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LABORATORY INVESTIGATION OF LATERAL TRACK SHIFT

INTERIM REPORT

AUGUST 1980

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16. Abstract

This report describes test procedures and results of the AAR lateral track shift tests. The tests included static and dynamic lateral track loadings under various vertical loads, relative effects of single and double axle loading, panel shift tests and single tie tests.

These tests, which were conducted at the AAR's Track Laboratory, were designed to quantify and determine the lateral strength of the track using various methods. The test results are limited to an unconsolidated track condition.

The results indicate that a lateral stiffness of the track can be determined from each of the three methods used. These results, obtained from each of the methods tested, are compared in this report.

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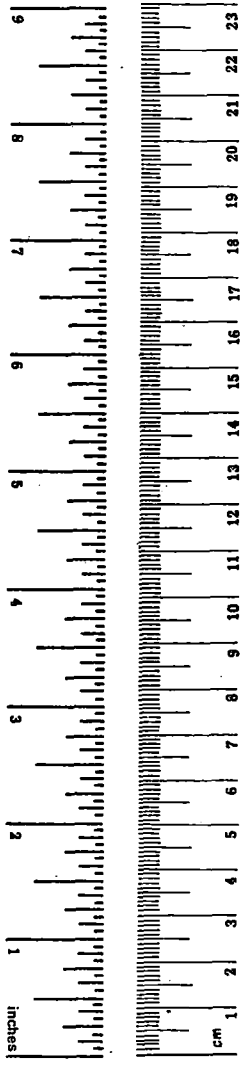
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

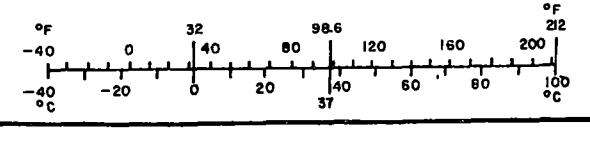
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights 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



PREFACE

These tests were conducted under Task Three, Laboratory Testing, of Contract DOT-FR-30038, sponsored by the Federal Railroad Administration, Office of Research and Development, Improved Track Structures Research Division.

The principal objective of these laboratory tests was to investigate the lateral resistance of track subjected to varying combinations of lateral and vertical loadings.

The valuable suggestions of Mr. Howard Moody, Contracting Officer's Technical Representative, Federal Railroad Administration and Mr. Donald P. McConnell, Transportation System Center, Department of Transportation, are gratefully acknowledged.

Special thanks go also to the two members of Subcommittee Two of the Track Strength Characterization Program: Messrs J. F. Scott and A. Worth of CN Rail for their valuable assistance in the evaluation and interpretation of the test results.

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1.0 INTRODUCTION

With the increasing use of continuously welded rail, the resistance of the track structure to lateral movement is of great importance to the track engineer. The ability to predict the lateral restraint characteristics of a track structure can provide valuable information regarding the track's ability to withstand traffic loadings, and provide useful information for the planning and conduct of track maintenance activities. In order to better understand the phenomenon of lateral track shift, a series of tests were conducted at the Association of American Railroad's Track Laboratory, located in Chicago, Illinois.

Conventional track structure is frequently subjected to severe lateral, as well as vertical and longitudinal forces. These forces could, as an example, be caused by the curving action of railroad vehicles, thermal stresses in the rails, freight car truck hunting, track imperfections, or any combination of the above. Since it is impossible to eliminate all of the lateral forces applied to track, the lateral strength of the track must be known, in order to define safe operating conditions for traffic over known sections of track.

The ability of track to withstand gage widening under applied lateral loads was discussed in an earlier report (1). This report will deal with the ability of track to resist lateral movements under applied lateral loads.

Those forces in the track structure that oppose the applied lateral loads could result from frictional forces at the tie-ballast interfaces, and bearing forces from the tie-shoulder interface. To study these opposing forces, three types of tests were conducted: lateral track shift tests with simulated single and dual-axle (truck) loads, a panel shift test with uniform load, and a single tie stiffness test.

This report describes the specific test procedures, presents the results of the various misalignment tests, and discusses the test conclusions and recommendations.

2.0 LATERAL TRACK STIFFNESS TEST

To study the mechanism of lateral track shift, a series of twenty tests was conducted at the AAR's Track Laboratory. These tests consisted of seventeen lateral shift tests, one lateral track panel shift test, and two single tie shift tests. The procedures for these twenty tests are presented in this Section.

2.1 Test Procedures

The test track, used for the lateral shift tests, was constructed using 136 RE rail; #5 AREA cross ties, 7 inches by 9 inches by 9 feet, spaced on 19.5 inch centers; #12 AREA tie plates, with two cut spikes per plate (spikes were fully driven); #4 AREA limestone ballast, 12 inches deep, with 12 inch shoulders, and CA-8 Illinois Specification limestone subballast; 6 inches deep. The AREA Manual for Railway Engineering (2) was used as a guide throughout the construction of the track.

Track loading was accomplished using four 100 Kip capacity hydraulic jacks for vertical loads, and two 50 Kip capacity hydraulic jacks for lateral loads, as shown in Figure 1.

Vertical and lateral wheel loads were applied to both rails by means of a specially-designed loading bolster, shown in Figure 2. The use of this bolster reproduced the loading geometry of a 100-ton capacity freight car truck

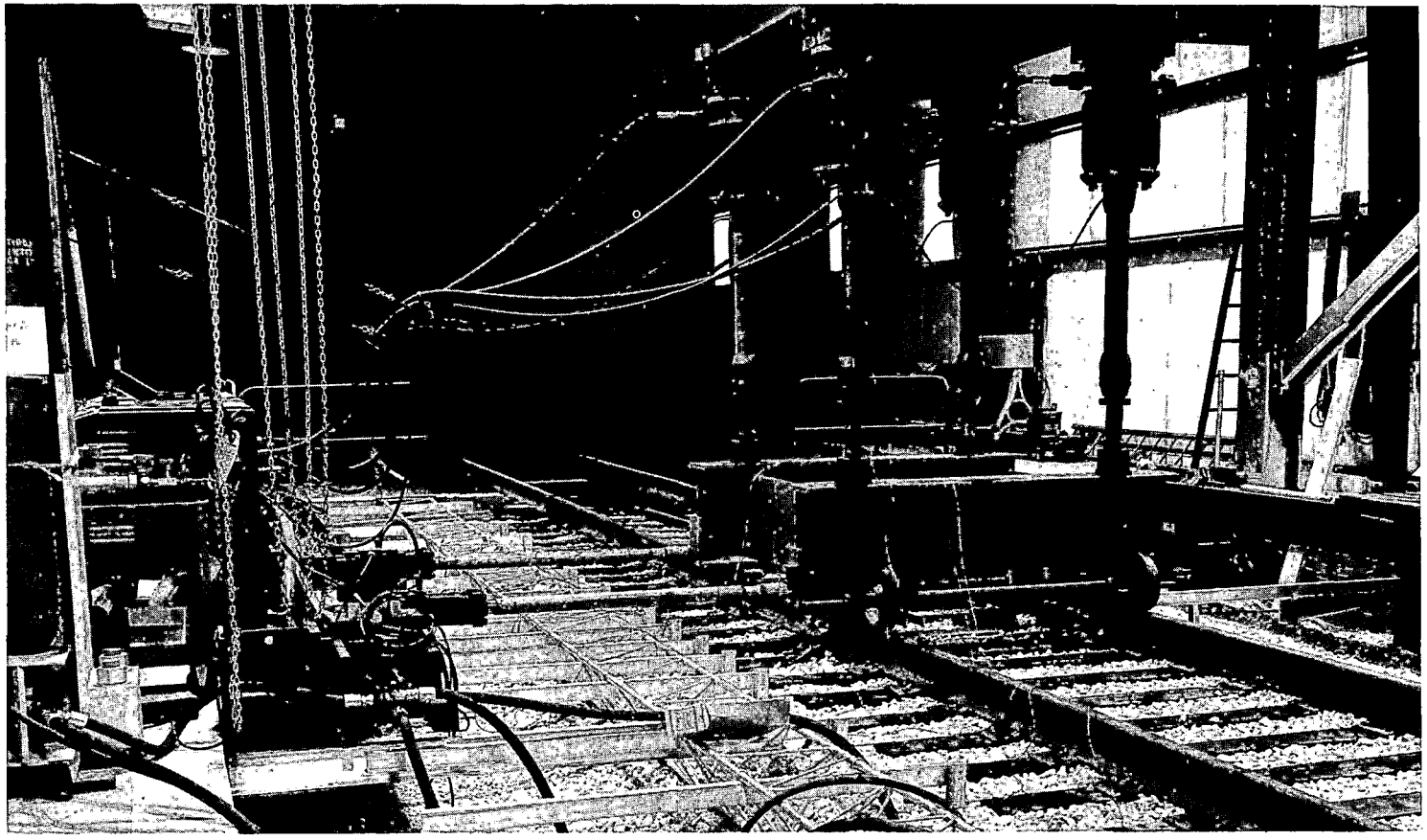


Figure 1. Test Set-Up for the Single Point Lateral Load Test, Showing Vertical and Lateral Hydraulic Jacks and Instrumentation.

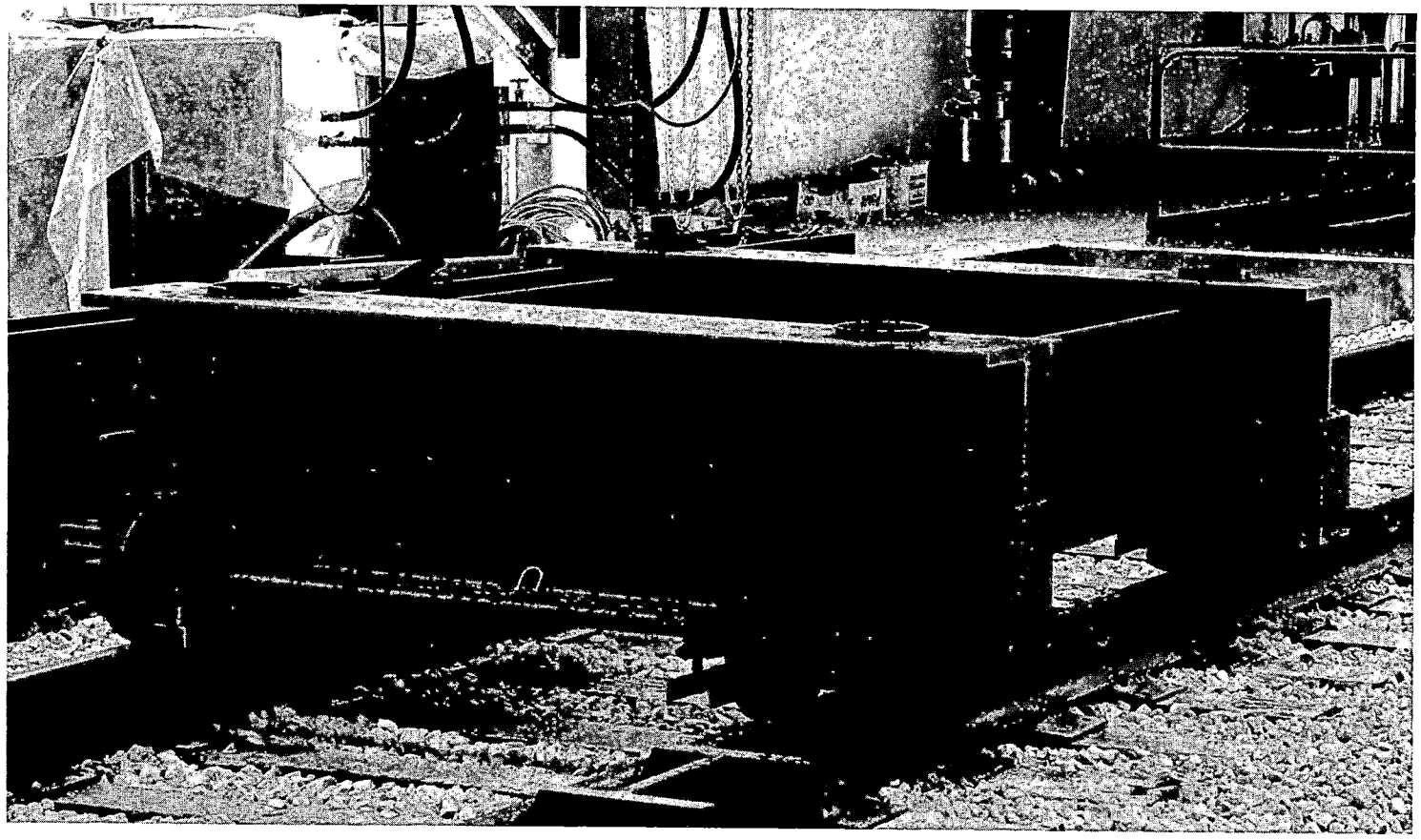


Figure 2. Loading Bolster Used to Apply Vertical and Lateral Loads to the Test Track.

with 36 inch diameter wheels. During the tests, vertical loads were applied to both rails to simulate either single or dual-axle (truck) vertical loadings. Lateral loads were applied through the wheel flange(s) of the loading bolster to the gauge side of one rail, to simulate either single or dual-axle (truck) lateral wheel loadings. All vertical loads were measured by strain gauge pressure transducers installed in the hydraulic lines. Lateral loads were measured by strain gauges mounted on the lateral jack load stilts.

One rail was braced on the field side opposite the primary load application point, for the single-axle lateral load tests, and at the adjacent tie for the double axle lateral load tests. Bracing was accomplished by placing specially cut tie plates under the railhead and spiking them to the tie, as shown in Figure 3. This bracing was necessary to prevent the rail from rotating and thus converting some of the applied load into the gauge widening mode. Since the purpose of this test was to study lateral track shift, any widening of the gage or rotation of the rail was to be avoided.

Instrumentation, other than for load measurements, consisted of 17 absolute lateral track deflection channels. Deflections were measured at the loading point tie, the next two consecutive ties, and then at every other tie for ten ties in one direction from the loading point. In the other

Figure 3. Rail Bracing With Modified Tie Plate.

direction, deflections were measured at four consecutive ties and then at every other tie for 16 ties from the loading point. Figure 4 shows the test track and the locations of the deflection and load measurement points. All deflection data was measured by means of four inch displacement transducers, mounted on the reference frame with cantilever beams, and connected to the ties with a ball-joint arrangement, as shown in Figure 5.

After the instrumentation installation and check-out, the lateral track stiffness test was started. Prior to any load application, zero reference readings (for all data channels) were recorded. During the actual loading sequence, the vertical load was applied first and a set of readings taken. The lateral load was then applied and increased, until a predetermined deflection of the tie at the loading point was reached, at which time the load was held constant and another set of data taken. The lateral load was then increased to the next desired deflection value, and another set of readings taken. This procedure was continued until the maximum track deflection shown in Table 1 was reached. The lateral load was then released to zero, and the procedure repeated until the tests shown in Table 1 were completed.

It is important to note that, when adjacent axle loadings were simulated, i.e. Tests 5 to 9, Table 1, the same procedure was used in the application of the loads and

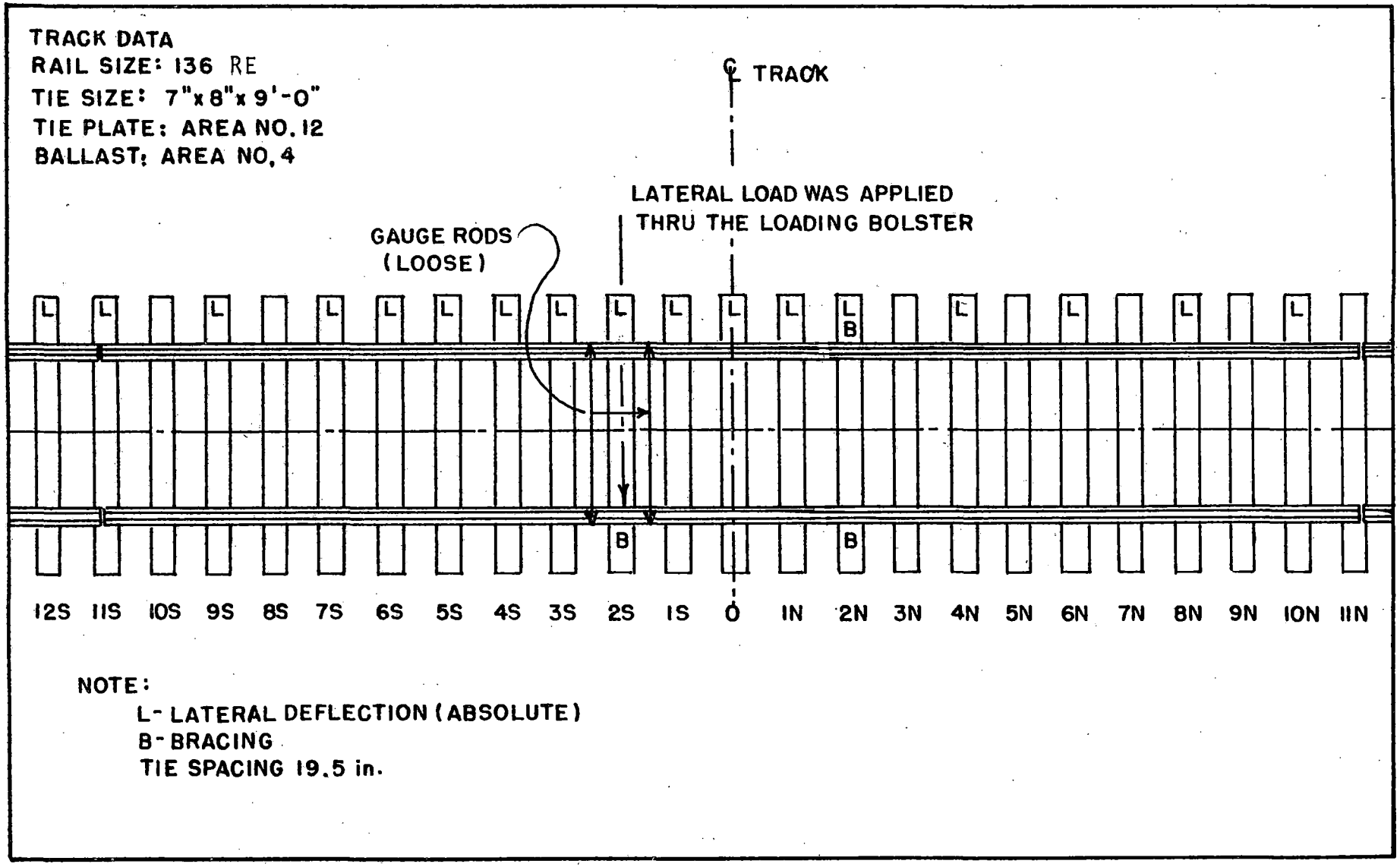


FIGURE 4. LOCATION OF DEFLECTION TRANSDUCERS AND LOAD APPLICATION POINT FOR THE SINGLE APPLIED LATERAL LOAD TESTS.

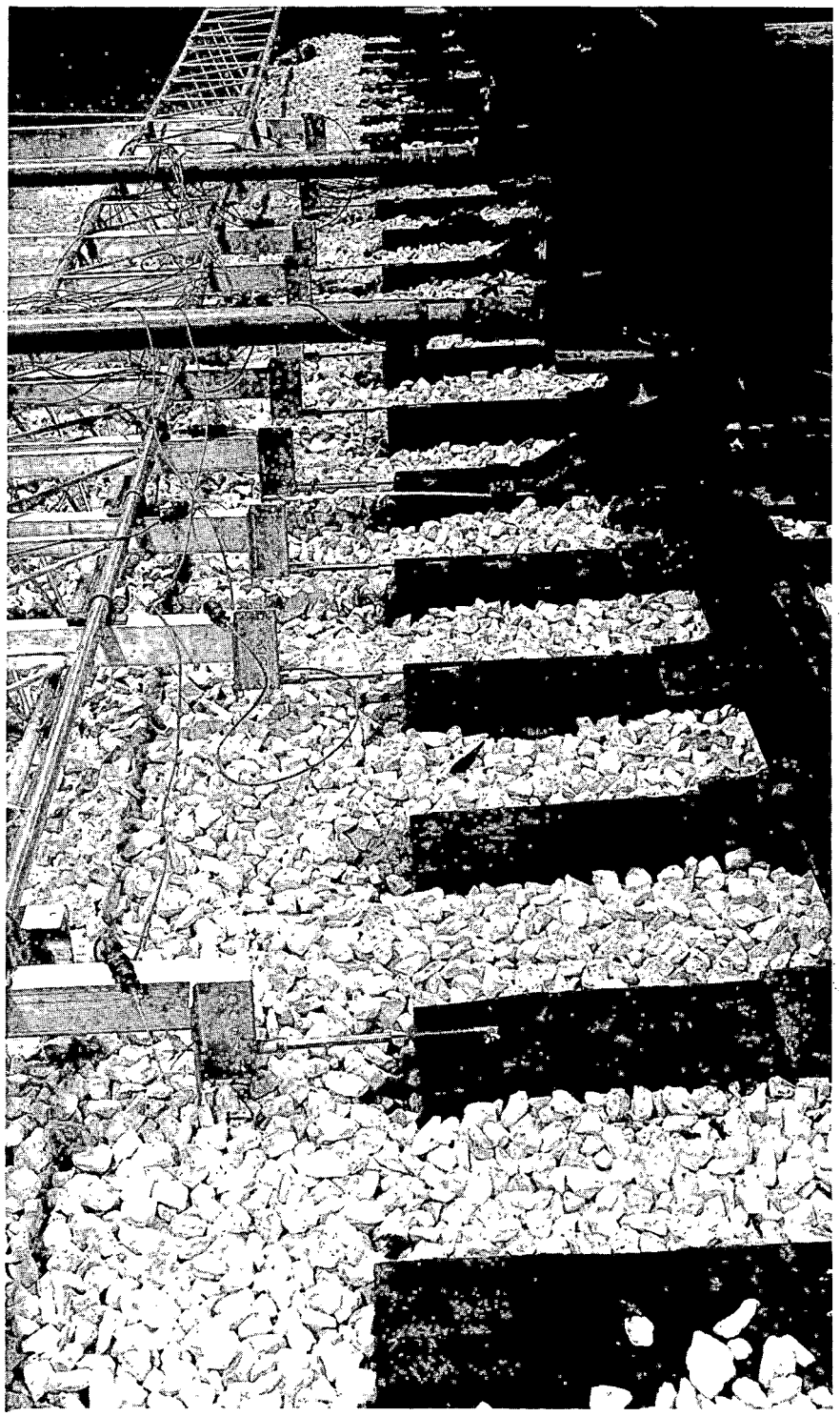


Figure 5. Instrumentation Set-Up, Showing Reference Frame and Cantilever Beams That Support the Deflection Transducers.

