective adjacent ties. Tie #1154 was tested under a 30 kip vertical load. Also, tie #1154 was in extremely poor condition, as evidenced by a missing tie plate and missing spikes on one adjacent tie. The other adjacent tie was spaced about 30 inches away from the test tie.

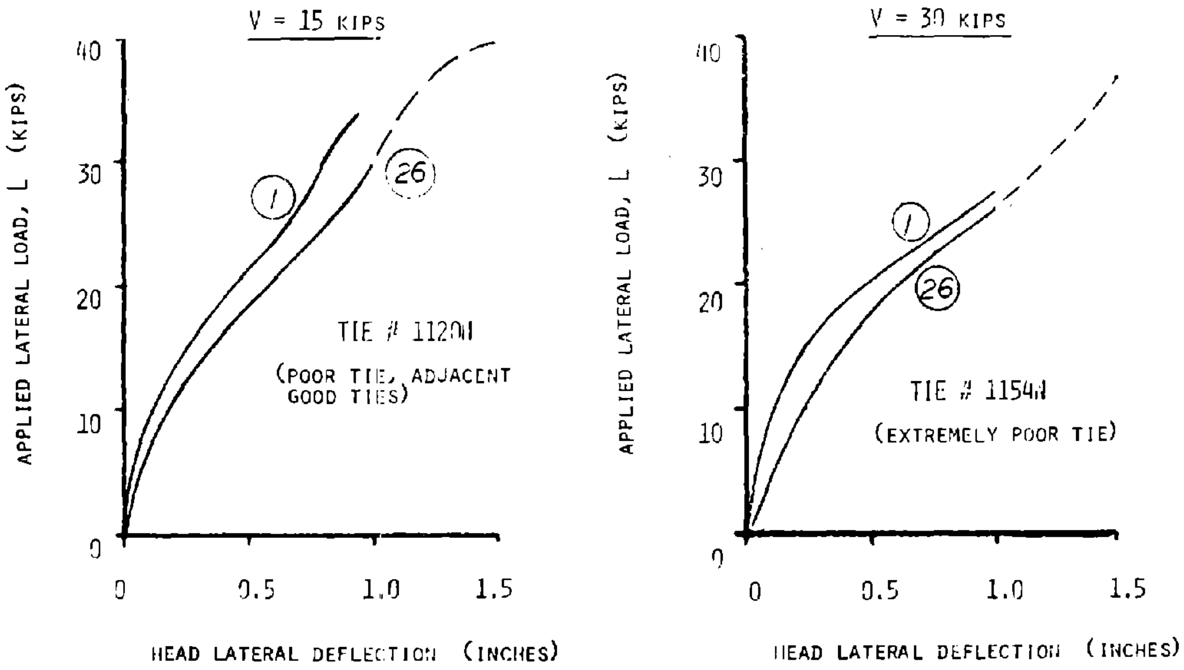
Figure 3.15 shows the load versus deflection curves for the 1st and 26th cycles for both ties. As can be seen, for each, there is a small loss of strength between cycles 1 and 26. At a lateral rail head deflection of 0.5 inches there is approximately 14 percent loss of strength for tie #1120 and about 12 percent loss of strength for tie #1154. This small weakening was observed to have occurred mainly during the first cycle while subsequent cycles were almost identical in the load versus deflection response.

Note that both ties #1120 and #1154 show approximately the same overall strength. That is, both ties have a lateral load capacity of about 20 kips at a lateral railhead deflection of 0.5 inches. It is expected, however, that the tie under the 30 kip vertical load would exhibit a stiffer response than the tie under a lesser, or 15 kips vertical load. In this case, tie #1154 was a much more degraded tie.

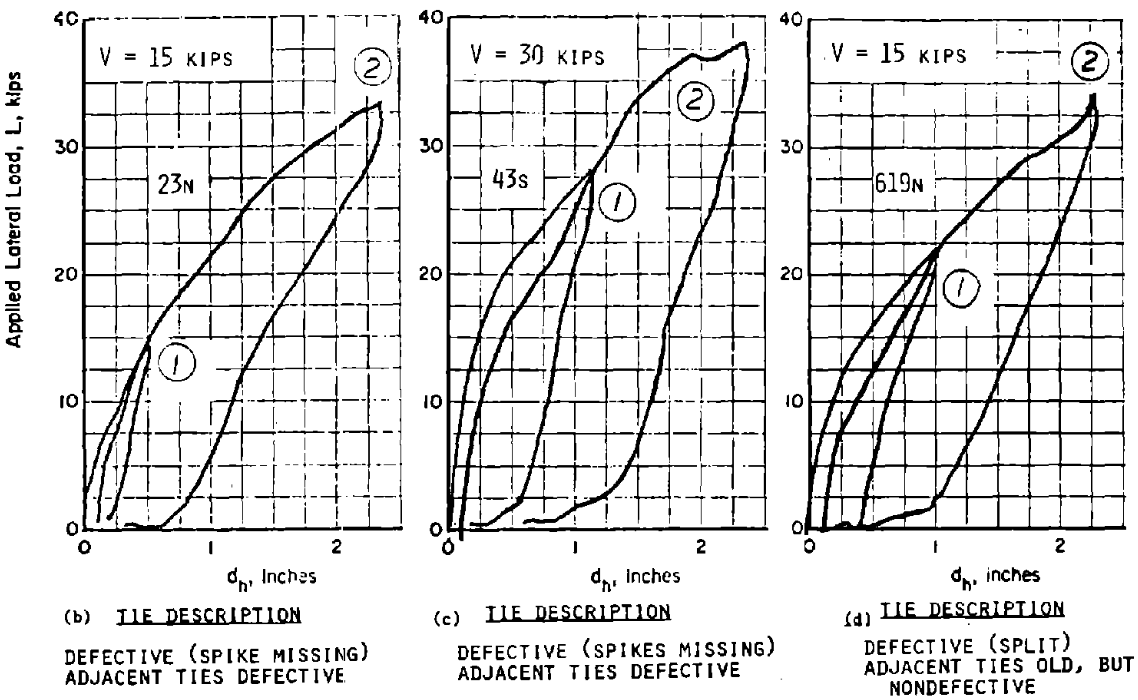
Similar cyclic loading tests with vertical preloads of 15 kips were performed by the AAR. The load versus deflection curves in these tests, for cycles after cycle one, show a characteristic flattening of the curve for railhead deflections between 0.1 to 0.6 inches. The response may be described by three regimes where the track appears: i) initially stiff, ii) seems to weaken somewhat, and then iii) becomes stiff again. This weakening region may be due to a loss of strength as the spikes are

FIGURE 3.13 - TIE #1120

FIGURE 3.14 - TIE #1154



CYCLIC LOAD INFLUENCE COMPARISON FOR 26 CYCLES



TWO CYCLE TEST: INFLUENCE OF INITIAL DEFLECTION

FIGURE 3.15 - CYCLIC LOAD INFLUENCE COMPARISON

pulled out. This characteristic flattening* of the load deflection curve is observed to a much lesser extent in the Logan field test data as can be seen in Figure 3.15.

In the test series described in this report, several two cycle tests were performed. The tests were conducted to determine the influence of initial deflection on subsequent load deflection response. Lateral load versus deflection curves for three of these two cycle tests are shown in Figure 3.15. For tie #23N, the first cycle produced an initial rail head deflection of 0.5 inch, while ties #435 and #619N showed about 1.0 inch initial deflection. In all three cases the second loading cycle produced the same deflections (0.5 inches for tie #23N and 1.0 inch for ties #435 and #619N) at the same lateral load levels as the first cycle. This result is shown in Figure 3.15. Based upon these results it appears that an initial deflection, produced by the first load cycle, yields no significant loss of strength for the tie conditions and the load levels tested.

3.4 SPECIAL CASES: JOINTS AND MISSING TIES

Several locations were selected for testing to perform special cases. These cases were comprised of joints and missing ties. Furthermore, these cases were performed to determine their effect on lateral rail strength capacity.

The joints chosen for testing typically spanned two ties, as shown in Figure 3.16, for example. The loads were applied to the center of the joint between the two ties. Load versus deflection curves for the joint tests conducted at ties #205, #1452, and #1463 are shown in Figure 3.17. From this curve it can be seen that lateral displacements of 2.5

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*Subsequent TSC tests in the AAR track laboratory confirmed this flattening to be attributed to the weakening of spike pullout stiffness for newly spiked track.