TABLE 1: VERTICAL AND LATERAL LOADING SEQUENCE FOR LATERAL TRACK STIFFNESS TESTS WITH SIMULATED SINGLE AND DUAL-AXLE LOADING.

SINGLE LATERAL LOADS

TEST NUMBER	VERTICAL LOADS V1 (KIPS)	TARGET DEFLECTION OF TIE AT LOAD POINT (IN.)
1	0	1.0
2	30	1.0
3	10	1.0
4	20	1.0

ADJACENT LOADS

TEST NUMBER	VERTICAL LOADS V1=V2 (KIPS)	LATERAL LOADS L1 (KIPS)	L2(KIPS)	TARGET DEFLECTION OF TIE AT LOAD POINT (IN.)
5	0	*	*	1.0
6	30	*	*	1.0
7	10	*	0	1.0
8	30	*	0	1.0
9	20	*	0	1.0

* LATERAL LOAD(S) INCREASED UNTIL TARGET DEFLECTION WAS REACHED.

for obtaining the data readings.

The track was realigned after each test by applying a lateral load in the opposite direction, and the shoulders were manually repacked before the start of the next test. The track was pushed in the same direction for all the tests given in Table 1. Note the track condition was always unconsolidated.

After the completion of the single point lateral load tests, eight lateral dynamic impulse tests were conducted, using various vertical and lateral loads, and various applied load time durations, as shown in Table 2.

The lateral impulse loads were applied to the track through the same loading bolster that was used in the static tests. Lateral impulse load time durations were controlled by means of a directional control valve in the hydraulic system. The strain-gauged load stilts were used to measure the lateral load amplitudes and time durations. Analog instrumentation was used to record the data on a recording oscillograph chart.

During each test, the vertical loads were first applied to the loading bolster, and the hydraulic accumulator charged up to the required pressure. By use of the directional control valve, the accumulator's pressure was discharged to the hydraulic cylinders, producing a dynamic lateral impulse load that was applied to the track through

TABLE 2: VERTICAL LATERAL LOADING SEQUENCE FOR LATERAL TRACK STIFFNESS TEST, DYNAMIC IMPULSE LOAD.

TEST NUMBER	VERTICAL LOADS (KIPS)	LATERAL LOADS (KIPS)	DURATION OF IMPULSE LOAD (MSEC.)
1	20	20	50
2	20	24	100
3	20	28	500
4	20	28	200
5	20	28	800
6	0	20	200
7	0	20	500
8	30	30	1000

the loading bolster. This procedure was repeated until all eight tests, shown in Table 2, were completed.

The dynamic loading system for these tests was the same one used for the gauge widening tests, and is described in Reference (1).

Absolute deflections during these tests were measured at five locations, one at the lateral impulse loading point and four at each consecutive tie on either side of the impulse loading point. The same instruments and placement methods were used as in the static lateral load tests.

2.2 Results

The results from the lateral track shift tests, single and dual-axle simulated loads, are presented in this section in tabular and graphical form. The tables found in this report show all of the measured deflections under each applied lateral and vertical load. A table is generated for all the tests given in Table 1. The graphical data plots show load deflections of the track at the point of loading, for both single and double-axle simulated loads (Tie 2S, Figure 5). An example of typical results from these tests are shown in Table 3 and Figure 6. Complete data tables and graphical plots for all twenty tests are given in Appendix A.

TABLE 3: LATERAL TRACK STIFFNESS TEST - SINGLE POINT LATERAL LOADS AND TIE DEFLECTIONS FOR ZERO VERTICAL LOADS.

LATERAL LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S*	1S	0
847.0	0.000	0.000	0.000	0.000	0.000	0.000	-0.000	0.000	0.000
1634.4	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.000
3549.7	0.000	0.000	0.000	0.001	0.001	0.000	0.012	0.006	0.003
5516.1	0.000	0.001	0.000	0.002	0.006	0.000	0.026	0.018	0.010
7665.5	0.000	0.001	0.000	0.004	0.020	0.017	0.050	0.039	0.022
9376.5	0.000	0.001	0.000	0.004	0.042	0.046	0.080	0.067	0.040
11415.2	0.000	-0.000	0.001	0.026	0.084	0.095	0.131	0.112	0.071
13317.7	0.000	-0.001	0.006	0.063	0.163	0.187	0.223	0.194	0.134
14173.2	0.000	-0.002	0.014	0.099	0.227	0.259	0.296	0.259	0.187
14956.4	0.000	0.000	0.031	0.158	0.330	0.371	0.413	0.368	0.277
16029.0	0.000	0.006	0.063	0.232	0.447	0.500	0.547	0.492	0.386
16901.5	0.000	0.015	0.099	0.301	0.550	0.609	0.660	0.598	0.478
17722.9	-0.000	0.033	0.164	0.407	0.706	0.776	0.829	0.762	0.622
18650.8	-0.011	0.076	0.283	0.580	0.930	1.004	1.063	0.987	0.822
42.6	-0.020	0.094	0.283	0.507	0.740	0.797	0.759	0.720	0.635

2S	1N	2N	4N	6N	8N	10N	12N	14N
847.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1634.4	0.000	0.000	0.000	0.000	-0.000	0.000	-0.000	0.000
3549.7	0.001	0.001	0.000	0.000	0.000	0.000	-0.000	0.000
5516.1	0.004	0.002	0.001	0.000	0.000	0.000	-0.000	0.000
7665.5	0.009	0.004	0.001	0.000	0.000	0.000	-0.000	0.000
9376.5	0.018	0.004	0.001	0.000	0.000	0.000	-0.000	0.000
11415.2	0.035	0.015	0.002	0.001	0.000	0.000	-0.000	-0.000
13317.7	0.079	0.036	0.002	-0.001	0.000	0.000	-0.000	-0.000
14173.2	0.118	0.057	0.003	-0.002	-0.000	0.000	-0.000	-0.000
14956.4	0.188	0.100	0.010	-0.005	-0.002	0.000	-0.000	-0.000
16029.0	0.276	0.162	0.026	-0.008	-0.006	0.000	-0.000	-0.000
16901.5	0.354	0.219	0.046	-0.009	-0.003	0.000	-0.001	0.000
17722.9	0.476	0.315	0.093	-0.000	-0.012	0.000	-0.001	0.000
18650.8	0.647	0.455	0.169	0.021	-0.017	0.000	-0.007	-0.000
42.6	0.531	0.399	0.174	0.031	-0.017	0.000	-0.011	-0.001

* LOCATION OF LOADING POINT
TIE SPACING 19.5 INCHES

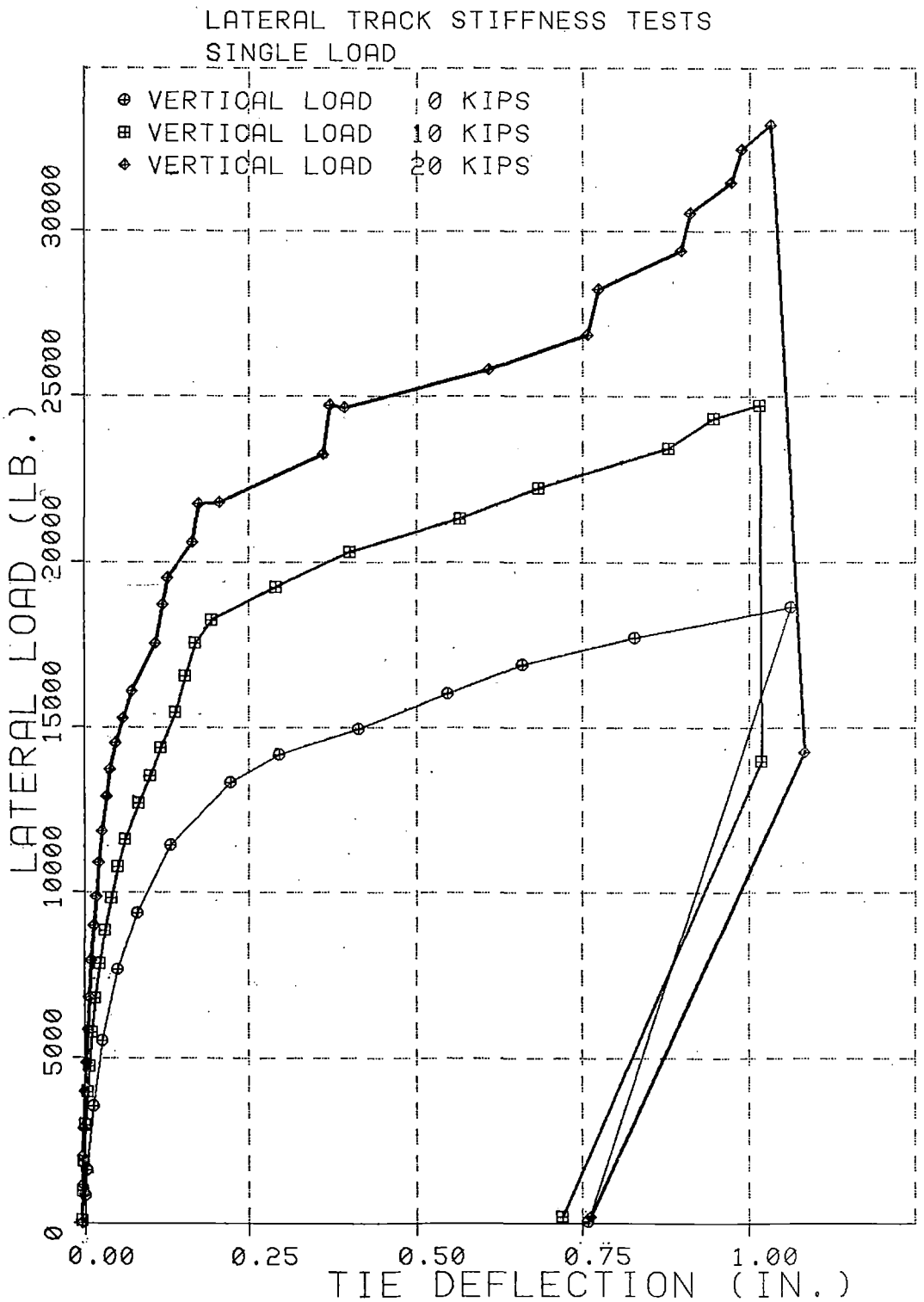


FIGURE 6. TRACK DEFLECTIONS VS LATERAL LOADS, FOR VARIOUS VERTICAL LOADS.

Table 3 shows the absolute track deflection at each measuring location, resulting from various lateral loads, for zero vertical load.

Figure 6 is a graph showing the maximum track deflection (at the loading point) vs lateral load, for 0, 10 and 20 Kip vertical loads.

The track deflection under a single lateral load of 18,600 lb. and zero vertical load is shown in Figure 7. It can be seen from this figure that the track deflection is symmetrical about the loading point, and there is a negative deflection beyond 8 ties from the loading point. This is a clear indication that the track deflects as a damped sine wave, i.e., the deflection wave oscillates from its original position between positive and negative deflections and decaying to zero at a finite distance from the load.

From the single and adjacent vertical load tests, the lateral load which would cause the track to deflect 0.10 inch was determined for each vertical load. From these data points, a third order polynomial was derived, using the least-squares method. The results are shown in Figure 8.

The results from the lateral dynamic single point load tests are given in Table 4. In this table the vertical load, lateral impulse load, and its rise time and time duration, and corresponding deflections at each tie are given. It is interesting to note that the results are symmetrical about the loading point.

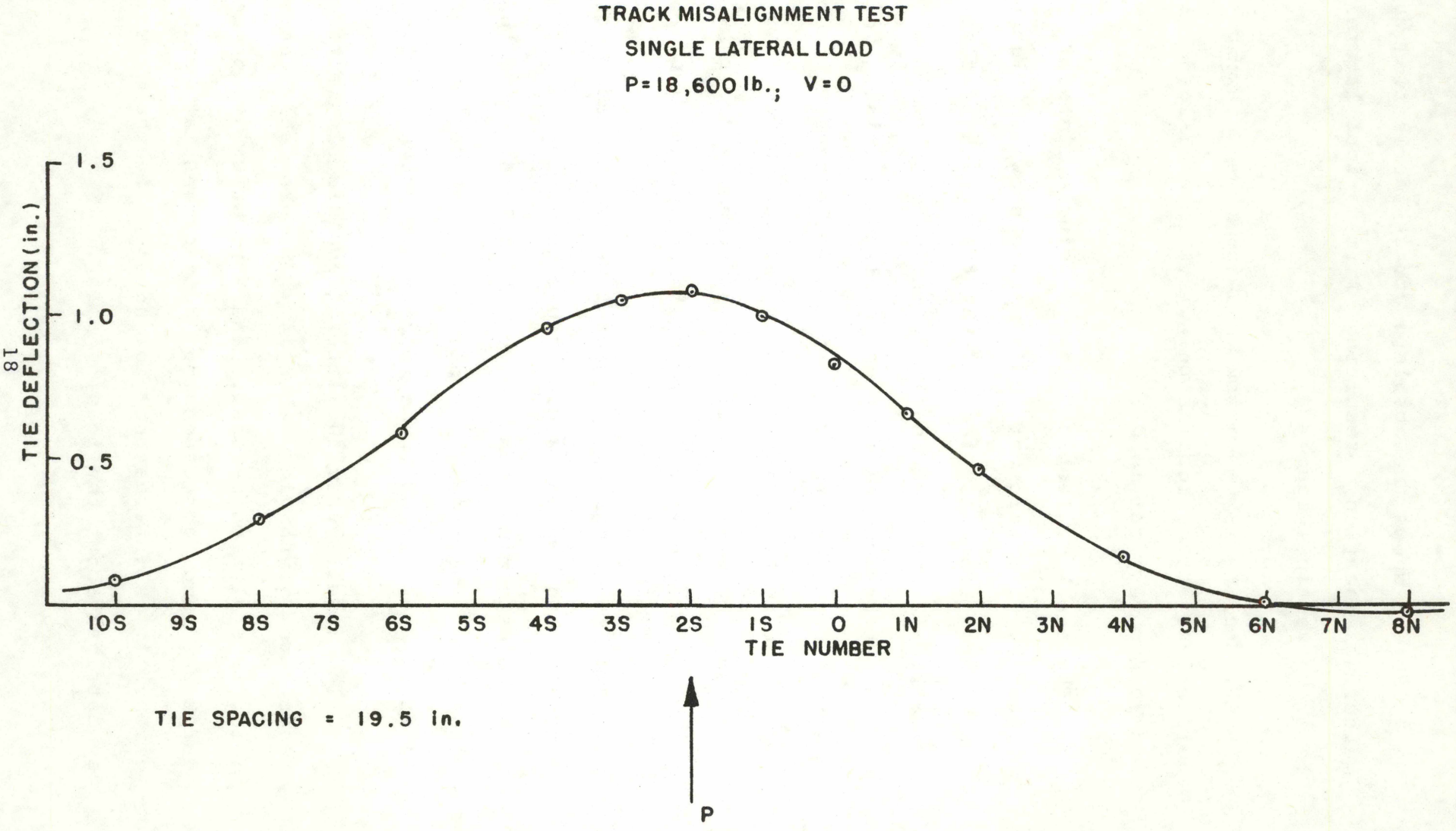


FIGURE 7. LATERAL TRACK DEFLECTION UNDER A LATERAL LOAD OF 18,600 lb. AND ZERO VERTICAL LOAD

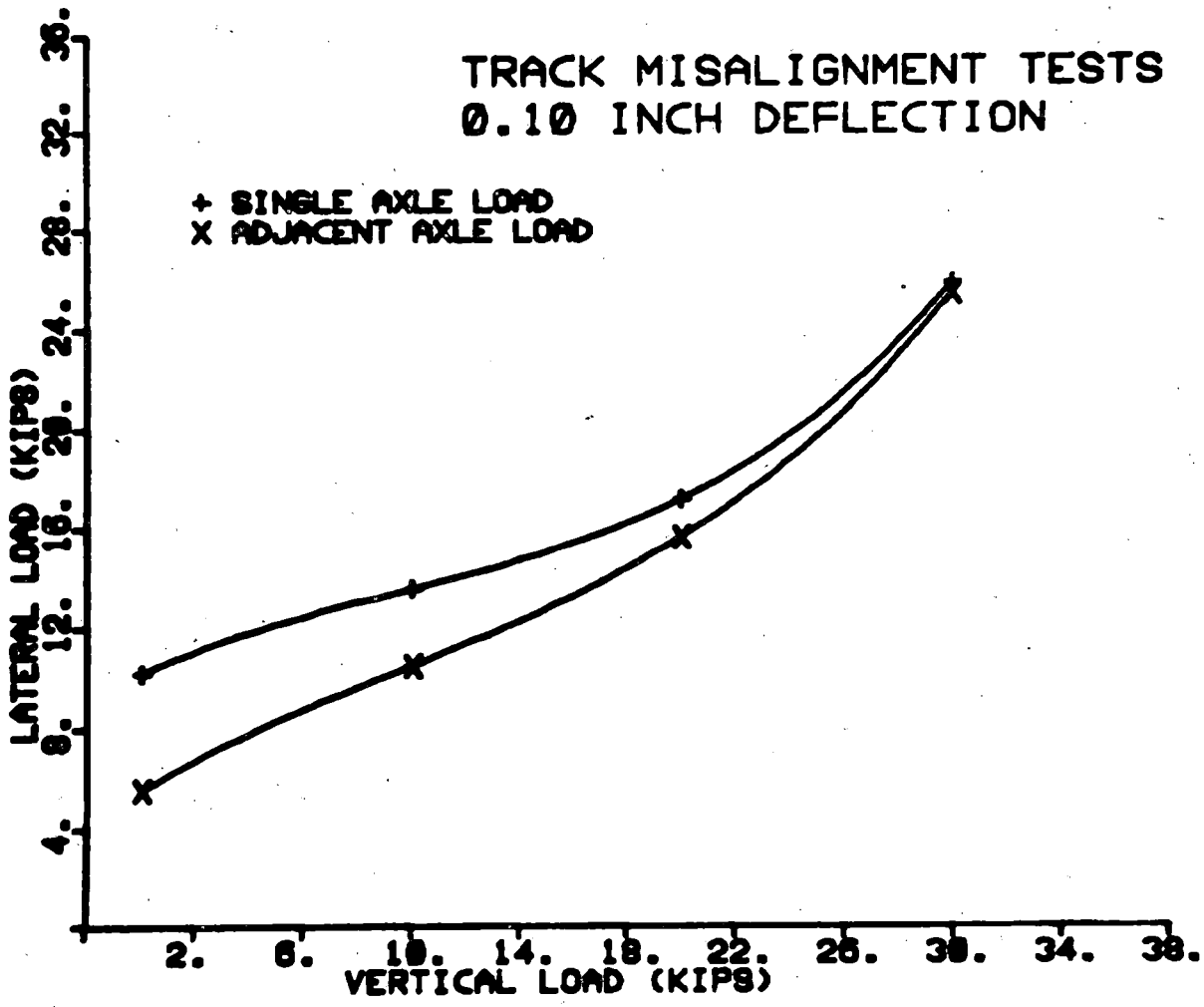


FIGURE 8. LATERAL VS VERTICAL TRACK LOADS, FOR 0.10 INCH TRACK DEFLECTION, SINGLE AND ADJACENT AXLE LOADS.

TABLE 4: LATERAL TRACK STIFFNESS TEST, DYNAMIC IMPULSE LOADS - VERTICAL LOADS, LATERAL LOADS, TIME DURATION OF LOADS AND TIE DEFLECTIONS FOR EACH TEST.

TEST	VERTICAL LOAD (KIPS)	LATERAL LOAD (LBS)	TIME (MSEC) RISE	DURATION	LATERAL DEFLECTION (IN.) @ TIE NUMBER 4S	3S	2S*	1S	0
1	20	18747.3	150	350	.550	.700	.725	.725	.575
2	20	20451.6	200	400	.763	.925	.988	.975	.800
3	20	24996.4	200	250	.775	.925	1.000	.950	.825
4	20	22724.0	50	150	.775	.925	1.000	.950	.800
5	20	26132.6	200	600	.825	.975	1.050	1.000	.850
6	0	15906.8	200	25	.925	1.100	1.150	1.125	.950
7	0	18179.2	250	600	1.075	1.250	1.325	1.275	1.100
8	30**	29541.2	100	950	.775	.900	.975	.950	.775

NOTE:

Fall time is 50 msec., except for tests 6 and 7 which are 100 msec.

Tie spacing - 19.5 in.

* Location of loading point

** Trace ran off oscillograph chart at 30 Kips vertical load.

3.0 PANEL STIFFNESS TEST

3.1 Test Procedures

The test track for the panel test was the same one used in the lateral track stiffness test. The shoulders were formed and repacked manually at the begining of the test.

The lateral load for this test was applied through the loading bolster and loading beam, a 12 inch M-section beam, 20 feet long. The beam was mounted under the loading bolster in a way that one flange was in contact with the gauge side of the railhead for the total distance of 20 feet*. It was centered under the loading bolster and braced with two cross members, as shown in Figure 9. In this manner the two concentrated loads applied to the loading bolster were distributed uniformly along the length of the loading beam. This test was conducted without vertical loads.

Instrumentation for this test was similar to that used for the single point lateral load test. Ten deflections and two loads were measured. The location of the deflection transducers, and the point of load application is shown in Figure 10.

* Note rail outside the 20 feet beam section was not spiked to the ties.

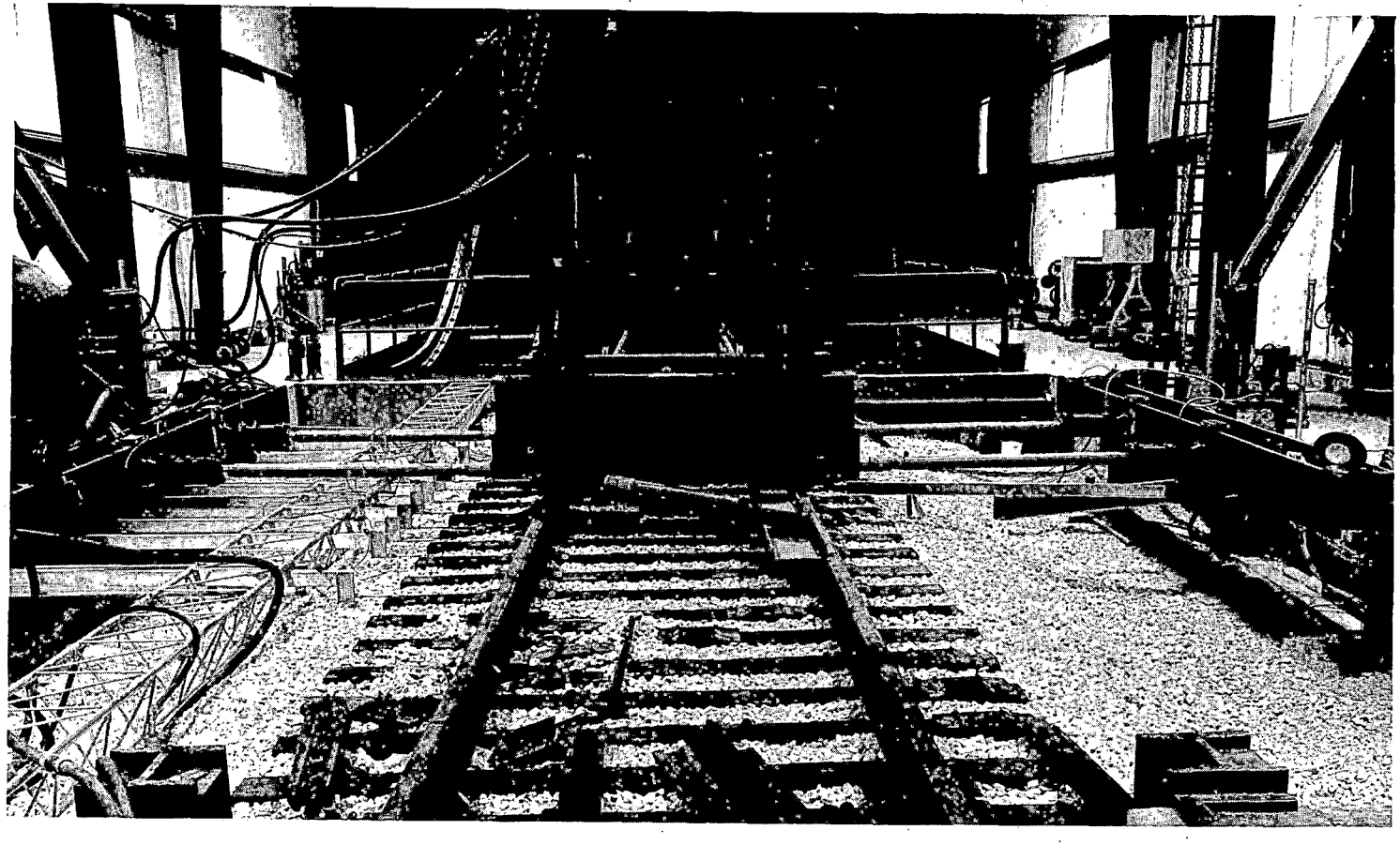


Figure 9. Loading Bolster With Wide Flange Loading Beam Used for Panel Test.

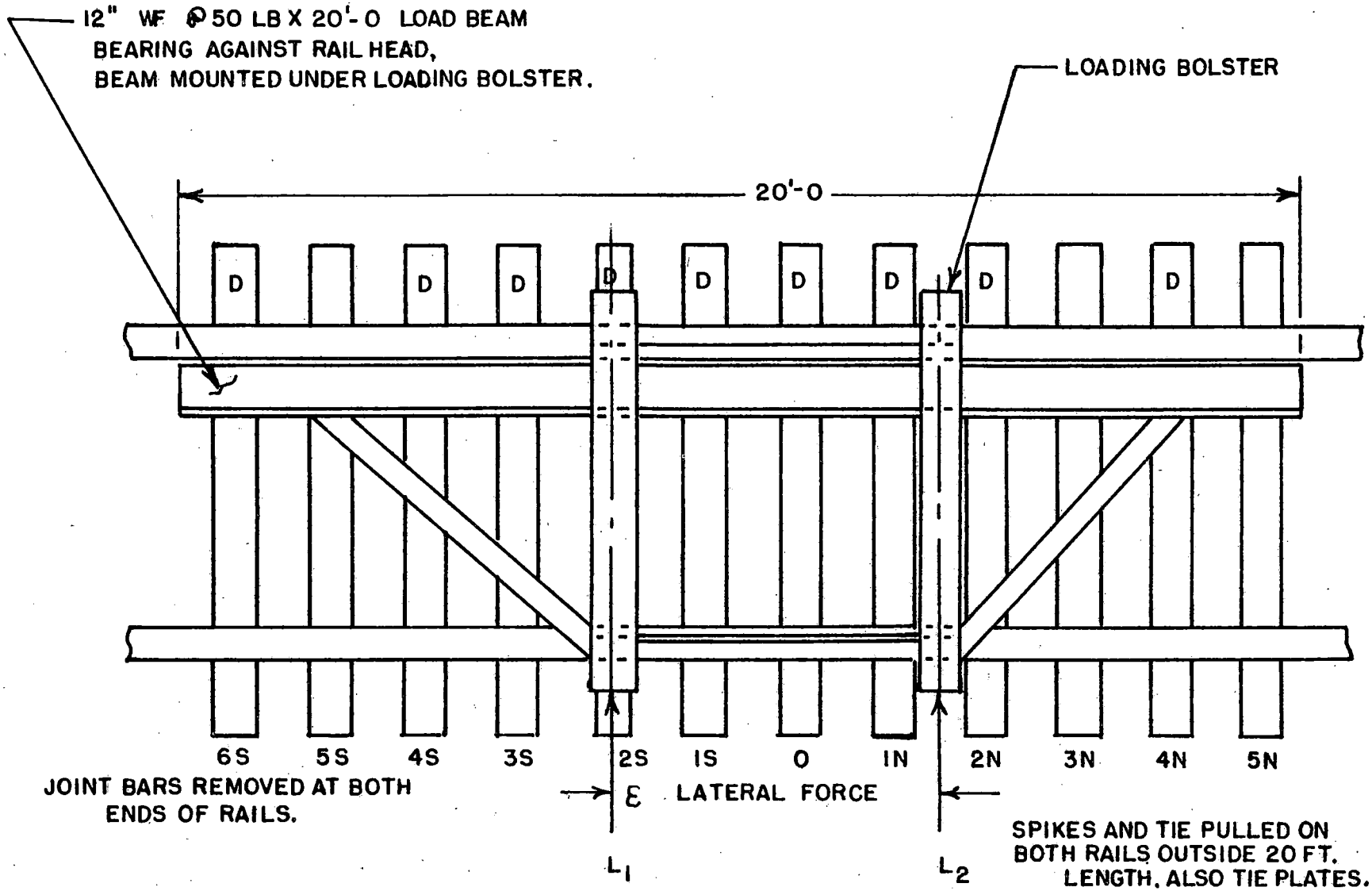


FIGURE 10. LOCATION OF DEFLECTION TRANSDUCERS AND LOAD APPLICATION POINTS, FOR THE PANEL TESTS.

After instrumentation installation and check-out, a zero reference reading (for all channels) was recorded. The lateral load was then applied and increased until a predetermined amount of track deflection was obtained, as measured at the center tie, at which time the load was held constant, and another set of readings taken. The load was then increased to the next predetermined amount of track deflection and another set of readings taken. This procedure was repeated until the track deflection reached a maximum of 2 inches. The load was than released to zero, and the final data readings taken.

3.2 Results

The results from these tests are given in this section in Table 5 and Figure 11. The table includes all measurements taken during the tests, and the graph shows the load deflection curve for the track panel shift.

Table 5 gives the two concentrated loads applied to the loading bolster, the uniform load applied to the railhead by the load beam and the deflections measured at each tie (Figure 7). The uniform load was determined by taking the sum of the two concentrated loads and dividing it by the 20 foot length of the loading beam.

Figure 11 shows the load deflection curve for the track panel. The deflection that is plotted in this curve is measured at the tie under the concentrated load, L1, as

TABLE 5: PANEL STIFFNESS TEST - LATERAL LOADS AND TIE DEFLECTIONS.

LOAD (LB.)		UNIFORM LOAD (LB/FT)	TIE DEFLECTION (IN.)				
2N	2S		6S	4S	3S	2S	1S
4315.9	4612.1	446.4	0.0534	0.0570	0.0620	0.0775	0.0764
4773.0	5097.6	493.5	0.1010	0.1033	0.1083	0.1251	0.1217
5137.9	5493.6	531.6	0.1698	0.1701	0.1707	0.1883	0.1790
5419.0	5800.2	561.0	0.2685	0.2619	0.2553	0.2715	0.2546
5679.0	6060.0	587.0	0.3259	0.3199	0.3116	0.3303	0.3104
5851.0	6255.9	605.3	0.3873	0.3804	0.3693	0.3885	0.3661
6098.4	6554.0	632.6	0.4488	0.4427	0.4301	0.4508	0.4265
6278.8	6745.7	651.2	0.5123	0.5060	0.4910	0.5119	0.4856
6538.8	7056.5	679.8	0.6271	0.6195	0.6034	0.6236	0.5945
6886.9	7503.7	719.5	0.7784	0.7650	0.7457	0.7696	0.7376
6991.8	7550.5	727.1	0.8842	0.8722	0.8531	0.8827	0.8528
7092.5	7674.0	738.3	1.0099	0.9199	0.9727	1.0030	0.9737
6928.9	7614.4	727.2	1.3187	0.9199	1.2431	1.2666	1.2288
6811.4	7525.0	716.8	1.5606	0.9198	1.4764	1.5036	1.4674
6891.1	7610.2	725.1	1.8368	0.9197	1.7359	1.7583	1.7208
6803.1	7559.1	718.1	2.1091	0.9197	1.9903	2.0027	1.9651
6463.3	7252.4	685.8	2.3499	2.3090	2.2529	2.2532	2.2237
5897.1	6605.1	625.1	2.3708	2.3217	2.2629	2.2587	2.2275
159.4	272.6	21.6	2.3452	2.2905	2.2148	2.1980	2.1700
2N	2S		0	1N	2N	4N	6N
4315.9	4612.1	446.4	0.0690	0.0796	0.0910	0.0523	0.0175
4773.0	5097.6	493.5	0.1123	0.1208	0.1292	0.0806	0.0354
5137.9	5493.6	531.6	0.1669	0.1708	0.1751	0.1142	0.0572
5419.0	5800.2	561.0	0.2355	0.2331	0.2305	0.1529	0.0862
5679.0	6060.0	587.0	0.2895	0.2858	0.2805	0.1949	0.1202
5851.0	6255.9	605.3	0.3425	0.3345	0.3255	0.2305	0.1450
6098.4	6554.0	632.6	0.4010	0.3882	0.3764	0.2734	0.1786
6278.8	6745.7	651.2	0.4566	0.4439	0.4234	0.3130	0.2098
6538.8	7056.5	679.8	0.5590	0.5405	0.5144	0.3930	0.2749
6886.9	7503.7	719.5	0.6989	0.6766	0.6486	0.5223	0.3927
6991.8	7550.5	727.1	0.8130	0.7944	0.7679	0.6439	0.5109
7092.5	7674.0	738.3	0.9352	0.9199	0.8916	0.7646	0.6241
6928.9	7614.4	727.2	1.1724	1.1455	1.1091	0.9619	0.7955
6811.4	7525.0	716.8	1.4074	1.3851	1.3407	1.1898	1.0208
6891.1	7610.2	725.1	1.6549	1.6313	1.5773	1.4158	1.2363
6803.1	7559.1	718.1	1.8916	1.8657	1.8049	1.6312	1.4544
6463.3	7252.4	685.8	2.1538	2.1302	2.0685	1.8942	1.7294
5897.1	6605.1	625.1	2.1566	2.1323	2.0703	1.8981	1.7362
159.4	272.6	21.6	2.0910	2.0665	2.0017	1.8978	1.7166

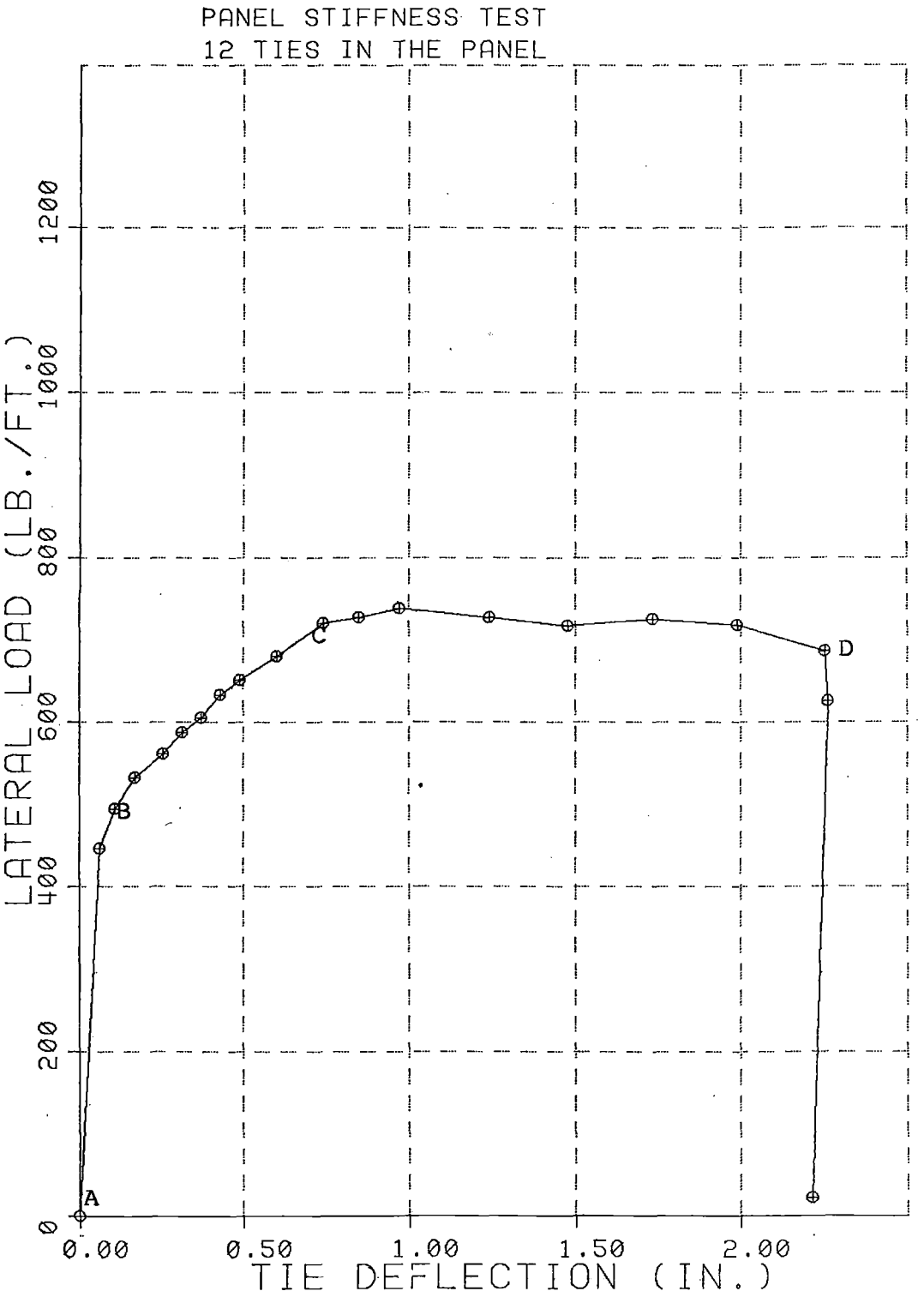


FIGURE 11. LATERAL LOADS VS TIE DEFLECTION (AT THE CONCENTRATED LOADING POINT), FOR PANEL TEST.

shown in Figure 10. The track deflected uniformly throughout the 20 foot section. At the maximum uniform load of 725 lb./ft., the average deflection was 1.62 inches.

The lateral track stiffness can be determined from the load-deflection curve, Figure 11, by aproximating the curve with four straight lines connecting points A, B, C, and D and determining the slope of the line A-B.

$$K = \frac{P}{Y} \quad \text{.....(1)}$$

Where K is the lateral track stiffness A-B (lb./in./in.)

P is the applied uniform load (lb./in.)

y is the average track deflection (in.)

Using this method the lateral track stiffness was found to be 625 lb./in./in.

4.0 SINGLE TIE STIFFNESS TESTS

4.1 Test Procedures

In the test track described in Section 2.1, two single tie push tests were conducted. The ties tested were located outside the central track test area, i.e. the section where the panel and lateral shift tests were conducted, in order to eliminate any disturbance of the track from other tests.

The lateral load was applied to the end of the tie and reacted on the wall adjacent to the test area. A hydraulic jack with a hand operated pump was used to apply the lateral load, which was measured using a strain gauge pressure transducer located in the hydraulic line. The absolute deflection of the tie was measured using a displacement transducer.

The tie plates and spikes were removed, the instrumentation installed and checked, and the hydraulic jack mounted in place. Figure 12 shows the test set-up for the single tie test. A zero reading for both channels was taken and the load increased to produce a predetermined amount of tie deflection, at which time additional data readings were taken. This procedure was repeated until two inches of tie deflection was obtained, and the final set of data under load taken before the load was released to zero. The final data was recorded at zero load to determine the amount of permanent deformation.

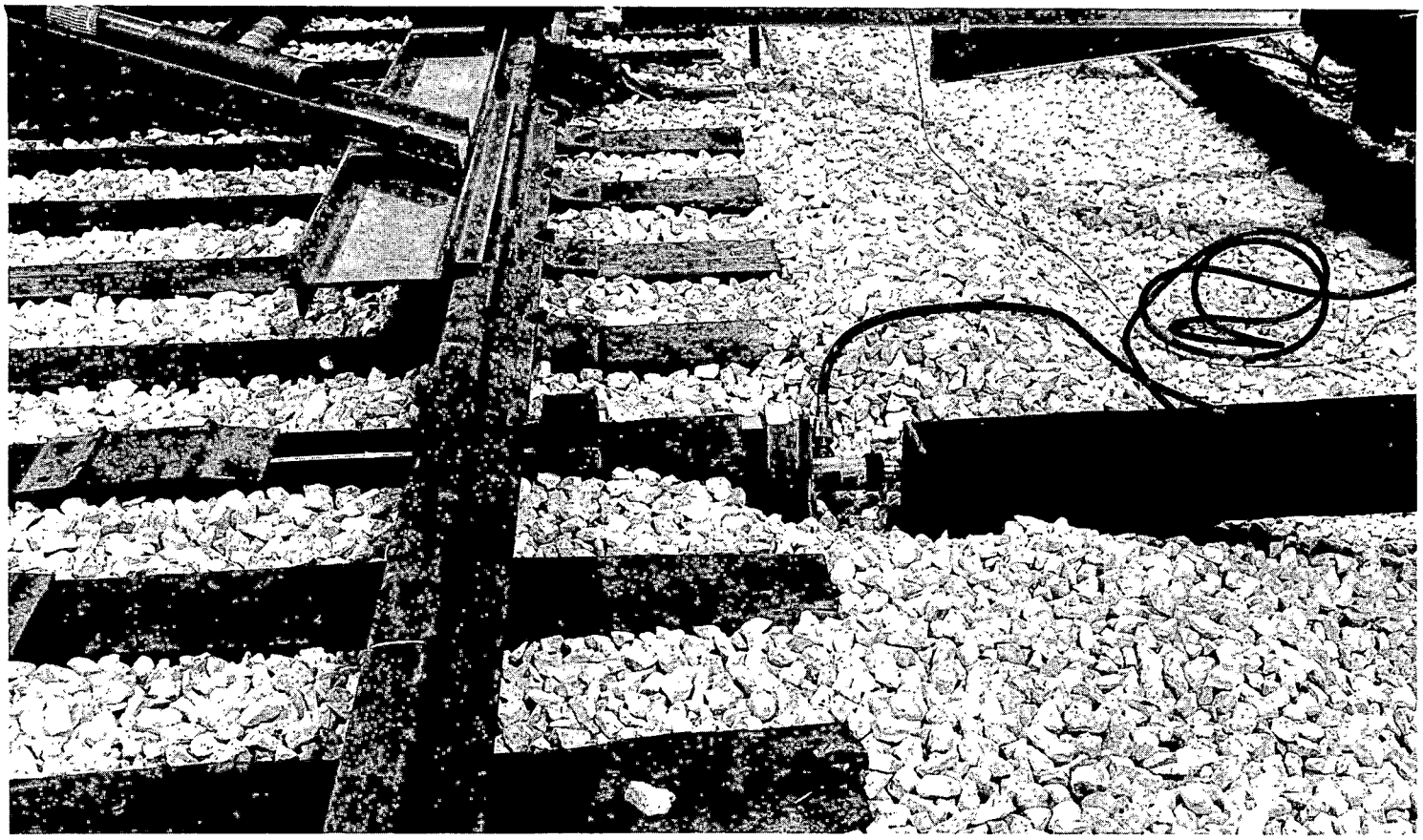


Figure 12. Loading Set-Up for Single Tie Lateral Load Test.