FIGURE 3.16 - JOINTS AT TIE #1452: NORTH AND SOUTH RAILS

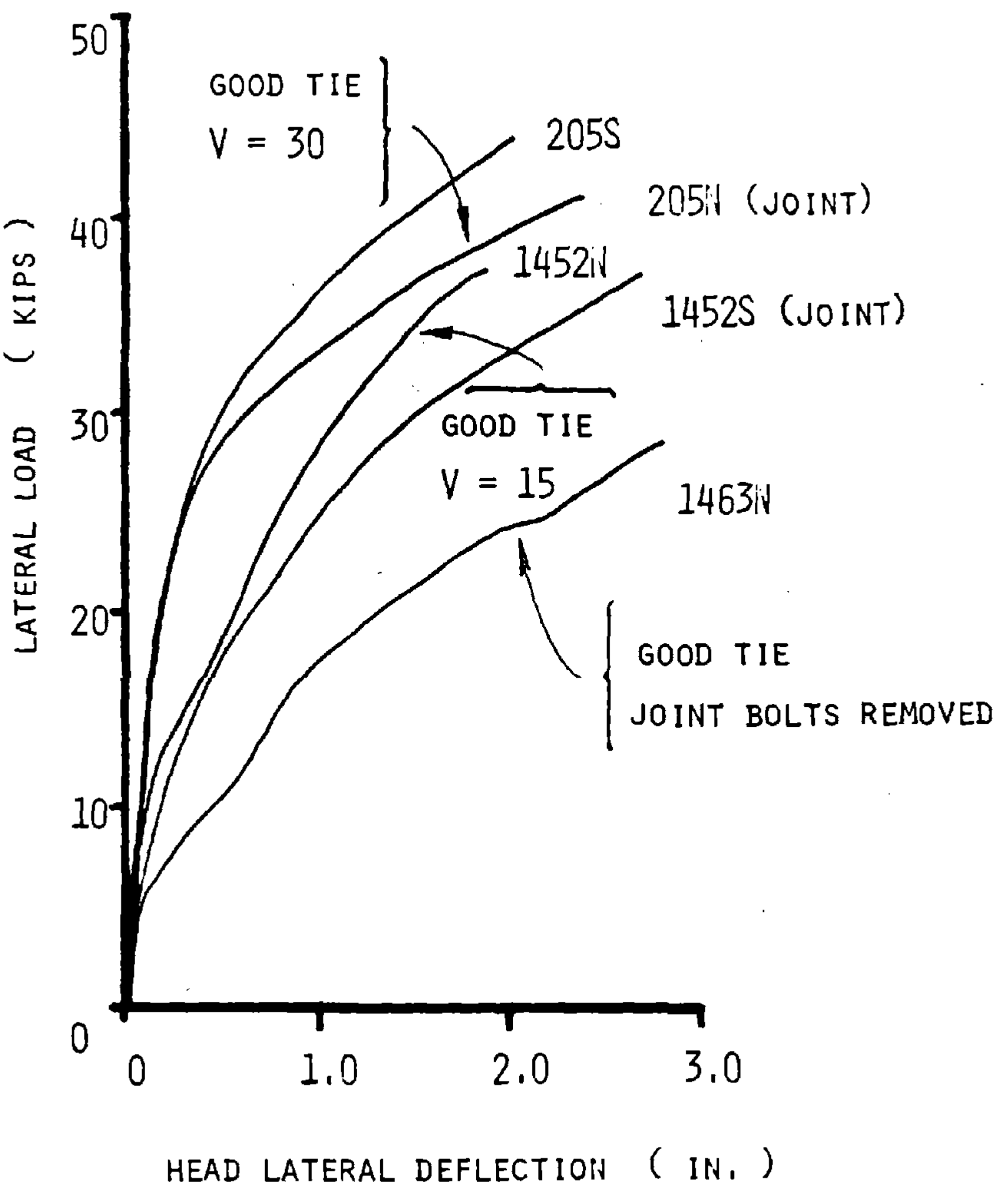


FIGURE 3.17 - JOINT TEST SUMMARY

inches were generally achieved. The joint and tie conditions for tie #1463 are illustrated in Figures 3.18a and 3.18b. Referring to these response curves, joints appear to be weaker than the rails opposite them (on the order of 10 percent at 1 inch deflection). A joint weakened by removal of bolts exhibited a 33 percent reduction in load capability at 1 inch deflection.

In order to examine the effect of missing ties on lateral strength capacity, ties were removed in two sections. In one section two ties were removed and then tested, ties #1077 and #1078, see Figure 3.19. Three missing ties were tested in the remaining section, ties #1066, #1067, and #1068 as shown in Figure 3.20. The load versus deflection curves for these cases are compared to lower bound (ties #403 and #127) 15 kip vertical load cases in Figure 3.21. Apparently no substantial strength difference between the two and the three missing tie cases was seen. However, in removing two or three ties a 20 percent loss of strength from the lower bound was found.

3.5 COMPONENT TEST RESULTS

3.5.1 Spike Pullout Resistance Tests

Tests were performed in both the laboratory and in the field to determine the spike pullout resistance. Using the Spike Pullout Resistance Device developed by Battelle in the laboratory, 142 tests were carried out in the field in zones adjoining the rail capacity tests. The results of the spike pullout tests are statistically summarized in Figure 3.22. These histograms show the distribution of the maximum spike pullout force for all the test locations. The data is further broken down by spike condition and tie condition. It appears that tie and spike condition greatly influence the amount of force necessary for spike pullout. Greater force is required for ties in good condition or for bent spikes than for ties in poor condition or for straight spikes. The spike pullout force varied from 60 to over 4500 lbs. About 50 percent of the tests required less than 1000 lbs, while approximately 13 percent required over 4500 lbs and the remaining 37 percent evenly distributed between 1000 and 4500 lbs.