For all of the tests described in this section, data were recorded on both magnetic and paper tape. These data were then reduced according to the techniques defined in Appendix A of Reference (3).

4.2 Results

The results from the two single tie lateral shift tests are given in tabular and graphical forms, as shown in Table 6, and Figures 13 and 14.

Table 6 gives the lateral loads and lateral tie deflections for both tests.

Figures 13 and 14 are plots of lateral load vs tie deflections. From the slope of the straight line, which is a linear approximation to the curve, the lateral tie stiffness of the track was determined from the following equation:

$$K = \frac{P}{Y} \quad \text{.....(2)}$$

Where K is the individual lateral tie stiffness A-B (lb./in.)

P is the applied lateral load (lb.) at point B of the curve (Figure 13 and 14)

y is the deflection of the tie (in.)

TABLE 6: SINGLE TIE LATERAL STIFFNESS TESTS - LATERAL LOADS AND DEFLECTIONS FOR BOTH TESTS.

TEST 1		TEST 2	
LOAD (LB.)	DEFLECTION (IN.)	LOAD (LB.)	DEFLECTION (IN.)
0.0	0.0000	0.0	0.0000
870.5	0.0690	902.7	0.0179
983.1	0.1553	1164.7	0.0786
1137.9	0.2791	1292.0	0.1247
1224.3	0.3291	1433.4	0.2008
1274.6	0.4278	1497.7	0.2613
1300.1	0.5429	1576.1	0.3298
1330.2	0.6731	1479.6	0.4233
1347.0	0.7836	1458.9	0.5108
1438.8	0.9531	1397.2	0.6036
1472.3	1.3048	1463.6	0.7525
1507.8	1.5639	1391.2	0.8565
1485.0	1.6690	1363.0	1.0057
1491.7	1.8174	1326.9	1.1085
1529.9	1.9627	1326.2	1.2424
1649.9	2.0768	1298.7	1.3569
688.9	2.0519	1306.1	1.4951
893.3	2.1879	1293.4	1.6187
992.5	2.3205	1356.3	1.7394
959.0	2.4581	1312.8	1.8812
910.7	2.5951	1355.0	2.0130
817.6	2.7483	-0.7	1.9572
837.7	2.8472		
-0.7	2.7800		

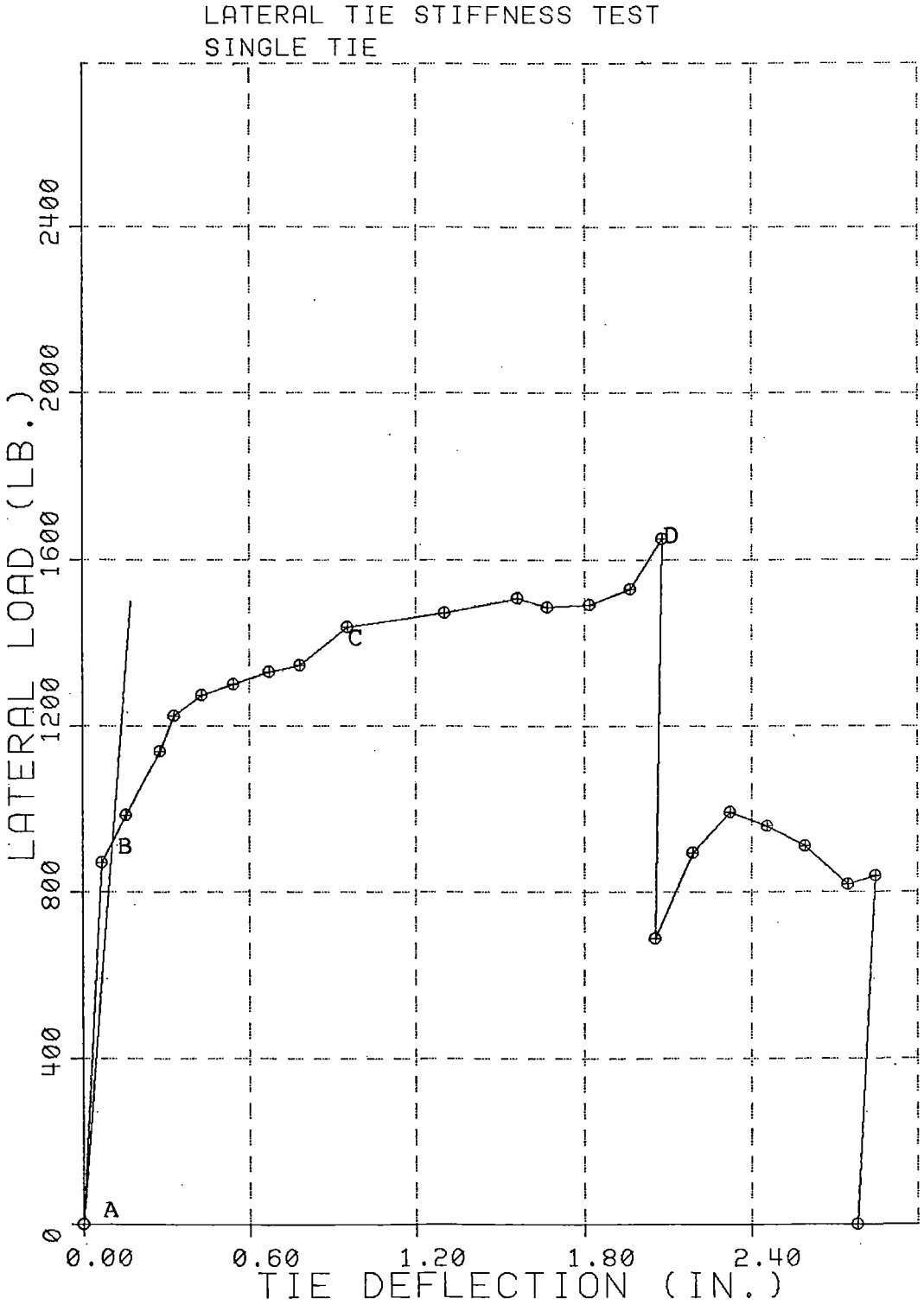


FIGURE 13. LATERAL LOADS VS TIE DEFLECTIONS, FOR SINGLE TIE TEST NUMBER 1

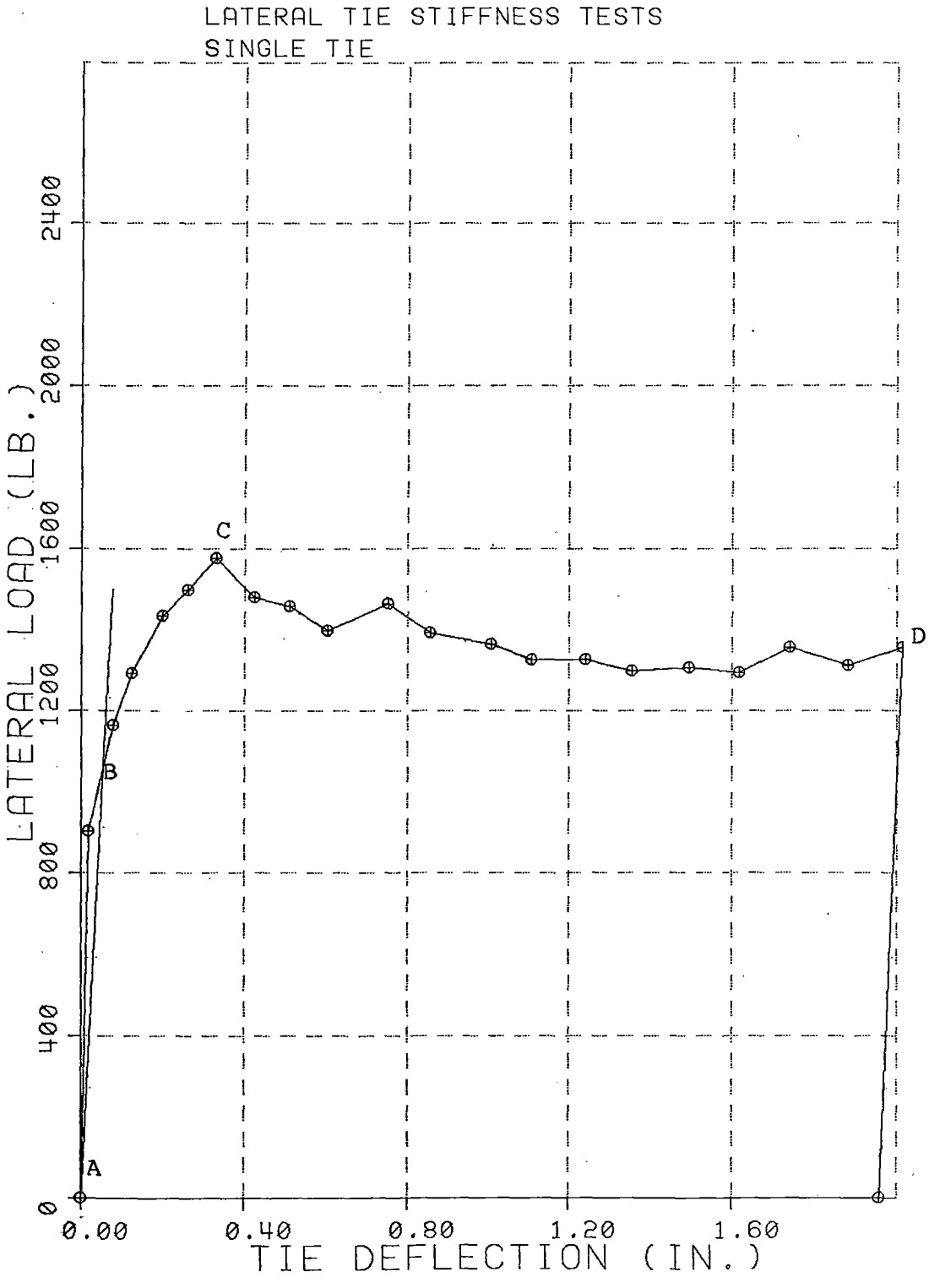


FIGURE 14. LATERAL LOADS VS TIE DEFLECTIONS, FOR SINGLE TIE TEST NUMBER 2.

at point B (Figure 13 and 14)

The stiffness determined by this method was 7800 lb./in. for Test Number 1, and 8600 lb./in. for Test Number 2.

5.0 DISCUSSION AND RECOMMENDATIONS

This program was conducted to obtain data on the lateral resistance of track using different methods for testing and data analysis. Three specific tests were conducted, each using distinctly different types of loads and loading conditions.

The primary objectives of this test series were to quantify the lateral track resistance, and to investigate different methods of measuring and evaluating lateral track stiffness. Additional objectives were to study the effects of vertical loads upon the lateral track resistance, and to compare the lateral track resistances obtained from single tie lateral stiffness and panel shift stiffness test.

Evaluation of the test data in Section 3, obtained from single lateral load tests, indicates that the lateral track resistance can be determined by approximation, after dividing the overall deflection curve into linear sections. The stiffness factor for the track can then be determined using equation (1) for each vertical applied load. Figure 15 is a plot of applied vertical load vs the track stiffness, and shows that the lateral track stiffness increased with increasing vertical loads. As an example (Figure 6), a 30 Kip vertical load required 28.9 Kips of lateral load to produce a 0.14 inch deflection, whereas with zero vertical load, a lateral load of only 11.7 Kips was required to produce the same amount of deflection.

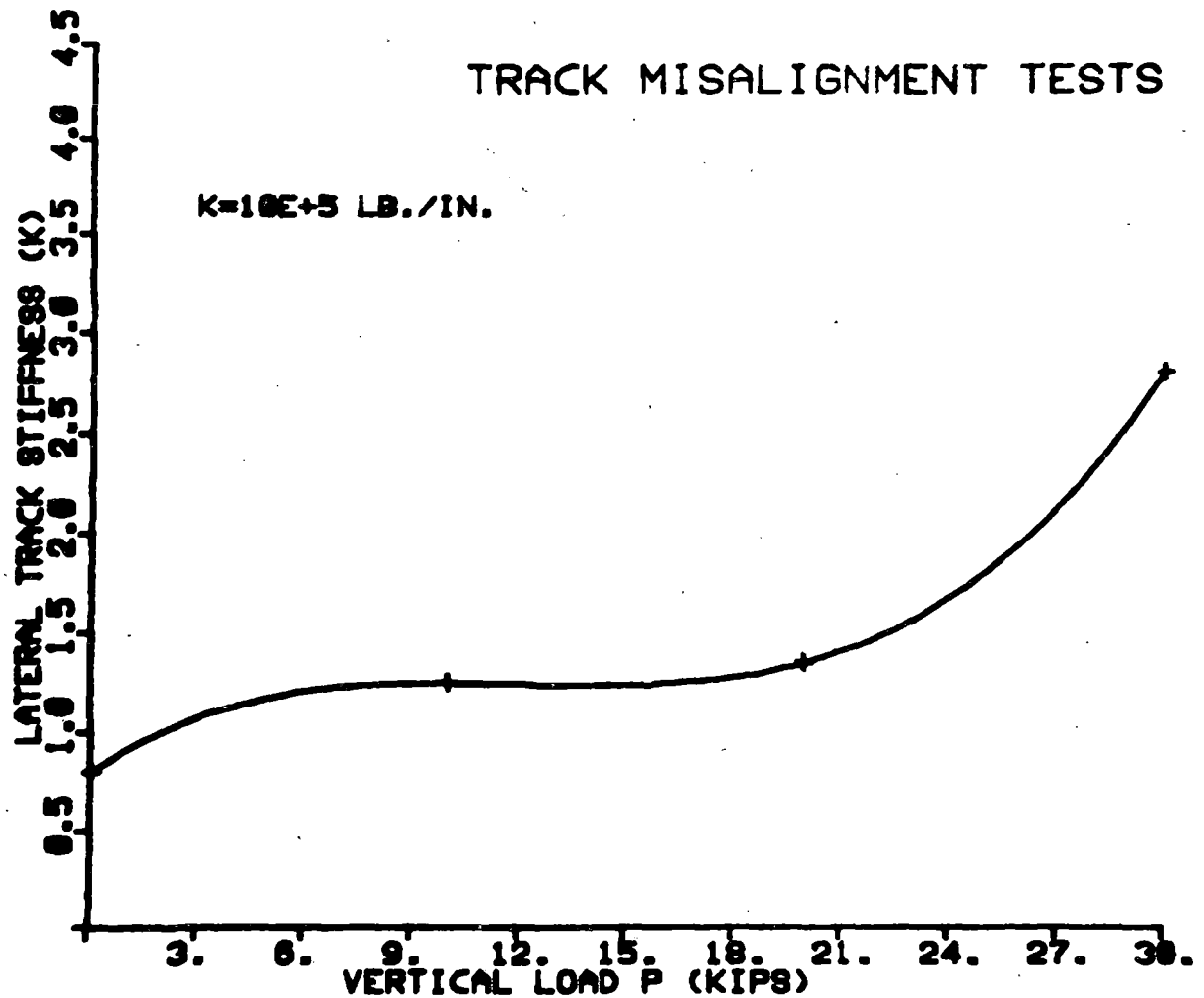


FIGURE 15. VERTICAL LOAD VS LATERAL TRACK STIFFNESS. FROM LATERAL TRACK STIFFNESS TEST, SINGLE LOAD.

This additional restraining force caused by the presence of a vertical load could be due to one or both of the following: the frictional increase between the bottom of the tie and the ballast, and the interlocking of the ballast particles within the layer of ballast around the tie-ballast interfaces. The second possibility is based on the results from the curves for the 20 Kip vertical load (Figure 6). It can be seen that, past the initial "break point," beyond which there were substantial deflections with small lateral load increases, there was a second point where the track stiffness suddenly increased to a value approximating that found in the lower portion of the curve. This stiffness is believed by the authors to be caused by the interlocking of ballast particles rather than by frictional build-up. The above explanations are based on the results from these tests. Additional tests, both field and laboratory, are needed to separate the frictional or ballast shearing forces, end bearing forces, and crib frictional forces, and to separate the effects of the vertical load by determining the mechanism for its contribution to the lateral track stiffness.

Looking at both methods for determining track stiffness that were used in this test series, the panel stiffness measured during the panel test was found to be approximately one-half of the value determined in the single tie tests. This ratio is somewhat lower than that obtained in tests conducted by the German Federal Railroad, where the panel

stiffness was 0.8 of that from single tie tests under static loadings on unconsolidated track and 0.7 for dynamic loadings conditions. Since most investigators believe that the panel test method for determining track stiffness is more representative of "real track" conditions, a comparison or correlation between panel and single tie tests should be further investigated under various track conditions and levels of track consolidation. This would be very helpful to the track engineer, since it is much easier to conduct a single tie test than a panel test.

The results of this series indicates that the lateral track stiffness can be determined by any one of the methods described above as long as a correlation factor has been determined. Once this factor is determined, the single tie method should be used since it is easiest to use and the results can be correlated to the other two methods. A vertical load on the track contributes toward the lateral stability of the track, but it should be noted that this is true for only a relatively short distance from the applied loading point, e.g. approximately 7 to 8 tie spacings (see Figure 7 of reference (5)). Additional work is needed to differentiate between various track restraining forces, such as crib forces, shear particles in the ballast, end bearing forces and friction between ties and ballast. Work is also needed to determine a correlation between tie and panel tests to facilitate field tests of lateral track stiffness.

6.0 REFERENCES

1. Choros, J., Zarembski, A. M., and Gitlin, I, "Laboratory Investigation of Track Gauge Widening Characteristics, Volume I," Report to Federal Railroad Administration, under Contract DOT-FR-30038.

2. Manual for Railway Engineering,Volume 1, American Railway Engineering Association, Chicago IL., 1976.

3. Zarembski, A. M., Choros, J., and Gitlin, I, "Track Components Property Tests, Volume I - Rail Tie and Fasteners," Report to Federal Railroad Administration, Under Contract DOT-FR-30038.

4. "Effect of the Spacing of Conecutive Axles on the Maximum Permissible Value of $\sum Y=S$ From the Standpoint of Track Displacements," Communication of ORE, Rail International, May 1979, pp511-513.

5. Choros, J., Zarembski, A. M., and Gitlin, I, "Vertical Track Modulus Test Results and Comparison of Analysis Techniques," Report to Federal Railroad Administration, Under Contract DOT-FR-30038.

APPENDIX A

DATA FROM THE MISALIGNMENT TESTS*

Included in this Appendix is the complete set of data obtained from the track misalignment tests.

* Note in all graphs and tables in this Appendix the notation of Track Misalignment Tests is used instead of Lateral Stiffness Test.