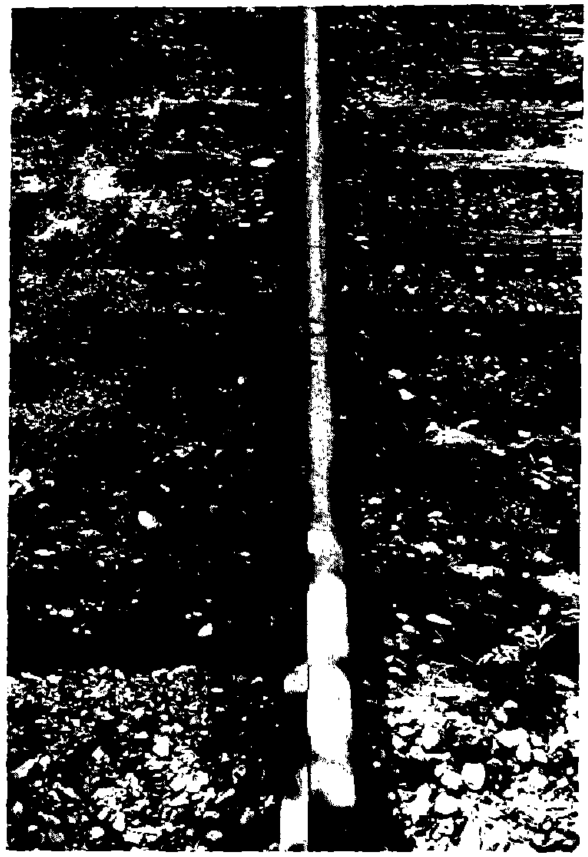


FIGURE 3.18a - JOINT AT TIE #1463: NORTH RAIL

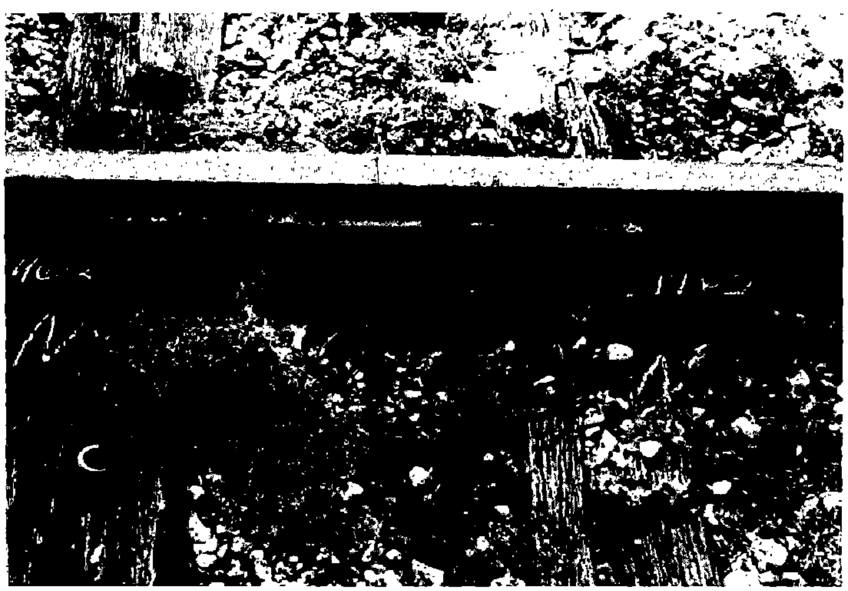


FIGURE 3.18b - JOINT AT TIE #1463: NORTH RAIL WITH BOLTS REMOVED

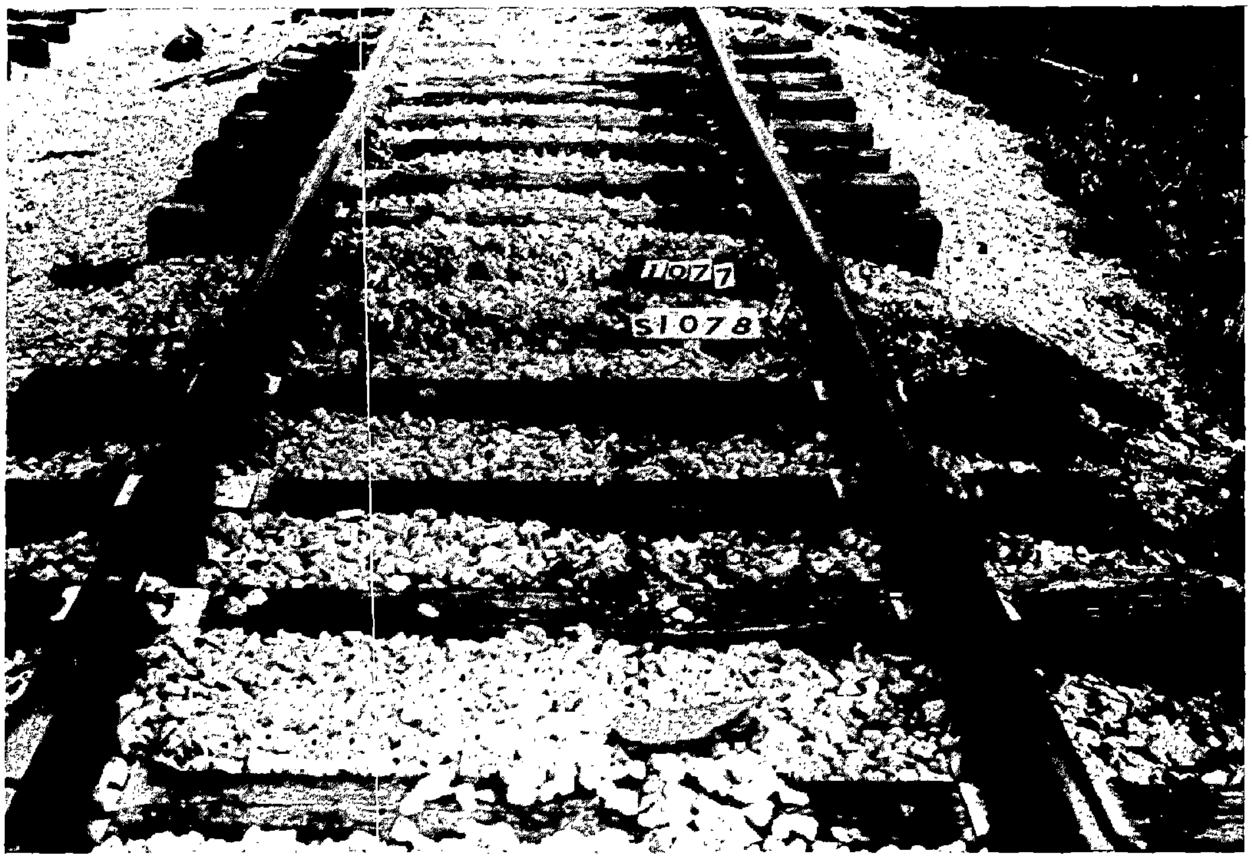
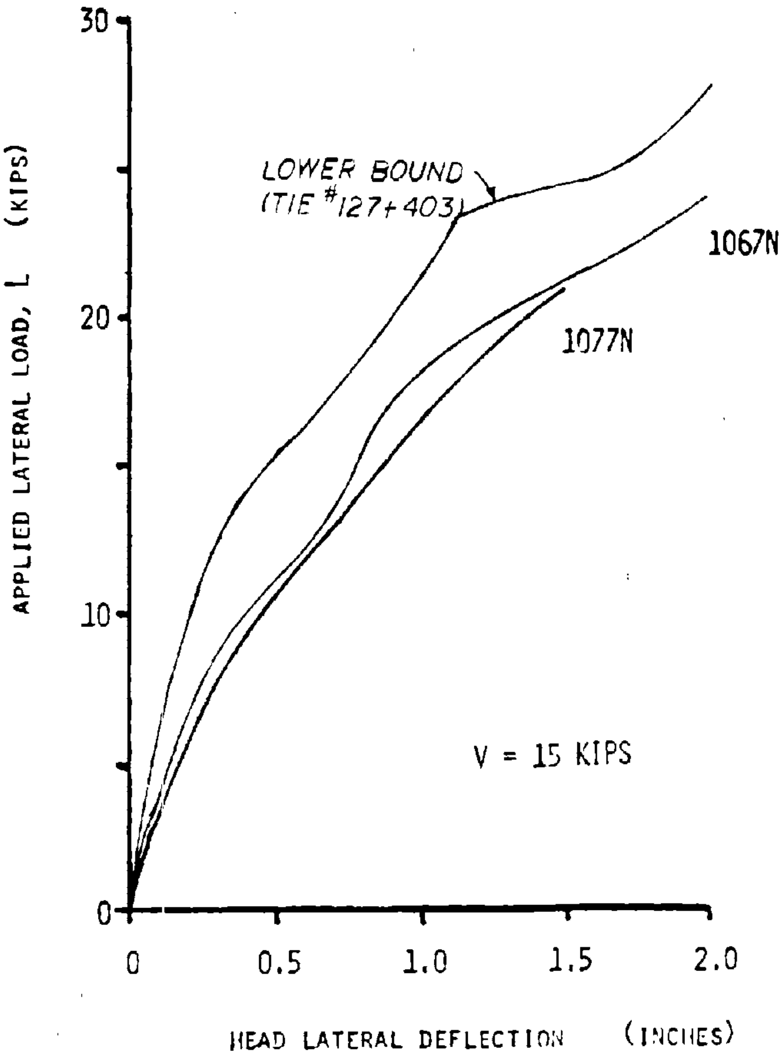