TRACK MISALIGNMENT
SINGLE LATERAL LOAD
TEST NUMBER 1
VERTICAL LOAD 0 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
847.0	0.000	0.000	0.000	0.000	0.000	0.000	-0.000	0.000	0.000
1634.4	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.000
3549.7	0.000	0.000	0.000	0.001	0.001	0.000	0.012	0.006	0.003
5516.1	0.000	0.001	0.000	0.002	0.006	0.000	0.026	0.018	0.010
7665.5	0.000	0.001	0.000	0.004	0.020	0.017	0.050	0.039	0.022
9376.5	0.000	0.001	0.000	0.004	0.042	0.046	0.080	0.067	0.040
11415.2	0.000	-0.000	0.001	0.026	0.084	0.095	0.131	0.112	0.071
13317.7	0.000	-0.001	0.006	0.063	0.163	0.187	0.223	0.194	0.134
14173.2	0.000	-0.002	0.014	0.099	0.227	0.259	0.296	0.259	0.187
14956.4	0.000	0.000	0.031	0.158	0.330	0.371	0.413	0.368	0.277
16029.0	0.000	0.006	0.063	0.232	0.447	0.500	0.547	0.492	0.386
16901.5	0.000	0.015	0.099	0.301	0.550	0.609	0.660	0.598	0.478
17722.9	-0.000	0.033	0.164	0.407	0.706	0.776	0.829	0.762	0.622
18650.8	-0.011	0.076	0.283	0.580	0.930	1.004	1.063	0.987	0.822
42.6	-0.020	0.094	0.283	0.507	0.740	0.797	0.759	0.720	0.635

2S	1N	2N	4N	6N	8N	10N	12N	14N
847.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1634.4	0.000	0.000	0.000	0.000	-0.000	0.000	-0.000	0.000
3549.7	0.001	0.001	0.000	0.000	0.000	0.000	-0.000	0.000
5516.1	0.004	0.002	0.001	0.000	0.000	0.000	-0.000	0.000
7665.5	0.009	0.004	0.001	0.000	0.000	0.000	-0.000	0.000
9376.5	0.018	0.004	0.001	0.000	0.000	0.000	-0.000	0.000
11415.2	0.035	0.015	0.002	0.001	0.000	0.000	-0.000	-0.000
13317.7	0.079	0.036	0.002	-0.001	0.000	0.000	-0.000	-0.000
14173.2	0.118	0.057	0.003	-0.002	-0.000	0.000	-0.000	-0.000
14956.4	0.188	0.100	0.010	-0.005	-0.002	0.000	-0.000	-0.000
16029.0	0.276	0.162	0.026	-0.008	-0.006	0.000	-0.000	-0.000
16901.5	0.354	0.219	0.046	-0.009	-0.008	0.000	-0.001	0.000
17722.9	0.476	0.315	0.093	-0.000	-0.012	0.000	-0.001	0.000
18650.8	0.647	0.455	0.169	0.021	-0.017	0.000	-0.007	-0.000
42.6	0.531	0.399	0.174	0.031	-0.017	0.000	-0.011	-0.001

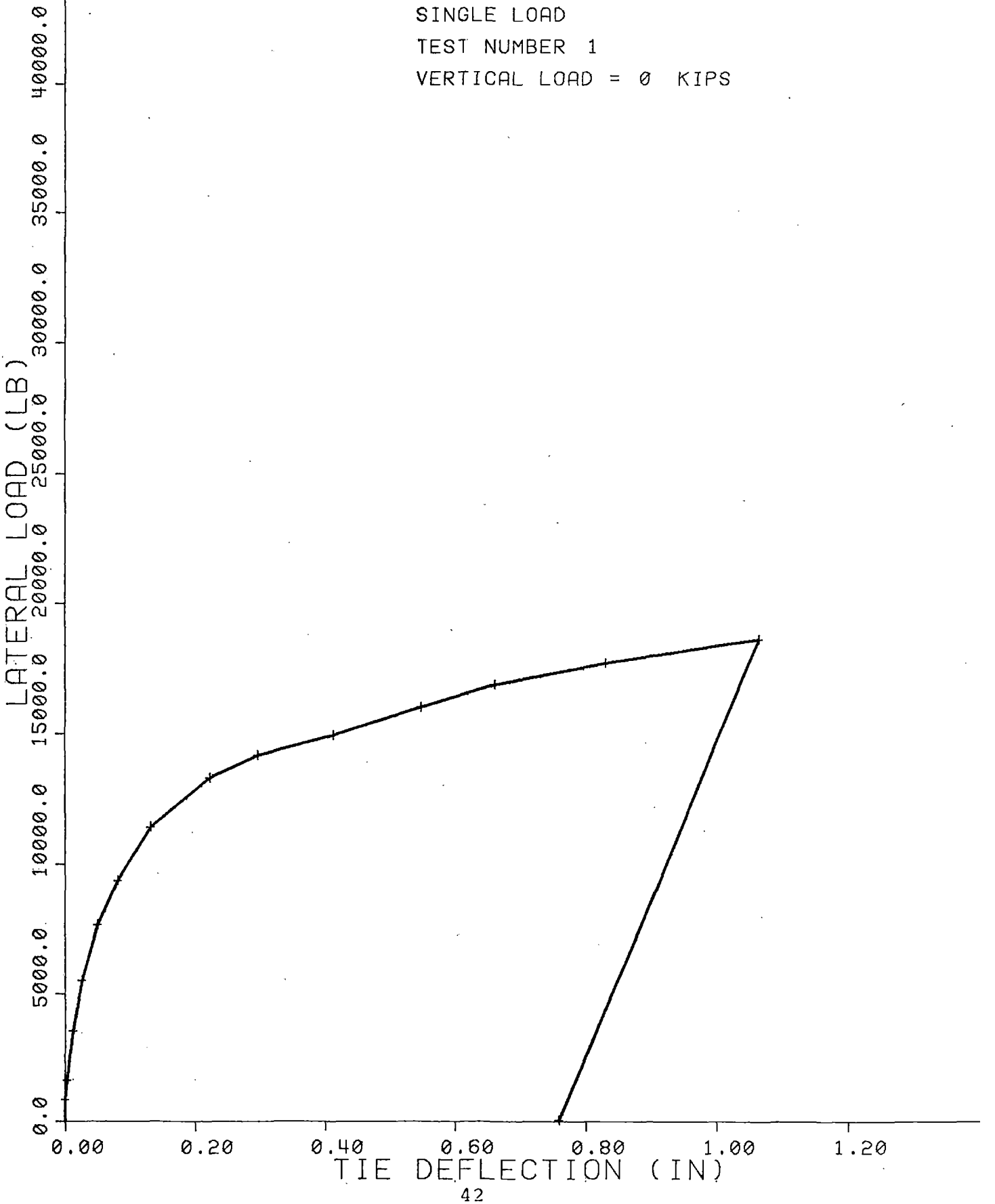
APPLIED VERTICAL LOAD = 11.67 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

SINGLE LOAD

TEST NUMBER 1

VERTICAL LOAD = 0 KIPS



TRACK MISALIGNMENT
SINGLE LATERAL LOAD
TEST NUMBER 2
VERTICAL LOAD 30 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
1570.5	0.000	-0.000	-0.000	0.001	0.001	0.001	0.002	0.001	-0.000
1932.3	0.000	-0.000	-0.000	0.001	0.001	0.001	0.003	0.002	0.000
3056.0	0.000	-0.000	-0.000	0.001	0.002	0.002	0.005	0.003	0.001
3937.0	0.000	-0.000	-0.000	0.001	0.002	0.003	0.007	0.004	0.001
4933.0	0.000	-0.000	-0.000	0.002	0.003	0.005	0.009	0.006	0.003
5801.2	0.000	-0.000	-0.000	0.002	0.004	0.006	0.011	0.007	0.004
6724.8	0.000	-0.000	-0.000	0.002	0.005	0.008	0.014	0.008	0.004
7618.7	0.000	0.000	-0.000	0.003	0.006	0.009	0.015	0.010	0.005
8789.1	0.000	0.000	-0.000	0.003	0.008	0.011	0.017	0.012	0.006
9670.2	0.000	0.001	0.000	0.003	0.009	0.013	0.020	0.014	0.007
10568.2	0.000	0.001	0.000	0.004	0.010	0.015	0.022	0.016	0.008
11755.7	0.000	0.001	0.000	0.004	0.012	0.018	0.025	0.018	0.009
12768.7	0.000	0.001	0.000	0.004	0.013	0.020	0.028	0.020	0.010
13662.5	0.000	0.001	0.000	0.005	0.015	0.022	0.031	0.022	0.011
14654.2	0.000	0.001	0.000	0.005	0.016	0.025	0.034	0.024	0.012
15769.3	0.000	0.001	0.001	0.006	0.018	0.027	0.038	0.027	0.014
16714.2	0.000	0.001	0.001	0.006	0.020	0.031	0.042	0.030	0.015
17757.0	-0.000	0.001	0.001	0.006	0.022	0.034	0.047	0.034	0.017
18659.3	0.000	0.001	0.001	0.007	0.024	0.037	0.051	0.037	0.018
19587.2	0.000	0.001	0.001	0.008	0.026	0.041	0.056	0.040	0.020
20540.6	0.000	0.001	0.001	0.008	0.028	0.045	0.061	0.044	0.022
21528.0	0.000	0.001	0.001	0.009	0.031	0.050	0.067	0.049	0.024
22566.5	0.000	0.001	0.001	0.009	0.034	0.055	0.074	0.054	0.027
23532.7	0.000	0.001	0.001	0.009	0.036	0.061	0.080	0.059	0.029
24388.2	0.000	0.001	0.001	0.009	0.039	0.067	0.088	0.065	0.033
25499.1	0.000	0.001	0.000	0.009	0.043	0.074	0.096	0.073	0.037
26452.5	0.000	0.001	-0.000	0.010	0.049	0.083	0.106	0.082	0.042
27363.3	0.000	0.000	-0.001	0.010	0.054	0.092	0.115	0.090	0.046
27989.0	0.000	0.000	-0.002	0.011	0.060	0.102	0.127	0.102	0.050
28921.1	0.000	-0.001	-0.004	0.012	0.070	0.115	0.142	0.117	0.057
217.1	0.000	-0.006	-0.009	0.004	0.047	0.116	0.085	0.077	0.041
174.5	0.000	-0.007	-0.009	0.008	0.045	0.116	0.077	0.067	0.040

2S	1N	2N	4N	6N	8N	10N	12N	14N
1570.5	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1932.3	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3056.0	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
3937.0	0.002	0.001	0.000	0.000	0.001	0.000	0.000	-0.000
4933.0	0.002	0.001	0.001	0.000	0.001	0.000	0.000	-0.000
5801.2	0.003	0.002	0.001	0.000	0.001	0.000	0.000	-0.000

6724.8	0.003	0.002	0.001	0.000	0.001	0.000	0.000	-0.000
7618.7	0.004	0.003	0.001	0.000	0.001	-0.000	0.000	-0.000
8789.1	0.005	0.003	0.001	0.000	0.001	0.000	0.000	-0.000
9670.2	0.006	0.003	0.002	0.001	0.001	0.000	0.000	-0.000
10568.2	0.006	0.004	0.002	0.001	0.001	0.000	0.000	-0.000
11755.7	0.007	0.004	0.002	0.001	0.001	0.000	0.000	-0.000
12768.7	0.008	0.005	0.002	0.001	0.001	0.000	0.000	-0.000
13662.5	0.009	0.005	0.003	0.001	0.001	0.000	0.000	-0.000
14654.2	0.009	0.005	0.003	0.001	0.001	0.000	0.000	-0.000
15769.3	0.010	0.006	0.003	0.001	0.001	0.000	0.000	-0.000
16714.2	0.011	0.006	0.003	0.001	0.001	0.000	0.000	-0.000
17757.0	0.012	0.007	0.003	0.001	0.001	-0.000	0.000	-0.000
18659.3	0.013	0.007	0.003	0.001	0.001	0.000	0.000	-0.000
19587.2	0.014	0.008	0.003	0.001	0.001	0.000	0.000	-0.000
20540.6	0.015	0.008	0.003	0.001	0.001	0.000	0.000	-0.000
21528.0	0.016	0.009	0.003	0.001	0.001	0.000	0.000	-0.000
22566.5	0.018	0.009	0.003	0.000	0.001	0.000	0.000	-0.000
23532.7	0.019	0.010	0.003	-0.000	0.001	-0.000	0.000	-0.000
24388.2	0.021	0.010	0.003	-0.001	0.001	0.000	0.000	-0.001
25499.1	0.024	0.011	0.002	-0.001	0.001	0.000	0.000	-0.001
26452.5	0.026	0.012	0.001	-0.002	0.001	-0.000	-0.000	-0.001
27363.3	0.029	0.012	0.001	-0.002	0.001	0.000	-0.000	-0.001
27989.0	0.032	0.013	-0.001	-0.003	0.001	0.000	-0.000	-0.001
28921.1	0.037	0.015	-0.003	-0.004	0.000	0.000	-0.000	-0.001
217.1	0.023	0.005	-0.009	-0.005	0.000	0.000	0.000	-0.000
174.5	0.023	0.008	-0.009	-0.005	0.001	0.000	0.000	-0.000

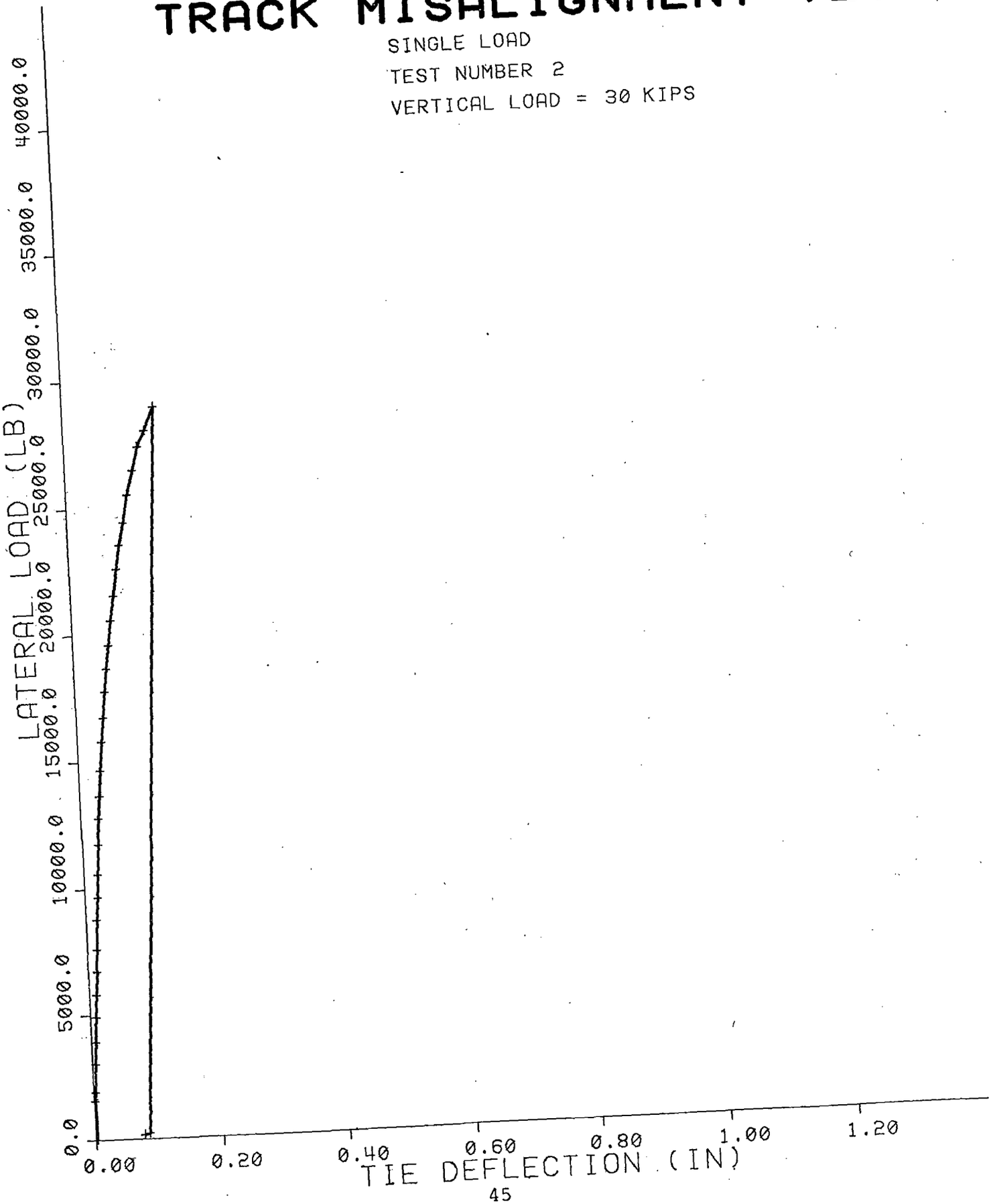
APPLIED VERTICAL LOAD = 29703.74 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

SINGLE LOAD

TEST NUMBER 2

VERTICAL LOAD = 30 KIPS



TRACK MISALIGNMENT
SINGLE LATERAL LOAD
TEST NUMBER 3
VERTICAL LOAD 10 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
63.8	0.000	-0.001	0.000	-0.000	-0.001	-0.000	-0.005	-0.003	0.000
983.2	-0.000	-0.001	0.000	-0.000	-0.001	0.000	-0.004	-0.003	-0.000
1864.2	0.000	-0.000	0.000	0.000	-0.002	0.000	-0.002	-0.002	0.000
2970.8	0.000	-0.000	0.000	0.001	-0.001	0.000	0.000	0.000	0.000
3971.1	0.000	-0.000	0.000	0.002	0.001	0.000	0.003	0.003	0.000
4750.0	0.000	-0.000	0.000	0.002	0.002	0.000	0.006	0.004	0.000
5762.9	0.000	0.000	0.001	0.002	0.004	0.000	0.010	0.007	0.001
6792.9	-0.000	0.001	0.001	0.003	0.007	0.000	0.016	0.011	0.002
7844.2	0.000	0.001	0.001	0.003	0.010	0.000	0.022	0.016	0.004
8857.2	0.000	0.001	0.001	0.003	0.015	0.005	0.031	0.022	0.007
9819.1	-0.000	0.001	0.001	0.004	0.019	0.013	0.039	0.029	0.010
10776.8	0.000	0.001	0.001	0.005	0.025	0.022	0.051	0.037	0.015
11594.0	-0.000	0.001	0.002	0.007	0.032	0.033	0.061	0.046	0.019
12696.3	-0.000	0.001	0.002	0.010	0.045	0.052	0.082	0.064	0.032
13526.3	0.000	0.000	0.002	0.012	0.055	0.067	0.099	0.078	0.042
14373.3	0.000	-0.001	0.002	0.015	0.067	0.083	0.116	0.093	0.053
15450.1	-0.000	-0.001	0.003	0.021	0.084	0.104	0.139	0.112	0.068
16561.0	0.000	-0.001	0.003	0.026	0.096	0.119	0.154	0.125	0.077
17539.9	-0.000	-0.001	0.003	0.031	0.109	0.134	0.169	0.139	0.087
18237.9	0.000	-0.002	0.004	0.042	0.129	0.158	0.194	0.161	0.105
19259.4	0.000	-0.004	0.013	0.085	0.213	0.250	0.291	0.252	0.181
20289.4	0.000	-0.003	0.032	0.141	0.308	0.354	0.401	0.354	0.267
21302.4	0.000	0.003	0.072	0.228	0.444	0.507	0.566	0.508	0.402
22217.5	-0.000	0.010	0.104	0.291	0.545	0.617	0.684	0.621	0.503
23426.3	0.000	0.024	0.176	0.408	0.722	0.805	0.879	0.808	0.666
24315.8	-0.000	0.035	0.199	0.446	0.778	0.866	0.946	0.872	0.723
24737.2	-0.000	0.040	0.224	0.489	0.840	0.932	1.015	0.938	0.780
13981.7	-0.000	0.056	0.266	0.538	0.874	0.956	1.019	0.943	0.794
200.0	-0.000	0.075	0.265	0.469	0.695	0.763	0.720	0.687	0.619

2S	1N	2N	4N	6N	8N	10N	12N	14N
63.8	-0.000	-0.000	0.000	-0.001	0.000	0.000	0.000	0.000
983.2	-0.000	-0.000	0.000	-0.001	0.000	0.000	0.000	0.000
1864.2	-0.000	-0.000	0.000	-0.001	0.000	0.000	0.000	0.000
2970.8	0.000	0.000	0.000	-0.001	-0.000	0.000	0.000	0.000
3971.1	0.001	0.001	0.001	-0.001	0.000	0.000	0.000	0.000
4750.0	0.002	0.001	0.001	-0.001	-0.000	0.000	0.000	-0.000
5762.9	0.002	0.001	0.001	-0.001	0.000	0.000	0.000	-0.000
6792.9	0.003	0.002	0.001	-0.001	-0.000	0.000	-0.000	-0.000
7844.2	0.004	0.002	0.002	-0.001	-0.000	0.000	0.000	-0.000

8857.2	0.006	0.003	0.002	-0.001	-0.000	0.000	0.000	-0.000
9819.1	0.007	0.003	0.002	-0.001	-0.000	0.000	0.000	-0.000
10776.8	0.009	0.003	0.002	-0.000	-0.000	0.000	0.000	-0.000
11594.0	0.012	0.005	0.002	-0.000	-0.000	0.000	0.000	-0.000
12696.3	0.018	0.007	0.002	-0.001	-0.000	0.000	-0.000	-0.000
13526.3	0.023	0.010	0.002	-0.001	-0.000	0.000	0.000	-0.000
14373.3	0.029	0.012	0.001	-0.001	-0.000	0.000	0.000	-0.000
15450.1	0.039	0.017	0.001	-0.002	-0.000	0.000	0.000	-0.000
16561.0	0.045	0.020	0.001	-0.003	-0.000	0.000	0.000	-0.000
17539.9	0.053	0.023	0.001	-0.003	-0.000	0.000	0.000	-0.000
18237.9	0.066	0.030	0.001	-0.005	-0.000	0.000	0.000	-0.000
19259.4	0.125	0.064	0.008	-0.009	-0.005	0.000	0.000	-0.000
20289.4	0.196	0.109	0.023	-0.012	-0.010	0.000	-0.000	-0.000
21302.4	0.315	0.193	0.056	-0.010	-0.016	0.000	-0.001	0.000
22217.5	0.404	0.259	0.086	-0.004	-0.019	-0.000	-0.003	0.000
23426.3	0.542	0.366	0.139	0.012	-0.021	0.000	-0.004	-0.000
24315.8	0.587	0.402	0.157	0.017	-0.022	0.000	-0.005	-0.001
24737.2	0.634	0.438	0.175	0.022	-0.023	0.000	-0.006	-0.001
13981.7	0.649	0.453	0.183	0.025	-0.022	0.000	-0.006	-0.000
200.0	0.544	0.405	0.191	0.038	-0.022	-0.000	-0.006	-0.000