FIGURE 3.19 - TIE #1077: TWO MISSING TIE CASE

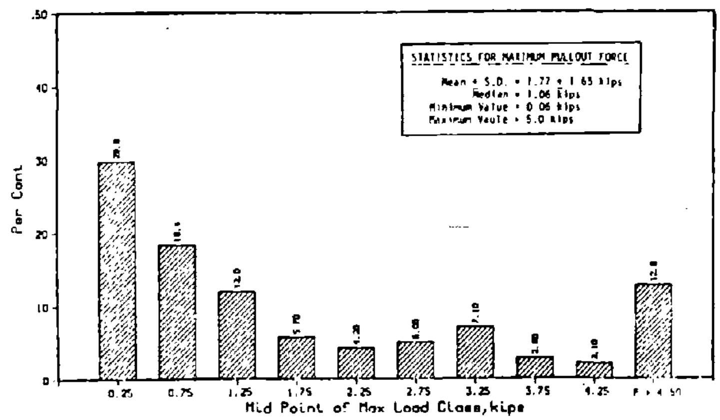
FIGURE 3.20 - TIE #1067: THREE MISSING TIE CASE



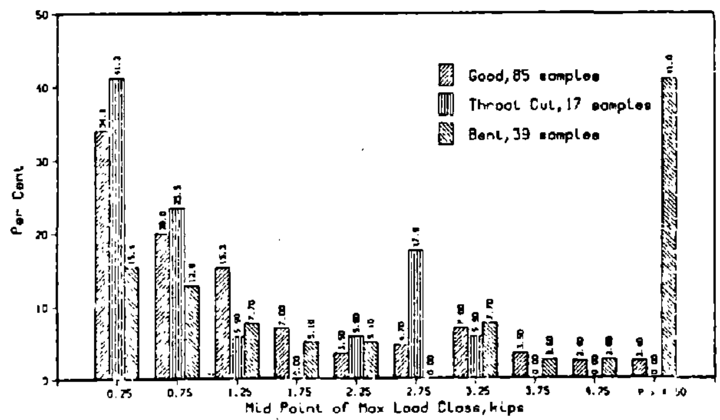
TIE DESCRIPTION

1067: TIE #1066, #1067, AND #1068 REMOVED
1077: TIE #1077 AND #1078 REMOVED

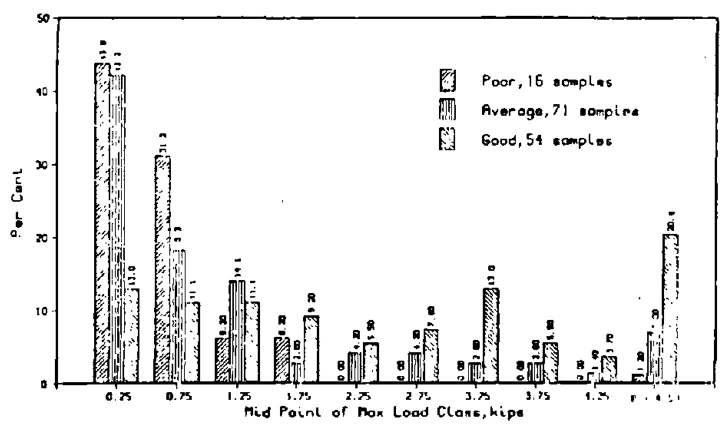
FIGURE 3.21 - MISSING TIE COMPARISON



HISTOGRAM OF MAXIMUM SPIKE PULLOUT FORCES
MEASURED AT 142 LOCATIONS



HISTOGRAM OF MAXIMUM SPIKE PULLOUT FORCES
BROKEN DOWN BY SPIKE CONDITION



HISTOGRAM OF MAXIMUM SPIKE PULLOUT FORCES
BROKEN DOWN BY TIE CONDITION

FIGURE 3.22 - STATISTICAL SUMMARY OF SPIKE PULLOUT
RESISTANCE TEST RESULTS [2]

In the laboratory tests, initial pullout stiffnesses were investigated for varying spike/tie configurations. The initial stiffness is defined as the initial slope of the vertical pullout load versus displacement curve. Figure 3.23 shows the spike pullout resistances for new, good, and poor spike tie configurations. The initial stiffnesses found from these curves are 35 kips/ inch for a new tie, 6.9 kips/inch for a good tie, and 1.6 kips/inch for a poor tie.

3.5.2 Tie Plate Lateral Resistance

The tie plate lateral resistance tests were also performed in both the laboratory and the field. The Tie Plate Lateral Resistance Device was used in these tests. In the laboratory tests, lateral loads were applied to a surrogate rail segment. In the field tests the plates of the two adjacent ties in either direction from the test tie were removed. Eleven field tests were performed. In both the laboratory and field tests, vertical load and tie condition were varied. The results of the laboratory and field experiments, shown in Figure 3.24, are in good agreement.

Vertical load apparently has a strong influence on the tie plate lateral resistance. From Figure 3.24, three different classes of resistance can be defined. The low class resistance consists of the lowest two curves having a linear resistance of about 6000-8000 lbs/inch. The resistance in this region is mainly caused by tie plate cutting and sliding with little resistance offered by the spikes. The medium resistance class has bilinear characteristics. The first portion is caused by plate cutting and sliding while the second is constant force caused by the yielding of the wood around the spikes. The high resistance class consists of the new laboratory ties. It is characterized by successive regions of stiffening and softening, probably caused by spike bending and rigid body deflections along with tie plate sliding and no tie plate cutting.

3.5.3 Vertical Tie/Tie Plate Modulus

Special tests were conducted to measure the tie plate modulus. Analysis techniques attempting to predict rail lateral response utilized

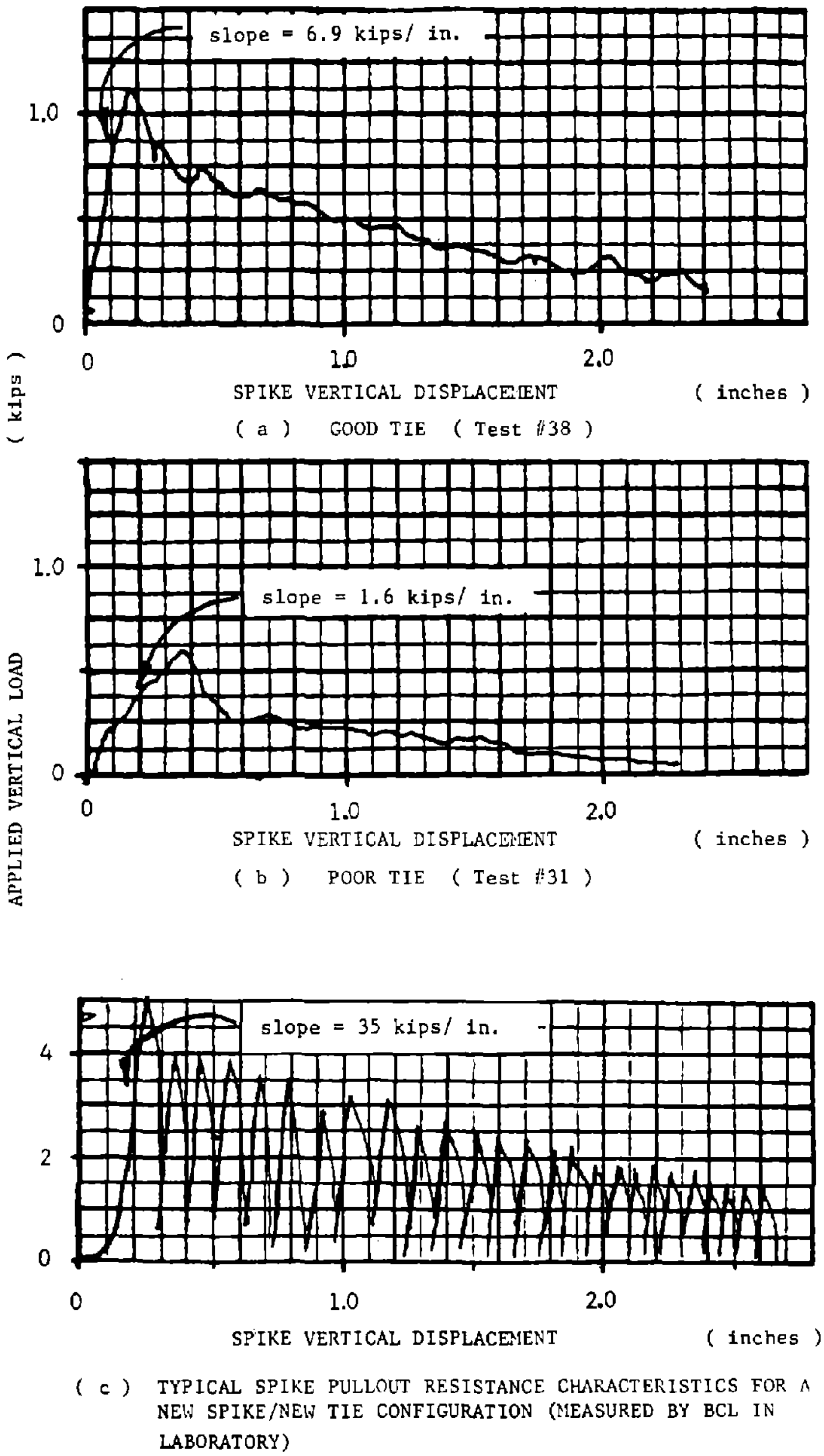
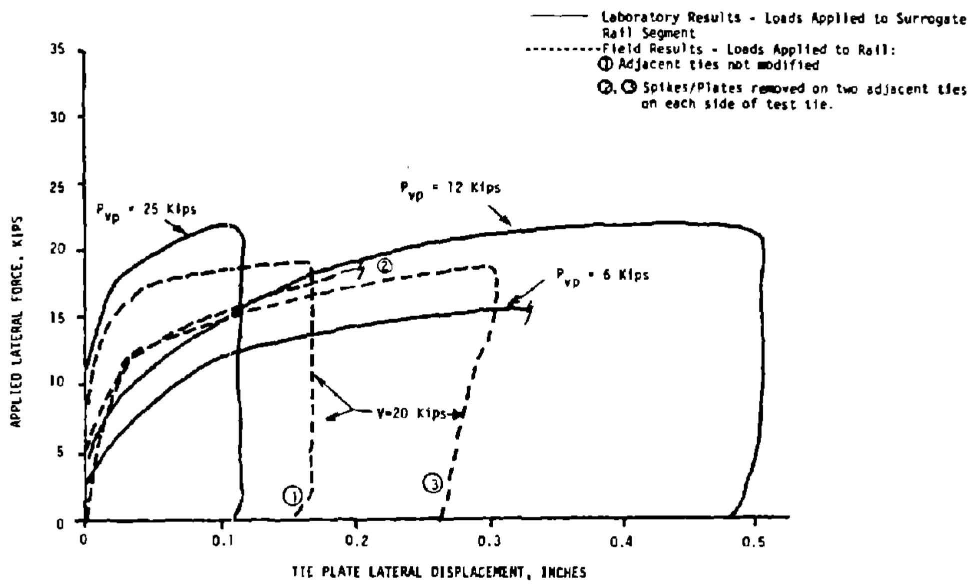
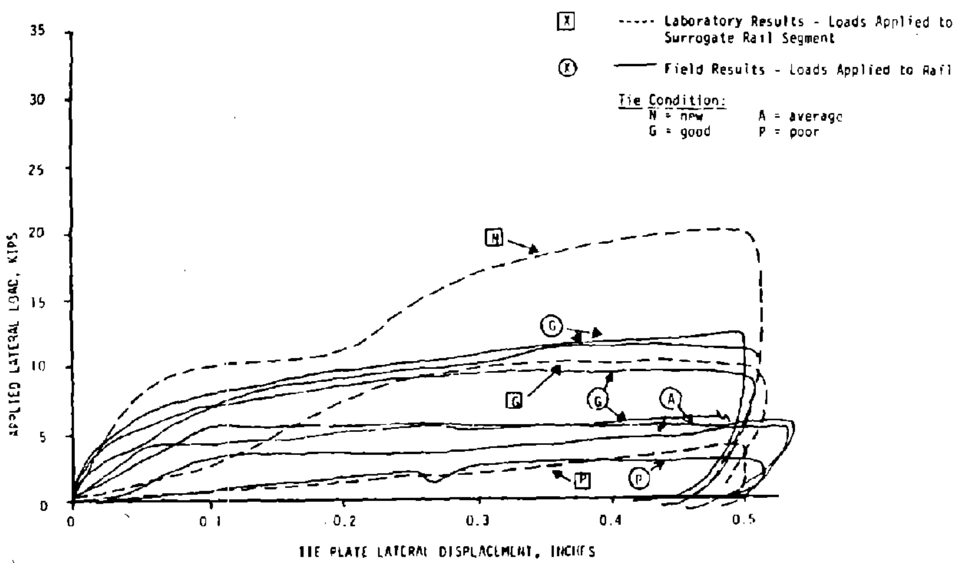