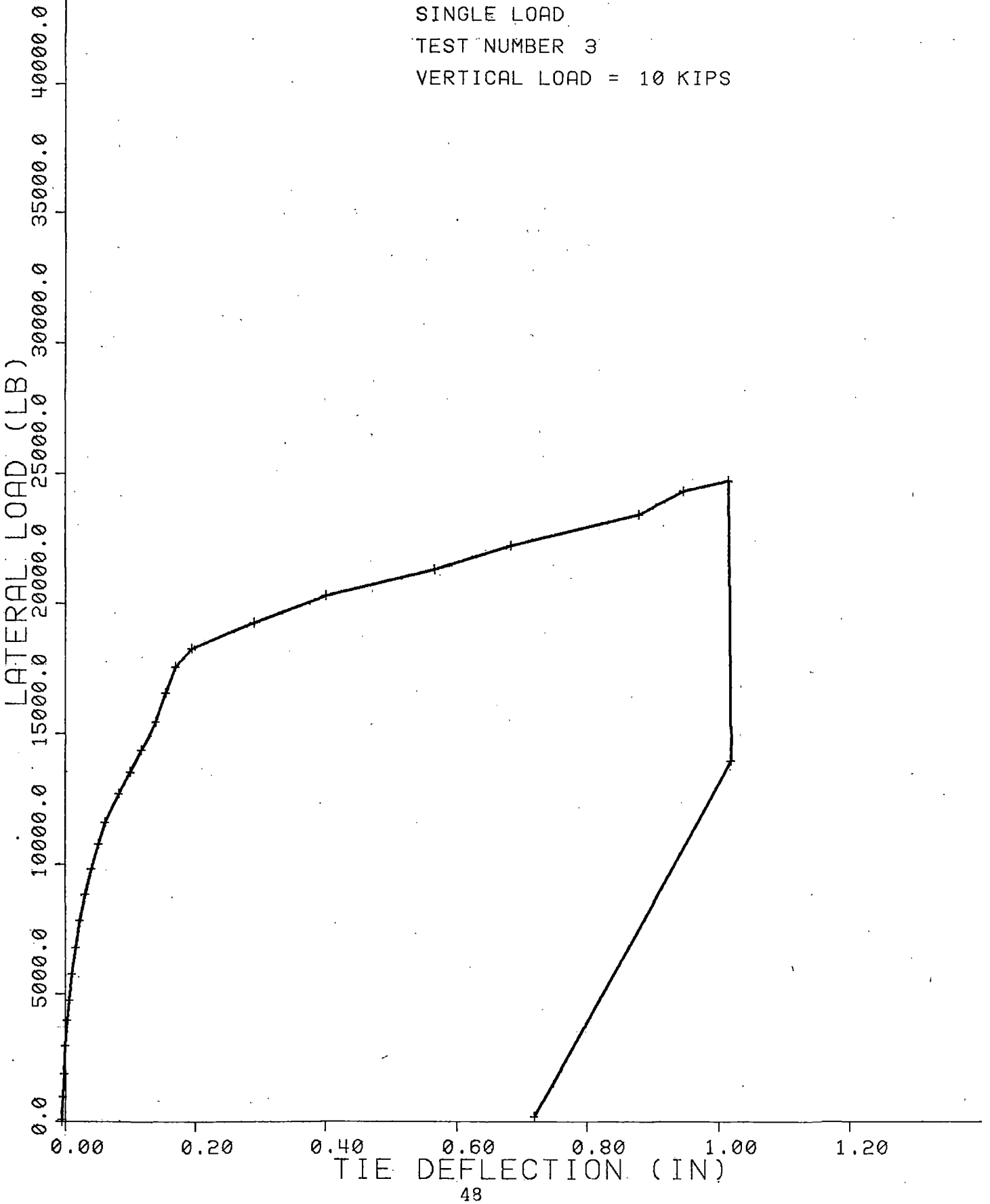
APPLIED VERTICAL LOAD = 9745.63 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

SINGLE LOAD

TEST NUMBER 3

VERTICAL LOAD = 10 KIPS



TRACK MISALIGNMENT
SINGLE LATERAL LOAD
TEST NUMBER 4
VERTICAL LOAD 20 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
-4.3	-0.000	-0.002	-0.000	0.001	-0.001	-0.000	-0.005	-0.002	-0.000
1149.2	-0.000	-0.002	-0.000	0.001	-0.001	-0.000	-0.004	-0.001	-0.000
2021.7	-0.000	-0.001	-0.000	0.001	-0.000	0.000	-0.003	0.000	-0.000
2885.7	-0.000	-0.001	-0.000	0.001	0.001	-0.000	-0.002	0.001	-0.000
3962.6	0.000	-0.001	-0.000	0.002	0.001	0.000	0.000	0.003	-0.000
4852.1	-0.000	-0.001	-0.000	0.002	0.002	-0.000	0.003	0.004	-0.000
5860.8	0.000	-0.001	-0.000	0.003	0.004	0.000	0.004	0.006	0.000
6814.2	0.000	-0.001	-0.000	0.003	0.005	0.000	0.007	0.008	0.001
7946.4	-0.000	-0.001	-0.000	0.003	0.007	-0.000	0.010	0.010	0.002
9001.9	-0.000	-0.001	-0.000	0.003	0.008	0.000	0.014	0.013	0.003
9870.2	0.000	-0.001	0.000	0.004	0.010	0.003	0.018	0.015	0.005
10908.7	0.000	-0.001	0.000	0.004	0.012	0.007	0.022	0.018	0.006
11840.8	0.000	-0.000	0.000	0.005	0.014	0.011	0.027	0.022	0.008
12900.6	-0.000	-0.000	0.000	0.005	0.017	0.017	0.034	0.026	0.010
13717.8	-0.000	-0.000	0.001	0.006	0.019	0.021	0.039	0.031	0.012
14518.0	0.000	-0.000	0.001	0.006	0.022	0.028	0.048	0.038	0.015
15271.4	-0.000	-0.000	0.000	0.007	0.028	0.038	0.059	0.049	0.020
16097.1	0.000	-0.001	0.001	0.008	0.034	0.048	0.073	0.061	0.027
17539.9	-0.000	-0.003	-0.001	0.012	0.056	0.079	0.109	0.094	0.044
18727.4	-0.000	-0.003	-0.001	0.014	0.064	0.089	0.120	0.103	0.049
19531.8	0.000	-0.004	-0.001	0.015	0.070	0.096	0.128	0.110	0.052
20591.6	-0.000	-0.008	-0.002	0.022	0.096	0.130	0.165	0.146	0.077
21762.1	-0.000	-0.008	-0.002	0.024	0.103	0.138	0.174	0.153	0.082
21800.4	-0.000	-0.010	-0.002	0.031	0.127	0.167	0.205	0.183	0.105
23260.3	-0.000	-0.020	0.002	0.098	0.259	0.317	0.361	0.329	0.220
24728.7	0.000	-0.019	0.003	0.100	0.266	0.326	0.371	0.337	0.225
24643.6	-0.000	-0.020	0.003	0.111	0.286	0.348	0.393	0.358	0.242
25801.3	-0.000	-0.018	0.035	0.222	0.468	0.552	0.609	0.565	0.423
26844.0	-0.000	-0.010	0.079	0.304	0.601	0.694	0.758	0.709	0.553
28218.8	-0.000	-0.009	0.084	0.313	0.614	0.711	0.773	0.723	0.561
29397.8	-0.000	-0.003	0.123	0.381	0.724	0.831	0.897	0.843	0.665
30542.7	-0.000	-0.002	0.127	0.389	0.736	0.845	0.911	0.855	0.674
31466.3	-0.000	0.006	0.148	0.425	0.793	0.904	0.973	0.912	0.721
32492.1	-0.000	0.007	0.152	0.433	0.807	0.921	0.989	0.926	0.731
33258.2	-0.000	0.009	0.164	0.457	0.846	0.967	1.033	0.969	0.769
14254.1	-0.000	0.031	0.229	0.549	0.930	1.038	1.083	1.016	0.830
208.6	-0.000	0.048	0.226	0.465	0.725	0.818	0.762	0.737	0.631

2S	1N	2N	4N	6N	8N	10N	12N	14N
-4.3	0.000	-0.000	-0.001	-0.003	-0.000	0.000	0.001	0.000

1149.2	0.000	0.000	-0.001	-0.003	-0.000	0.000	0.001	-0.000
2021.7	0.000	0.000	-0.001	-0.003	-0.000	0.000	0.001	-0.000
2885.7	0.001	0.001	-0.001	-0.003	-0.000	-0.000	0.001	-0.000
3962.6	0.001	0.001	-0.001	-0.003	-0.000	0.000	0.001	0.000
4852.1	0.001	0.001	-0.001	-0.003	-0.000	0.000	0.001	0.000
5860.8	0.002	0.002	-0.000	-0.003	-0.000	0.000	0.001	0.000
6814.2	0.003	0.002	0.000	-0.003	-0.000	0.000	0.001	-0.000
7946.4	0.004	0.003	0.000	-0.003	-0.000	0.000	0.001	-0.000
9001.9	0.004	0.003	0.000	-0.003	-0.000	0.000	0.001	-0.000
9870.2	0.005	0.003	0.001	-0.003	-0.000	0.000	0.001	-0.000
10908.7	0.006	0.004	0.001	-0.002	-0.000	0.000	0.001	-0.000
11840.8	0.007	0.004	0.001	-0.002	-0.000	0.000	0.001	-0.000
12900.6	0.008	0.004	0.001	-0.002	-0.000	-0.000	0.001	-0.000
13717.8	0.009	0.005	0.001	-0.002	-0.000	0.000	0.001	-0.000
14518.0	0.010	0.006	0.001	-0.002	-0.000	0.000	0.001	-0.000
15271.4	0.013	0.006	0.001	-0.003	-0.000	0.000	0.001	-0.000
16097.1	0.017	0.007	-0.001	-0.004	-0.000	0.000	0.001	-0.000
17539.9	0.028	0.011	-0.005	-0.008	-0.000	0.000	0.001	-0.000
18727.4	0.031	0.012	-0.005	-0.009	-0.000	0.000	0.001	-0.000
19531.8	0.034	0.013	-0.006	-0.010	-0.001	0.000	0.001	-0.000
20591.6	0.051	0.022	-0.009	-0.016	-0.001	0.000	0.001	-0.000
21762.1	0.054	0.023	-0.009	-0.016	-0.001	0.000	0.001	-0.000
21800.4	0.070	0.030	-0.012	-0.021	-0.001	0.000	0.001	-0.000
23260.3	0.153	0.070	-0.012	-0.035	-0.008	-0.000	0.000	-0.000
24728.7	0.156	0.071	-0.012	-0.036	-0.009	0.000	0.000	-0.000
24643.6	0.170	0.079	-0.011	-0.037	-0.010	0.000	0.000	-0.000
25801.3	0.328	0.188	0.030	-0.034	-0.019	0.000	-0.001	0.000
26844.0	0.437	0.269	0.069	-0.023	-0.021	0.000	-0.002	0.000
28218.8	0.443	0.273	0.070	-0.023	-0.021	-0.000	-0.002	0.000
29397.8	0.527	0.334	0.098	-0.015	-0.021	0.000	-0.002	0.000
30542.7	0.532	0.336	0.099	-0.015	-0.021	-0.000	-0.002	0.000
31466.3	0.568	0.361	0.108	-0.014	-0.022	-0.000	-0.003	0.000
32492.1	0.575	0.366	0.110	-0.013	-0.022	0.000	-0.003	0.000
33258.2	0.602	0.385	0.117	-0.012	-0.022	0.000	-0.003	0.000
14254.1	0.663	0.439	0.146	-0.003	-0.022	-0.000	-0.003	0.001
208.6	0.540	0.383	0.154	0.011	-0.022	0.000	-0.003	0.001

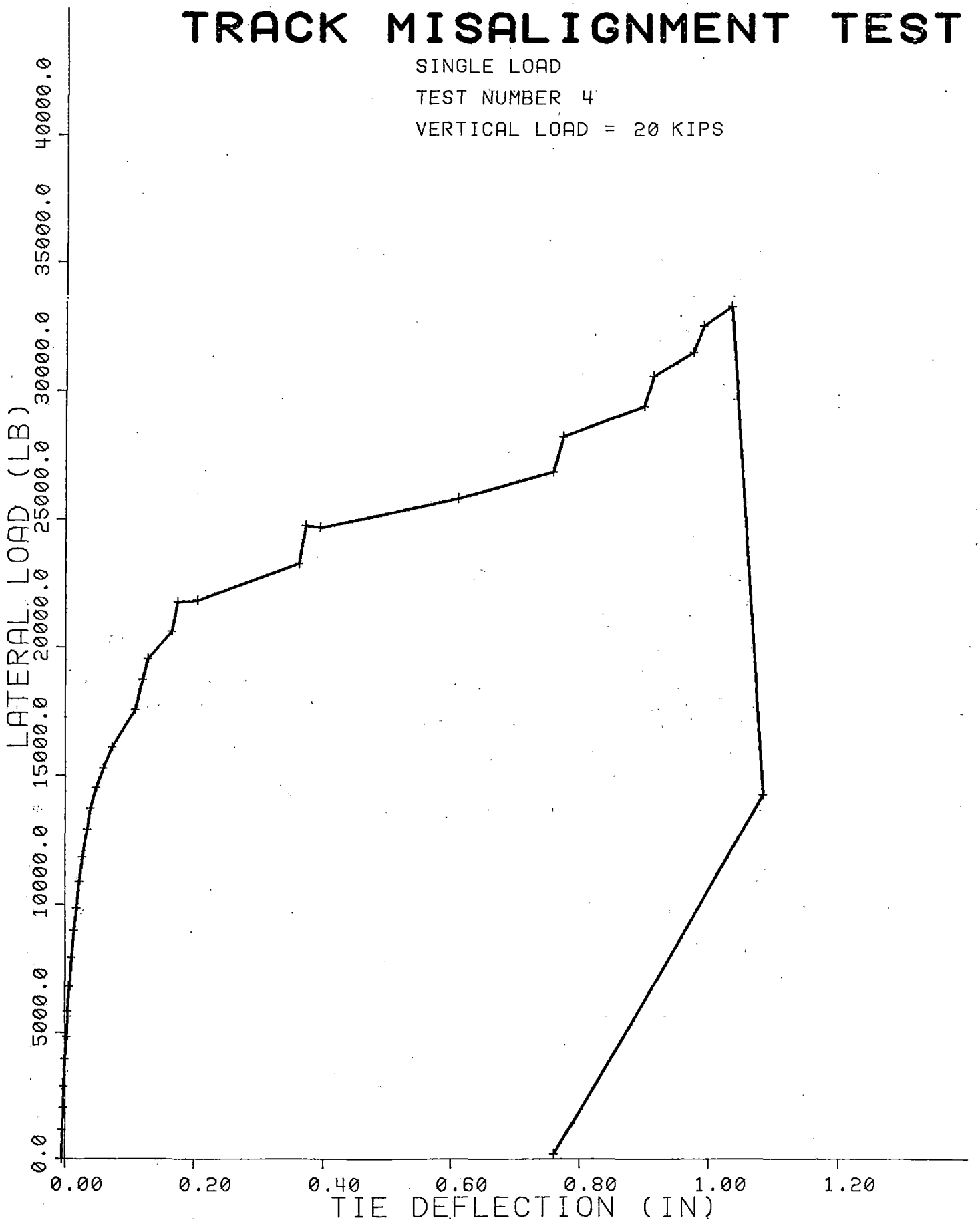
APPLIED VERTICAL LOAD = 19899.75 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

SINGLE LOAD

TEST NUMBER 4

VERTICAL LOAD = 20 KIPS



TRACK MISALIGNMENT
ADJACENT LATERAL LOAD
TEST NUMBER 1
VERTICAL LOAD 0 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
991.7	0.000	-0.000	-0.000	0.000	0.003	0.000	0.011	0.009	0.005
1642.9	0.000	-0.000	-0.001	0.002	0.012	0.000	0.033	0.030	0.022
2570.8	0.000	-0.001	-0.001	0.012	0.043	0.034	0.086	0.081	0.067
3758.3	0.000	-0.004	-0.001	0.033	0.099	0.107	0.174	0.170	0.151
4618.0	0.000	-0.013	0.002	0.080	0.196	0.224	0.306	0.308	0.280
5537.4	0.000	-0.017	0.007	0.155	0.334	0.386	0.479	0.486	0.440
6563.1	0.000	-0.016	0.033	0.229	0.471	0.546	0.650	0.664	0.600
7699.5	0.000	-0.012	0.087	0.332	0.654	0.757	0.877	0.906	0.836
8448.6	0.000	-0.001	0.129	0.405	0.779	0.901	1.042	1.089	1.025
204.3	0.000	0.005	0.136	0.387	0.720	0.850	0.880	0.924	0.881

2S	1N	2N	4N	6N	8N	10N	12N	14N
991.7	0.002	0.003	0.001	0.001	0.000	0.000	-0.000	0.000
1642.9	0.013	0.009	0.001	0.001	0.000	0.000	0.000	0.000
2570.8	0.050	0.035	0.004	0.000	0.001	0.000	0.000	0.000
3758.3	0.122	0.091	0.015	-0.000	0.001	0.000	0.000	0.000
4618.0	0.238	0.185	0.056	0.003	0.001	0.000	0.000	0.000
5537.4	0.380	0.299	0.109	0.012	0.000	0.000	-0.001	0.001
6563.1	0.522	0.419	0.181	0.038	-0.001	0.000	-0.003	0.000
7699.5	0.750	0.632	0.339	0.123	0.017	0.000	-0.009	-0.002
8448.6	0.942	0.815	0.494	0.224	0.055	0.000	-0.013	-0.006
204.3	0.811	0.709	0.451	0.221	0.056	0.000	-0.014	-0.008

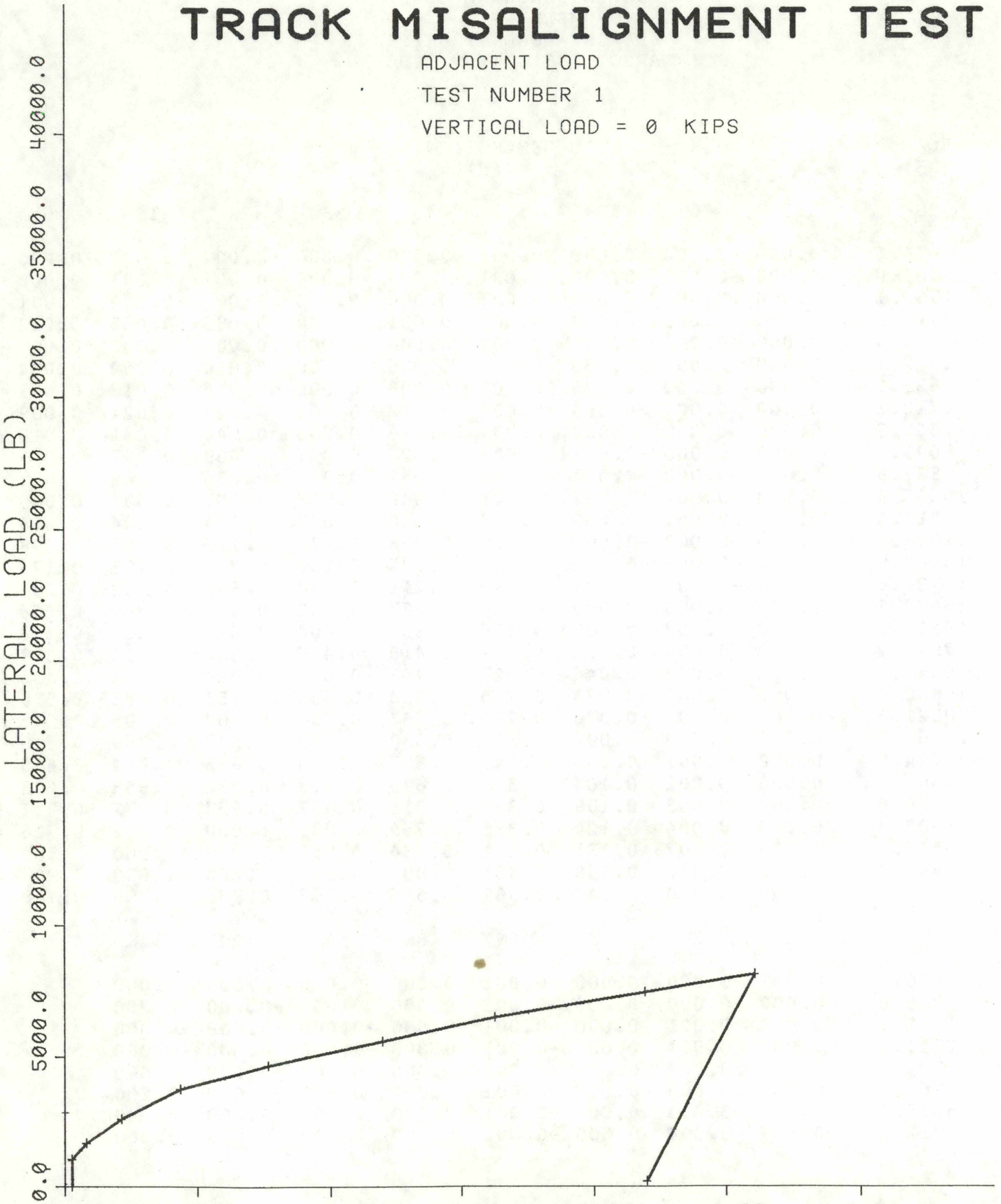
APPLIED VERTICAL LOAD = -23.90 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