FIGURE 3.23 - TYPICAL SPIKE PULLOUT RESISTANCES [2]



(a) CONDUCTED ON USED TIES WITH CONSTANT VERTICAL PRELOAD



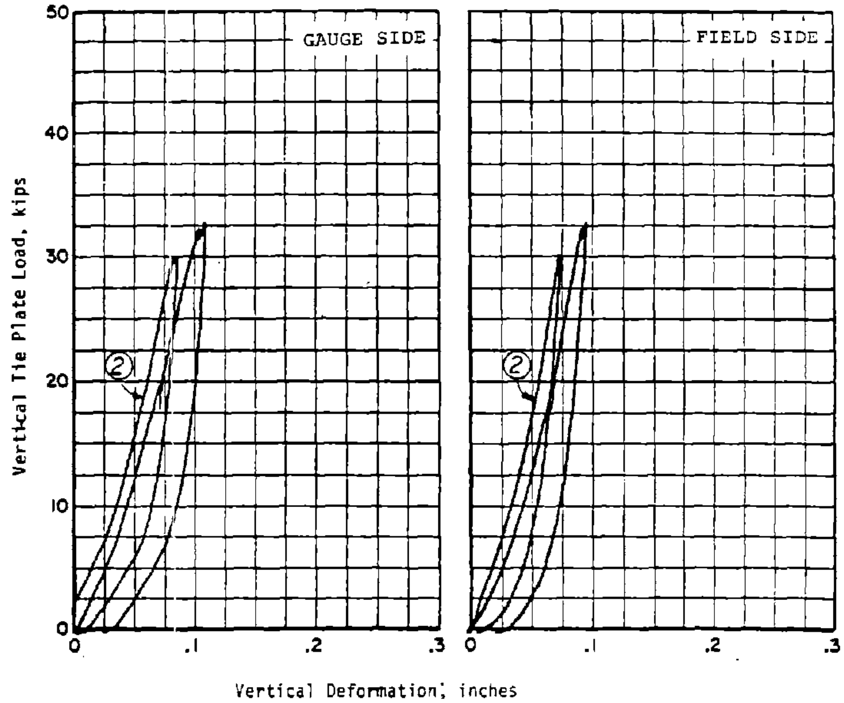
(b) CONDUCTED ON TIES IN SEVERAL CONDITIONS (NO VERTICAL PRELOAD)