ADJACENT LOAD

TEST NUMBER 1

VERTICAL LOAD = 0 KIPS



TRACK MISALIGNMENT
ADJACENT LATERAL LOAD
TEST NUMBER 2
VERTICAL LOAD 10 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
-76.6	0.000	-0.000	0.000	0.001	-0.000	0.000	-0.002	0.000	-0.000
906.6	0.000	-0.000	0.000	0.001	-0.000	0.000	-0.001	0.001	0.000
1762.1	0.000	-0.000	0.000	0.001	0.000	0.000	0.001	0.002	0.001
2711.2	0.000	0.000	0.000	0.001	0.001	0.000	0.003	0.003	0.002
3702.9	0.000	0.000	0.000	0.002	0.003	0.000	0.006	0.006	0.003
4762.7	0.000	0.000	0.000	0.002	0.005	0.000	0.010	0.009	0.004
5635.2	0.000	0.000	0.000	0.002	0.008	0.000	0.016	0.013	0.007
6712.1	0.000	0.000	0.000	0.003	0.013	0.000	0.027	0.021	0.009
7669.7	0.000	0.000	0.000	0.004	0.019	0.005	0.040	0.031	0.015
8691.2	0.000	0.000	-0.001	0.005	0.027	0.021	0.059	0.047	0.023
9597.8	0.000	-0.000	-0.001	0.007	0.031	0.036	0.076	0.062	0.031
10555.4	0.000	-0.001	-0.002	0.011	0.040	0.058	0.101	0.084	0.045
11713.1	0.000	-0.001	-0.002	0.016	0.050	0.077	0.124	0.104	0.058
12632.5	0.000	-0.002	-0.002	0.026	0.093	0.130	0.183	0.158	0.098
13568.9	0.000	-0.003	-0.002	0.039	0.125	0.169	0.226	0.195	0.128
14726.6	0.000	-0.006	-0.001	0.085	0.211	0.268	0.333	0.292	0.207
15675.7	0.000	-0.006	0.000	0.126	0.277	0.342	0.413	0.362	0.266
16710.0	0.000	-0.007	0.009	0.156	0.332	0.404	0.481	0.423	0.318
17876.2	-0.000	-0.004	0.033	0.207	0.418	0.498	0.582	0.515	0.399
18642.3	0.000	-0.003	0.044	0.227	0.453	0.537	0.624	0.551	0.430
19800.0	0.000	-0.001	0.074	0.285	0.558	0.656	0.751	0.675	0.539
20821.5	0.000	-0.001	0.076	0.290	0.567	0.667	0.762	0.685	0.545
21664.2	0.000	0.000	0.091	0.323	0.630	0.742	0.847	0.768	0.619
22724.0	0.000	0.001	0.098	0.341	0.667	0.785	0.895	0.814	0.660
23566.7	0.000	0.002	0.104	0.356	0.695	0.818	0.933	0.853	0.693
24426.5	0.000	0.003	0.109	0.365	0.711	0.837	0.953	0.872	0.711
25503.3	0.000	0.004	0.120	0.388	0.750	0.882	1.000	0.922	0.756
26546.1	0.000	0.007	0.131	0.411	0.784	0.919	1.039	0.960	0.787
11466.3	0.000	0.010	0.148	0.431	0.801	0.946	1.068	1.030	0.906
76.6	0.000	0.020	0.147	0.369	0.645	0.772	0.795	0.798	0.748

2S	1N	2N	4N	6N	8N	10N	12N	14N
-76.6	0.001	0.000	0.000	-0.001	-0.000	-0.000	-0.000	-0.000
906.6	0.002	0.000	0.000	-0.001	-0.000	0.000	-0.000	0.000
1762.1	0.002	0.001	0.000	-0.001	-0.000	-0.000	-0.000	-0.000
2711.2	0.003	0.001	0.000	-0.001	-0.000	-0.000	-0.000	-0.000
3702.9	0.004	0.002	0.000	-0.001	-0.000	0.000	-0.000	-0.000
4762.7	0.005	0.003	-0.000	-0.001	-0.000	0.000	-0.000	-0.000
5635.2	0.006	0.003	0.000	-0.001	-0.000	0.000	-0.000	-0.000
6712.1	0.007	0.004	0.000	-0.001	-0.000	0.000	-0.000	-0.000

7669.7	0.008	0.005	0.000	-0.000	-0.000	0.000	0.191	-0.000
8691.2	0.012	0.006	0.000	-0.000	-0.000	0.000	-0.000	-0.000
9597.8	0.016	0.007	0.000	-0.000	-0.000	0.000	-0.000	0.166
10555.4	0.023	0.010	0.000	-0.000	-0.000	0.000	-0.000	-0.001
11713.1	0.032	0.012	0.000	0.000	-0.000	0.000	-0.000	-0.001
12632.5	0.058	0.026	-0.000	-0.001	-0.000	-0.000	-0.000	-0.001
13568.9	0.078	0.036	-0.000	-0.003	0.000	0.000	-0.000	-0.001
14726.6	0.135	0.071	0.000	-0.011	-0.000	-0.000	-0.000	-0.001
15675.7	0.178	0.098	-0.000	-0.018	-0.002	-0.000	-0.000	-0.001
16710.0	0.218	0.123	0.000	-0.026	-0.008	-0.000	-0.000	-0.001
17876.2	0.283	0.165	-0.000	-0.038	-0.024	-0.000	-0.001	-0.001
18642.3	0.306	0.179	0.000	-0.042	-0.028	-0.000	-0.001	-0.001
19800.0	0.393	0.240	-0.000	-0.053	-0.046	-0.000	-0.001	-0.002
20821.5	0.397	0.242	0.000	-0.054	-0.048	-0.000	-0.001	-0.002
21664.2	0.457	0.284	0.007	-0.058	-0.057	-0.000	-0.001	-0.003
22724.0	0.487	0.306	0.012	-0.061	-0.061	-0.000	-0.002	-0.003
23566.7	0.514	0.324	0.018	-0.062	-0.064	-0.000	-0.003	-0.003
24426.5	0.527	0.332	0.020	-0.063	-0.066	-0.000	-0.003	-0.003
25503.3	0.565	0.362	0.034	-0.064	-0.070	-0.000	-0.004	-0.003
26546.1	0.589	0.377	0.039	-0.064	-0.071	0.000	-0.004	-0.004
11466.3	0.753	0.569	0.212	0.008	-0.064	-0.000	-0.016	-0.007
76.6	0.653	0.531	0.229	0.033	-0.055	0.000	-0.016	-0.008

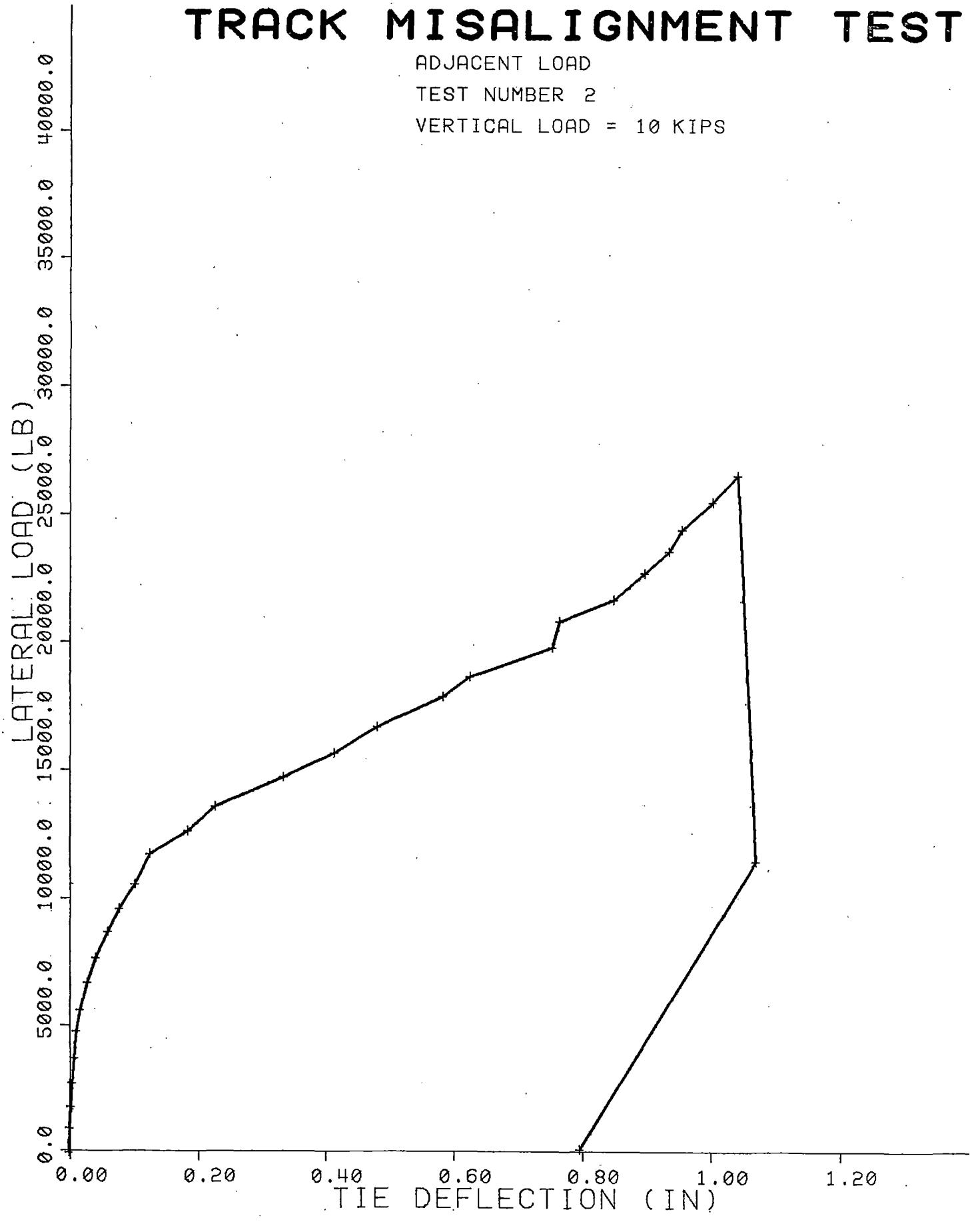
APPLIED VERTICAL LOAD = 9668.65 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

ADJACENT LOAD

TEST NUMBER 2

VERTICAL LOAD = 10 KIPS



TRACK MISALIGNMENT
ADJACENT LATERAL LOAD
TEST NUMBER 3
VERTICAL LOAD 30 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
	2S	13S	10S	8S	6S	4S	3S	2S	1S	0
1872.7	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.002	0.000
3907.2	-0.000	0.001	0.000	0.001	0.001	0.000	0.004	0.004	-0.000
5941.7	0.000	0.001	0.000	0.002	0.003	0.000	0.007	0.006	-0.000
7993.2	0.000	0.001	0.001	0.003	0.005	0.000	0.010	0.009	0.000
9959.6	0.000	0.001	0.001	0.003	0.007	0.000	0.014	0.011	0.001
10874.7	0.000	0.001	0.001	0.004	0.008	0.000	0.017	0.013	0.001
11917.4	0.000	0.001	0.001	0.004	0.009	0.000	0.019	0.015	0.001
13007.0	0.000	0.001	0.002	0.004	0.011	0.000	0.022	0.016	0.001
13913.6	0.000	0.001	0.002	0.005	0.012	0.000	0.024	0.018	0.001
14884.0	0.000	0.002	0.002	0.005	0.014	0.001	0.027	0.020	0.002
15931.1	0.000	0.002	0.002	0.006	0.015	0.004	0.030	0.022	0.003
16867.4	0.000	0.002	0.002	0.006	0.017	0.006	0.033	0.024	0.004
17940.0	0.000	0.002	0.002	0.006	0.019	0.010	0.036	0.026	0.005
18901.9	0.000	0.002	0.003	0.007	0.021	0.013	0.040	0.029	0.006
19876.6	0.000	0.002	0.003	0.007	0.023	0.016	0.044	0.031	0.008
20842.8	0.000	0.002	0.003	0.007	0.025	0.021	0.048	0.034	0.009
21911.1	0.000	0.001	0.003	0.008	0.029	0.026	0.054	0.038	0.011
22809.1	0.000	0.001	0.003	0.008	0.032	0.030	0.059	0.042	0.012
23626.3	0.000	0.001	0.003	0.008	0.035	0.036	0.064	0.045	0.014
24452.0	0.000	0.001	0.003	0.009	0.040	0.043	0.073	0.051	0.016
25826.8	0.000	-0.001	0.004	0.013	0.066	0.080	0.110	0.080	0.026
27244.1	0.000	-0.001	0.004	0.014	0.070	0.084	0.115	0.083	0.027
27950.7	0.000	-0.003	0.004	0.016	0.072	0.087	0.118	0.085	0.028
28733.8	0.000	-0.003	0.004	0.016	0.077	0.093	0.124	0.091	0.030
29997.9	0.000	-0.009	0.007	0.065	0.172	0.195	0.221	0.166	0.064
31096.0	0.000	-0.009	0.007	0.067	0.174	0.199	0.225	0.169	0.066
32053.7	0.000	-0.009	0.008	0.067	0.177	0.202	0.228	0.170	0.067
32870.9	0.000	-0.009	0.008	0.069	0.180	0.206	0.232	0.174	0.069
33751.9	0.000	-0.000	0.051	0.201	0.364	0.392	0.408	0.316	0.158
35113.9	0.000	0.000	0.053	0.204	0.369	0.399	0.414	0.320	0.161
35858.7	0.000	0.001	0.054	0.206	0.373	0.404	0.417	0.322	0.162
8325.2	0.000	0.013	0.100	0.288	0.476	0.523	0.565	0.531	0.420
229.8	0.000	0.020	0.110	0.271	0.428	0.509	0.448	0.438	0.368

	2S	1N	2N	4N	6N	8N	10N	12N	14N
1872.7	0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.000
3907.2	0.002	0.000	0.000	0.000	0.000	-0.000	0.000	-0.000
5941.7	0.003	0.001	0.000	0.001	0.000	-0.000	0.000	-0.000
7993.2	0.004	0.002	0.000	0.001	0.000	0.000	0.000	-0.000
9959.6	0.006	0.003	0.000	0.001	0.000	0.000	0.000	-0.000

10874.7	0.006	0.003	0.000	0.001	0.000	0.000	0.000	-0.000
11917.4	0.007	0.004	0.000	0.001	0.000	0.000	0.000	-0.000
13007.0	0.007	0.004	0.000	0.001	0.000	0.000	0.000	-0.000
13913.6	0.008	0.005	0.000	0.002	0.000	0.000	0.000	-0.000
14884.0	0.009	0.005	0.000	0.002	0.000	0.000	0.000	-0.000
15931.1	0.010	0.006	0.000	0.002	0.000	0.000	0.000	-0.000
16867.4	0.010	0.006	0.000	0.002	0.000	0.000	0.000	-0.000
17940.0	0.011	0.007	0.000	0.002	0.000	0.000	0.000	-0.001
18901.9	0.012	0.007	0.000	0.002	0.000	-0.000	0.000	-0.001
19876.6	0.012	0.008	0.000	0.002	0.000	-0.000	0.000	-0.001
20842.8	0.013	0.008	0.000	0.001	0.000	-0.000	-0.000	-0.001
21911.1	0.014	0.009	0.000	0.001	-0.000	-0.000	-0.000	-0.001
22809.1	0.015	0.009	0.000	0.001	-0.000	-0.000	-0.001	-0.001
23626.3	0.016	0.010	0.000	0.000	-0.001	-0.000	-0.001	-0.001
24452.0	0.016	0.010	0.000	0.000	-0.001	-0.000	-0.001	-0.001
25826.8	0.019	0.011	0.000	0.000	-0.001	-0.000	-0.001	-0.001
27244.1	0.021	0.011	0.000	0.000	-0.001	-0.000	-0.001	-0.001
27950.7	0.021	0.011	0.000	0.000	-0.001	-0.000	-0.001	-0.001
28733.8	0.022	0.012	0.000	0.001	-0.001	-0.000	-0.001	-0.001
29997.9	0.033	0.012	0.000	0.001	-0.001	-0.000	-0.001	-0.001
31096.0	0.035	0.014	0.000	0.001	-0.001	-0.000	-0.001	-0.001
32053.7	0.036	0.014	0.000	0.001	-0.001	-0.000	-0.001	-0.001
32870.9	0.037	0.014	0.000	0.001	-0.001	-0.000	-0.001	-0.001
33751.9	0.077	0.023	0.000	0.001	-0.001	-0.000	-0.001	-0.001
35113.9	0.079	0.024	0.000	0.001	-0.001	-0.000	-0.001	-0.001
35858.7	0.080	0.025	0.000	0.001	-0.001	-0.000	-0.001	-0.001
8325.2	0.343	0.251	0.034	-0.015	-0.029	-0.000	-0.001	-0.001
229.8	0.312	0.241	0.044	-0.011	-0.028	-0.000	-0.001	-0.001

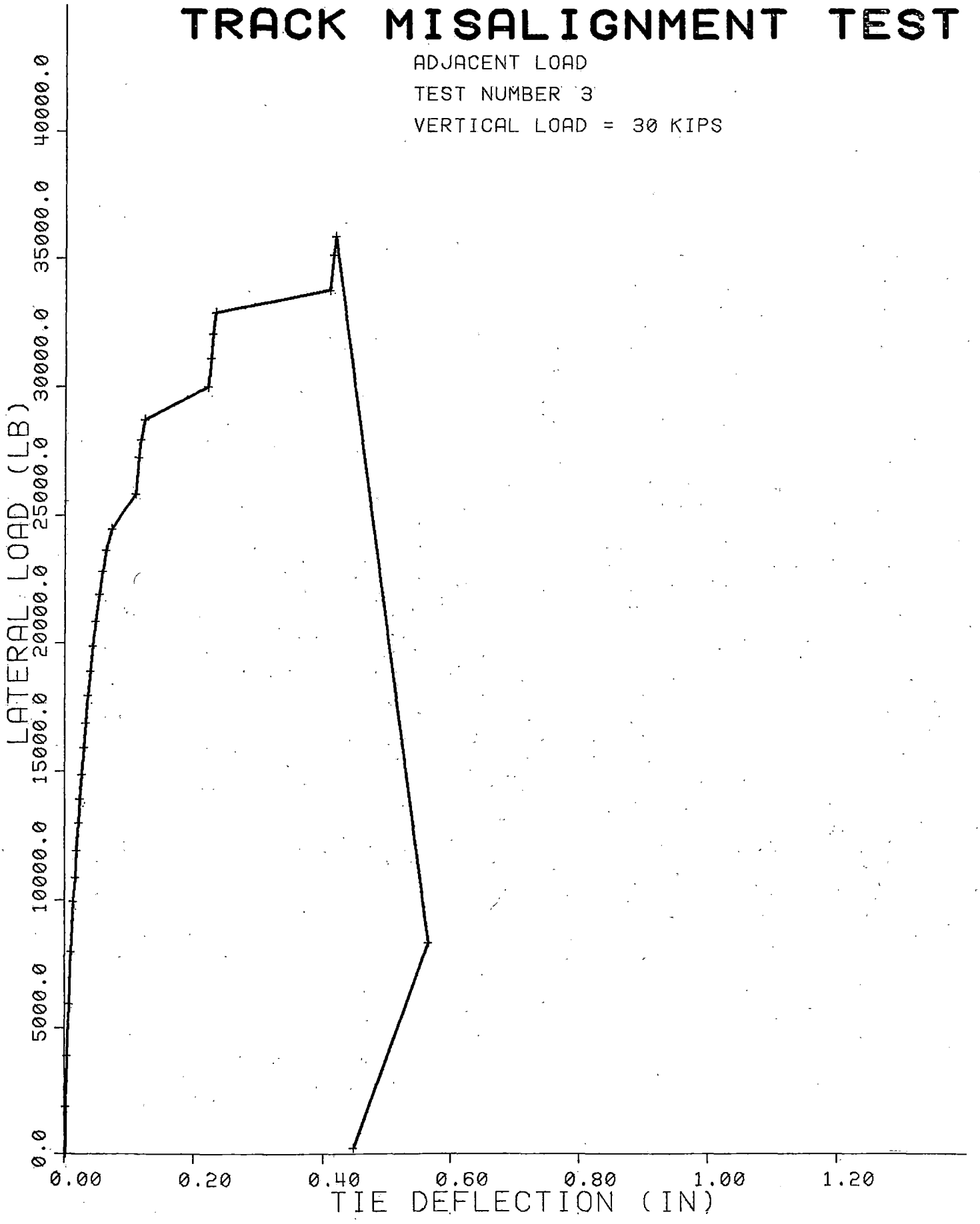
APPLIED VERTICAL LOAD = 30153.28 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