FIGURE 3.24 - COMPARISON OF FIELD AND LABORATORY RESULTS OF THE TIE PLATE LATERAL RESISTANCE TESTS

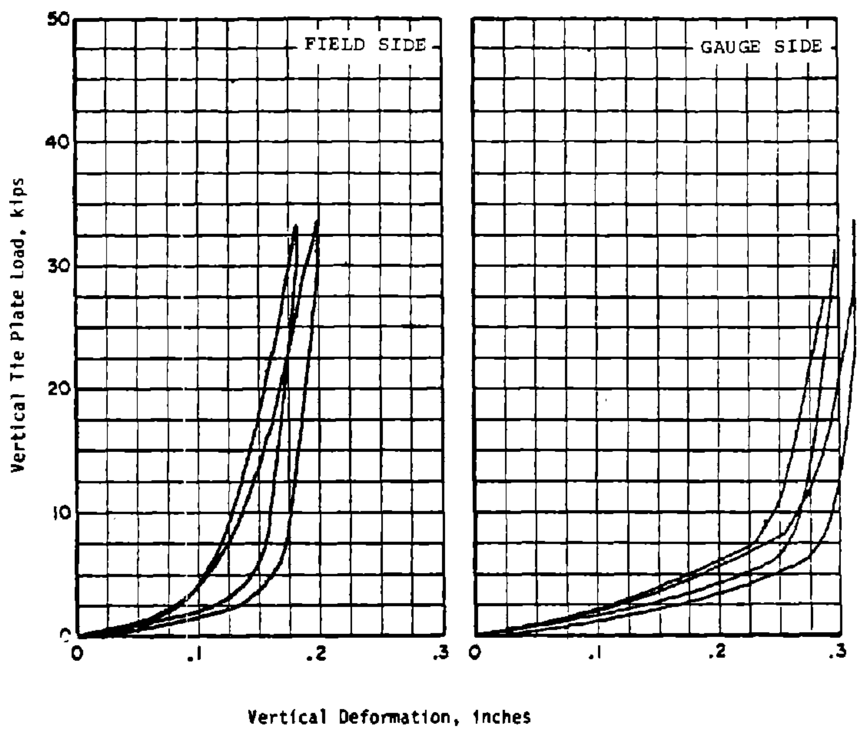
the tie/tie plate interaction with the rail as a nonlinear spring. Therefore, the results of this vertical tie/tie plate modulus test may be interpreted as a "spring stiffness."

The test set-up was shown in Figure 2.8. The adjacent tie plates for three ties in either direction of the tested tie plate were removed to allow for a more complete vertical load transfer into the tie at the load point.

The resulting stiffness curves for the gauge and field sides of two ties are shown in Figure 3.25. These ties represent good (#809) and bad (#822) conditions. Each test consisted of two cycles. The figure shows some variation in stiffness from the field to gauge side. This observation would seem to indicate nonuniform tie plate support. Furthermore, the good tie load-deflection behavior can be characterized by an almost linear response while the bad tie exhibits a highly nonlinear one. Note that the cyclic influence seems to bring about a stiffening effect as evidenced by the two cycles tested. This may indicate that the first cycle may have taken out the slack and free play within the system.



(a) "GOOD" TIE #809 NORTH



(b) "BAD" TIE #822 SOUTH

FIGURE 3.25 - VERTICAL TIE/TIE PLATE MODULUS RESULTS

4. CONCLUSIONS

The obtained test results enabled the quantification of rail restraint capacity in terms of establishing lower bounds on required lateral rail strength, and provided the basis for the development of rail restraint specifications for low speed track. in addition, the data resulted in an improved understanding of the gauge widening mechanism, and helped establish indicators for rail restraint failure and degraded rail capacity. Some specific conclusions are summarized in the following paragraphs.

1. A tie in "average to good" condition can exhibit 30-40% increase in lateral load carrying capacity (measured at 1 inch rail head deflection) as compared to a "bad" tie condition; damage in terms of permanent set for "good" ties is minimal. In the small deflection regime (up to 0.25 inches), load-deflection behavior for "good" versus "bad" ties tend to be very similar. Therefore, rail capacity evaluations cannot be based upon small deflection regime data.

2. The gauge widening mechanism in terms of rail rotation versus lateral shift was found to be highly lateral load dependent. For low lateral loads (15 kips), rail base movement was 70-90% of the rail head movement; for intermediate lateral loads (25 kips) it was 50-70%; and for high lateral load levels (35 kips), 30-50%.

3. Cyclic loading tests for determination of rail restraint "damage" caused by repetition of applied loads for "bad" ties indicated that in general, only a small weakening occurs, which takes place during the first cycle, while subsequent cycles exhibited identical load-deflection characteristics with no additional weakening.

4. Load versus deflection response curves to evaluate rail joint strengths indicate that joints appear to be weaker than the rails opposite them (10% at 1 inch deflection), while a joint weakened by removal of bolts exhibited a 33% reduction in lateral load capacity (at 1 inch deflection).

5. Comparison of rail strength capacity for two versus three missing ties indicated no substantial difference in strength; however, removing two or three ties resulted in 20% loss of strength over the lower bound (weakest tie condition) tested.

6. Component tests on spike pullout strength characteristics indicated a large variation in pullout force depending on tie and spike condition. Spike pull out force varied from 60 lbs to over 4500 lbs. About 50% of the spikes tested required less than 1000 lbs, while approximately 13% required over 4500 lbs (maximum being 7400 lbs), and the remaining 37% were evenly distributed between the 1000 and 4500 lbs pullout force levels.

7. Tie plate lateral resistance characteristics obtained in the field were similar to those measured in the laboratory. Tie plate lateral resistance is a complex interaction between the influences of spike stiffness, tie plate-to-tie sliding stiffness, tie plate-to-tie "cutting" stiffness and rail lateral stiffness. Therefore, a large variation in resistance behavior can be expected and was obtained depending on the tie/plate/spike conditions and the applied vertical load. A "good" versus "bad" tie comparison with zero vertical load, for example, shows a 20 kip versus 4 kip lateral load to produce the same 0.5 inch lateral tie plate deflection.

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