ADJACENT LOAD

TEST NUMBER 3

VERTICAL LOAD = 30 KIPS



TRACK MISALIGNMENT
ADJACENT LATERAL LOAD
TEST NUMBER 4
VERTICAL LOAD 30 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
	2S	13S	10S	8S	6S	4S	3S	2S	1S	0
-76.6	0.000	-0.006	-0.002	0.000	-0.001	0.000	-0.004	-0.001	0.000
987.4	0.000	-0.006	-0.002	0.001	-0.001	0.000	-0.003	0.001	0.000
1957.9	0.000	-0.006	-0.002	0.001	0.000	0.000	-0.002	0.002	0.000
3622.1	0.000	-0.005	-0.002	0.002	0.002	0.001	0.001	0.005	0.000
5375.6	0.000	-0.005	-0.002	0.002	0.004	0.003	0.005	0.009	0.002
7537.8	0.000	-0.005	-0.002	0.003	0.006	0.005	0.010	0.013	0.007
9359.4	0.000	-0.004	-0.001	0.004	0.009	0.009	0.014	0.017	0.011
10342.6	0.000	-0.004	-0.001	0.005	0.010	0.011	0.017	0.019	0.012
11419.5	0.000	-0.004	-0.001	0.006	0.012	0.014	0.020	0.022	0.015
12572.9	0.000	-0.003	-0.001	0.006	0.014	0.016	0.023	0.024	0.018
13462.5	0.000	-0.003	-0.001	0.007	0.015	0.019	0.027	0.027	0.020
14475.4	0.000	-0.003	-0.000	0.008	0.017	0.022	0.030	0.030	0.022
15382.0	0.000	-0.003	-0.000	0.008	0.019	0.024	0.033	0.033	0.025
16399.3	0.000	-0.003	-0.000	0.008	0.021	0.027	0.038	0.036	0.028
17369.7	0.000	-0.003	-0.000	0.009	0.023	0.031	0.042	0.040	0.031
18369.9	0.000	-0.002	0.000	0.010	0.025	0.035	0.046	0.044	0.034
19331.8	0.000	-0.002	0.001	0.010	0.028	0.039	0.051	0.049	0.038
20361.8	0.000	-0.002	0.001	0.011	0.031	0.044	0.058	0.054	0.043
21319.5	0.000	-0.001	0.001	0.012	0.034	0.049	0.064	0.060	0.049
22234.5	0.000	-0.001	0.001	0.012	0.038	0.056	0.072	0.068	0.056
23124.1	0.000	-0.001	0.001	0.013	0.042	0.063	0.080	0.077	0.064
23613.6	0.000	-0.002	0.001	0.014	0.047	0.072	0.093	0.091	0.076
25230.9	0.000	-0.006	-0.002	0.019	0.083	0.125	0.158	0.160	0.142
26278.0	0.000	-0.006	-0.002	0.020	0.087	0.131	0.165	0.167	0.150
26639.7	0.000	-0.007	-0.003	0.021	0.093	0.141	0.178	0.182	0.162
26405.7	0.000	-0.017	-0.004	0.050	0.178	0.246	0.296	0.305	0.266
27801.7	-0.000	-0.024	0.003	0.129	0.333	0.434	0.503	0.515	0.464
28401.8	0.000	-0.023	0.024	0.214	0.488	0.612	0.700	0.719	0.656
29444.6	0.000	-0.017	0.061	0.296	0.624	0.765	0.865	0.888	0.819
31645.1	0.000	-0.012	0.097	0.366	0.748	0.907	1.028	1.065	0.998
7950.6	-0.000	0.002	0.158	0.459	0.859	1.015	1.135	1.187	1.112
17.0	0.000	0.011	0.165	0.433	0.775	0.904	0.940	0.988	0.934

	2S	1N	2N	4N	6N	8N	10N	12N	14N
-76.6	0.002	-0.000	0.000	-0.004	-0.002	0.000	0.001	0.001
987.4	0.005	0.002	0.000	-0.004	-0.002	0.000	0.001	0.001
1957.9	0.006	0.004	0.000	-0.003	-0.002	0.000	0.001	0.001
3622.1	0.009	0.008	0.000	-0.003	-0.002	0.000	0.001	0.001
5375.6	0.013	0.012	0.000	-0.001	-0.001	0.000	0.002	0.001
7537.8	0.018	0.018	0.000	-0.000	-0.001	0.000	0.002	0.001

9359.4	0.023	0.023	0.000	0.001	-0.001	0.000	0.003	0.001
10342.6	0.026	0.025	-0.000	0.001	-0.001	0.000	0.003	0.001
11419.5	0.028	0.029	-0.000	0.002	-0.001	0.000	0.003	0.001
12572.9	0.032	0.033	0.000	0.002	-0.001	0.000	0.003	0.001
13462.5	0.035	0.036	-0.000	0.003	-0.000	0.000	0.003	0.001
14475.4	0.038	0.039	0.000	0.003	0.000	0.000	0.004	0.001
15382.0	0.041	0.043	0.000	0.003	0.000	0.000	0.004	0.001
16399.3	0.045	0.046	0.000	0.004	0.000	0.000	0.004	0.001
17369.7	0.049	0.050	0.000	0.004	0.001	-0.000	0.004	0.001
18369.9	0.054	0.055	0.000	0.005	0.001	0.000	0.004	0.001
19331.8	0.058	0.060	0.000	0.005	0.001	0.000	0.004	0.001
20361.8	0.065	0.066	0.000	0.006	0.001	0.000	0.004	0.001
21319.5	0.071	0.072	0.000	0.006	0.002	0.000	0.005	0.001
22234.5	0.079	0.079	0.000	0.006	0.002	0.000	0.005	0.001
23124.1	0.087	0.086	0.000	0.005	0.001	0.000	0.005	0.001
23613.6	0.098	0.095	0.000	0.005	0.001	0.000	0.005	0.001
25230.9	0.160	0.144	0.000	0.001	-0.002	0.000	0.005	0.001
26278.0	0.170	0.153	0.004	0.001	-0.003	-0.000	0.005	0.001
26639.7	0.183	0.164	0.007	0.001	-0.004	0.000	0.005	0.001
26405.7	0.276	0.233	0.029	-0.004	-0.018	0.000	0.005	0.001
27801.7	0.456	0.386	0.109	0.010	-0.026	-0.000	0.001	-0.000
28401.8	0.633	0.542	0.206	0.047	-0.025	-0.000	-0.004	-0.002
29444.6	0.787	0.679	0.300	0.092	-0.012	-0.000	-0.007	-0.003
31645.1	0.964	0.844	0.420	0.154	0.004	-0.000	-0.010	-0.006
7950.6	1.056	0.928	0.517	0.227	0.016	-0.000	-0.014	-0.009
17.0	0.896	0.799	0.488	0.221	0.022	-0.000	-0.015	-0.010

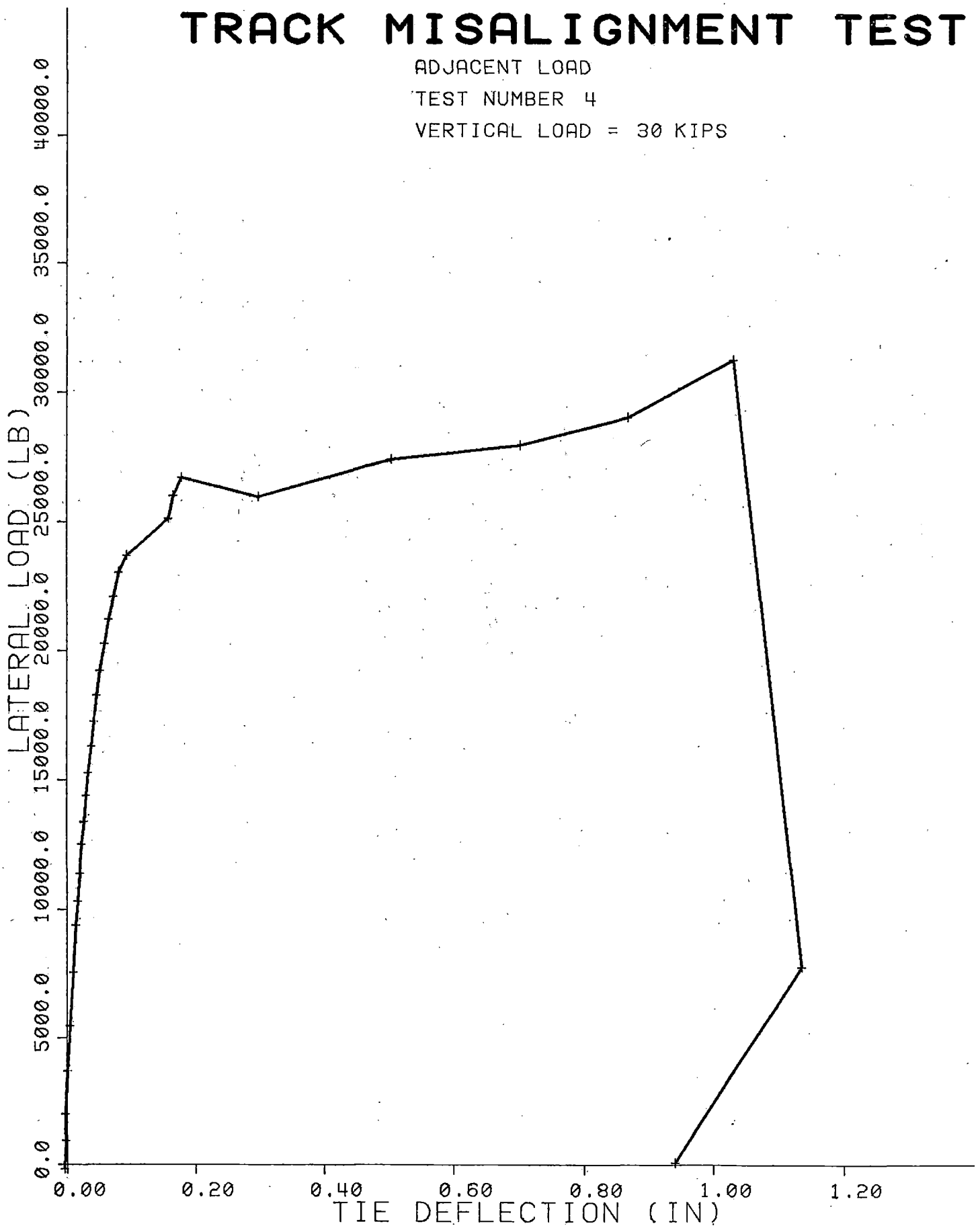
APPLIED VERTICAL LOAD = 30224.99 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

ADJACENT LOAD

TEST NUMBER 4

VERTICAL LOAD = 30 KIPS



TRACK MISALIGNMENT
ADJACENT LATERAL LOAD
TEST NUMBER 5
VERTICAL LOAD 20 KIPS
TARGET DEFLECTION 1.00 IN.

LOAD (LB)	TIE DEFLECTION (IN)								
2S	13S	10S	8S	6S	4S	3S	2S	1S	0
1889.8	0.000	0.000	-0.000	0.001	0.001	0.000	0.003	0.002	0.002
4013.6	-0.000	0.001	0.000	0.002	0.003	0.000	0.006	0.005	0.004
5941.7	-0.000	0.001	0.000	0.003	0.004	0.000	0.011	0.008	0.006
8129.4	0.000	0.001	0.000	0.003	0.007	0.000	0.016	0.012	0.008
9912.8	-0.000	0.001	0.000	0.004	0.011	0.000	0.025	0.017	0.010
10951.3	-0.000	0.001	0.000	0.004	0.014	-0.000	0.030	0.020	0.012
12006.8	-0.000	0.001	-0.000	0.004	0.018	0.000	0.038	0.026	0.014
13024.1	0.000	-0.000	-0.002	0.005	0.027	0.011	0.053	0.037	0.018
13939.2	0.000	-0.001	-0.003	0.005	0.033	0.020	0.065	0.046	0.022
14947.9	-0.000	-0.002	-0.005	0.007	0.044	0.034	0.079	0.057	0.027
16037.5	-0.000	-0.005	-0.007	0.012	0.068	0.065	0.112	0.083	0.040
17059.0	0.000	-0.005	-0.007	0.012	0.072	0.071	0.118	0.088	0.042
18025.1	0.000	-0.011	-0.008	0.033	0.128	0.135	0.182	0.140	0.072
19263.7	0.000	-0.012	-0.008	0.034	0.132	0.141	0.189	0.145	0.075
20000.0	-0.000	-0.017	-0.007	0.069	0.197	0.210	0.257	0.203	0.111
21085.4	-0.000	-0.017	-0.007	0.073	0.207	0.222	0.269	0.212	0.115
22004.7	0.000	-0.016	-0.003	0.129	0.293	0.313	0.358	0.284	0.162
23251.8	-0.000	-0.016	-0.003	0.133	0.301	0.324	0.369	0.292	0.166
23983.9	0.000	-0.016	-0.001	0.138	0.310	0.335	0.381	0.300	0.170
24796.8	0.000	-0.014	0.018	0.186	0.385	0.417	0.467	0.377	0.232
26039.6	0.000	-0.013	0.020	0.190	0.392	0.426	0.477	0.384	0.236
26835.5	0.000	-0.006	0.059	0.264	0.503	0.549	0.602	0.493	0.323
27818.7	-0.000	-0.001	0.083	0.302	0.550	0.605	0.654	0.535	0.355
28984.9	-0.000	0.008	0.126	0.371	0.652	0.714	0.763	0.634	0.437
30036.2	-0.000	0.009	0.132	0.382	0.669	0.734	0.781	0.649	0.446
31287.5	-0.000	0.024	0.178	0.461	0.783	0.857	0.913	0.773	0.549
32262.2	-0.000	0.025	0.180	0.465	0.788	0.862	0.917	0.775	0.551
33083.7	-0.000	0.025	0.181	0.467	0.791	0.866	0.921	0.779	0.553
33666.8	-0.000	0.029	0.199	0.505	0.856	0.943	1.001	0.857	0.621
11943.0	-0.000	0.032	0.210	0.523	0.883	0.995	1.080	1.009	0.845
315.0	-0.002	0.044	0.209	0.456	0.715	0.804	0.796	0.766	0.677

2S	1N	2N	4N	6N	8N	10N	12N	14N
1889.8	0.001	0.001	-0.000	0.000	0.000	0.000	0.000	0.000
4013.6	0.003	0.002	0.000	0.000	0.000	0.000	-0.000	-0.000
5941.7	0.004	0.003	0.000	0.001	0.000	0.000	-0.000	0.000
8129.4	0.006	0.005	0.000	0.001	0.001	0.000	0.000	0.000
9912.8	0.007	0.006	0.000	0.001	0.001	0.000	0.000	-0.000
10951.3	0.008	0.006	0.000	0.001	0.001	-0.000	-0.000	-0.000
12006.8	0.009	0.006	0.000	0.001	0.001	0.000	-0.000	-0.000

13024.1	0.010	0.007	0.000	0.001	0.001	0.000	0.000	-0.000
13939.2	0.011	0.007	0.000	0.001	0.001	0.000	-0.000	-0.000
14947.9	0.013	0.008	-0.000	0.001	0.001	0.000	0.000	-0.000
16037.5	0.018	0.008	0.000	0.002	0.001	0.000	0.000	-0.000
17059.0	0.019	0.009	0.000	0.002	0.001	0.000	0.000	-0.000
18025.1	0.032	0.012	0.000	0.002	0.001	0.000	-0.000	-0.000
19263.7	0.033	0.013	-0.000	0.001	0.001	-0.000	-0.000	-0.001
20000.0	0.053	0.017	-0.000	0.001	0.001	-0.000	-0.001	-0.001
21085.4	0.056	0.018	-0.000	0.000	0.001	-0.000	-0.001	-0.001
22004.7	0.084	0.028	-0.000	-0.001	0.001	-0.000	-0.001	-0.001
23251.8	0.086	0.029	-0.000	-0.001	0.001	-0.000	-0.001	-0.001
23983.9	0.088	0.030	-0.000	-0.001	0.001	-0.000	-0.001	-0.001
24796.8	0.130	0.050	-0.000	-0.006	0.000	-0.000	-0.001	-0.001
26039.6	0.132	0.050	-0.000	-0.006	0.000	0.000	-0.001	-0.001
26835.5	0.188	0.077	-0.004	-0.017	-0.002	-0.000	-0.001	-0.001
27818.7	0.212	0.086	-0.005	-0.020	-0.003	-0.000	-0.001	-0.001
28984.9	0.267	0.118	-0.006	-0.028	-0.007	-0.000	-0.001	-0.001
30036.2	0.271	0.119	-0.006	-0.028	-0.007	-0.000	-0.001	-0.001
31287.5	0.349	0.167	-0.006	-0.038	-0.015	-0.000	-0.001	-0.001
32262.2	0.350	0.168	-0.006	-0.039	-0.016	0.000	-0.001	-0.000
33083.7	0.351	0.169	-0.006	-0.039	-0.016	-0.000	-0.001	-0.001
33666.8	0.400	0.198	-0.006	-0.044	-0.021	-0.000	-0.001	-0.000
11943.0	0.674	0.487	0.139	0.008	-0.035	-0.000	-0.012	-0.002
315.0	0.568	0.445	0.158	0.034	-0.024	-0.000	-0.013	-0.003

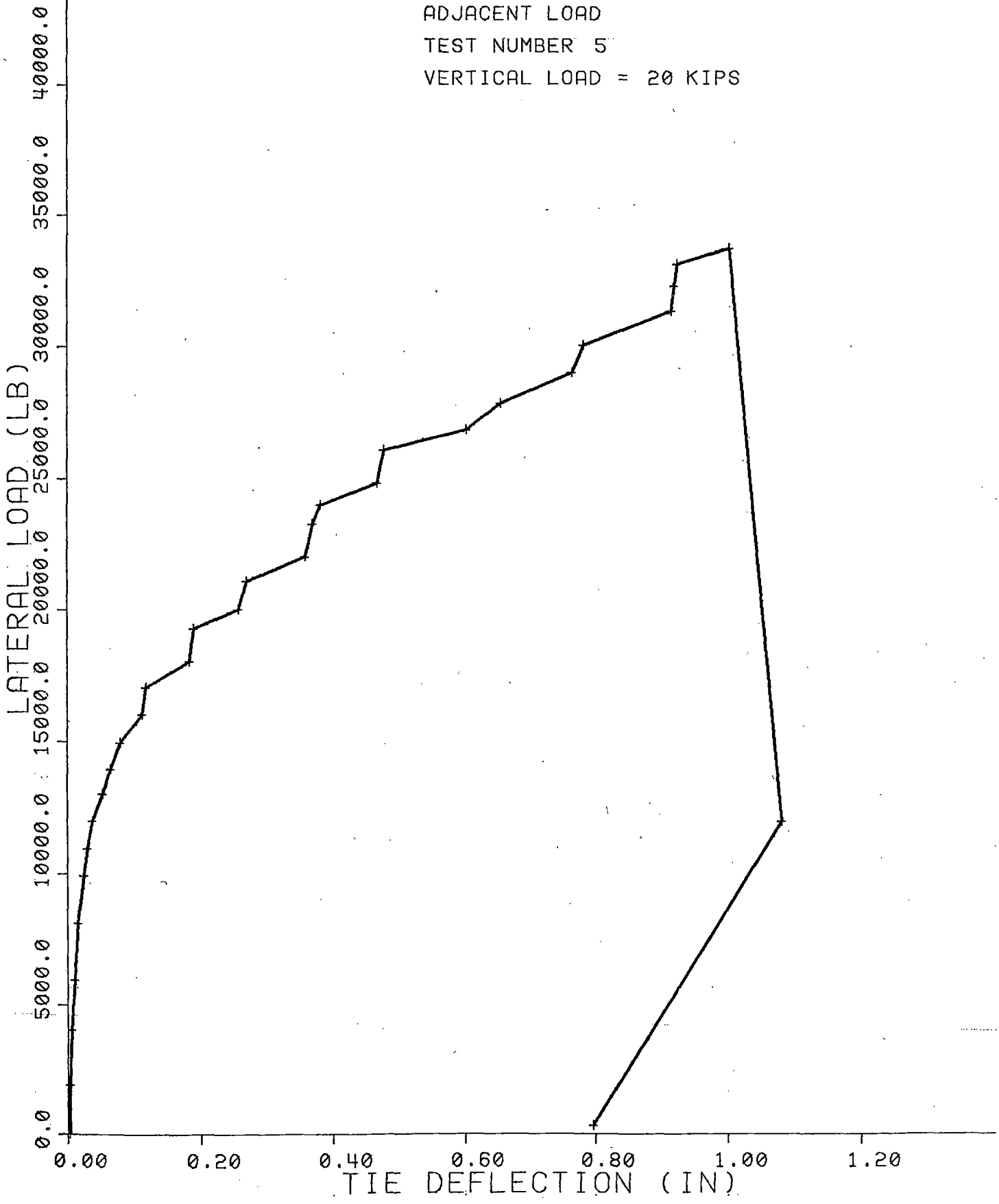
APPLIED VERTICAL LOAD = 20377.07 LB.
TIE SPACING 19.5 IN.

TRACK MISALIGNMENT TEST

ADJACENT LOAD

TEST NUMBER 5

VERTICAL LOAD = 20 KIPS



TRACK MISALIGNMENT

DYNAMIC IMPULSE TESTS

TEST	VERTICAL LOAD (KIPS)	LATERAL LOAD (LBS)	TIME (MSEC) RISE	DURATION	LATERAL DEFLECTION (IN.) @ TIE NUMBER 4S	3S	2S	1S	0
1	20	18747.3	150	350	.550	.700	.725	.725	.575
2	20	20451.6	200	400	.763	.925	.988	.975	.800
3	20	24996.4	200	250	.775	.925	1.000	.950	.825
4	20	22724.0	50	150	.775	.925	1.000	.950	.800
5	20	26132.6	200	600	.825	.975	1.050	1.000	.850
6	0	15906.8	200	25	.925	1.100	1.150	1.125	.950
7	0	18179.2	250	600	1.075	1.250	1.325	1.275	1.100
8	30*	29541.2	100	950	.775	.900	.975	.950	.775

note:

fall time is 50 msec. except for tests 6 and 7 which are 100 msec

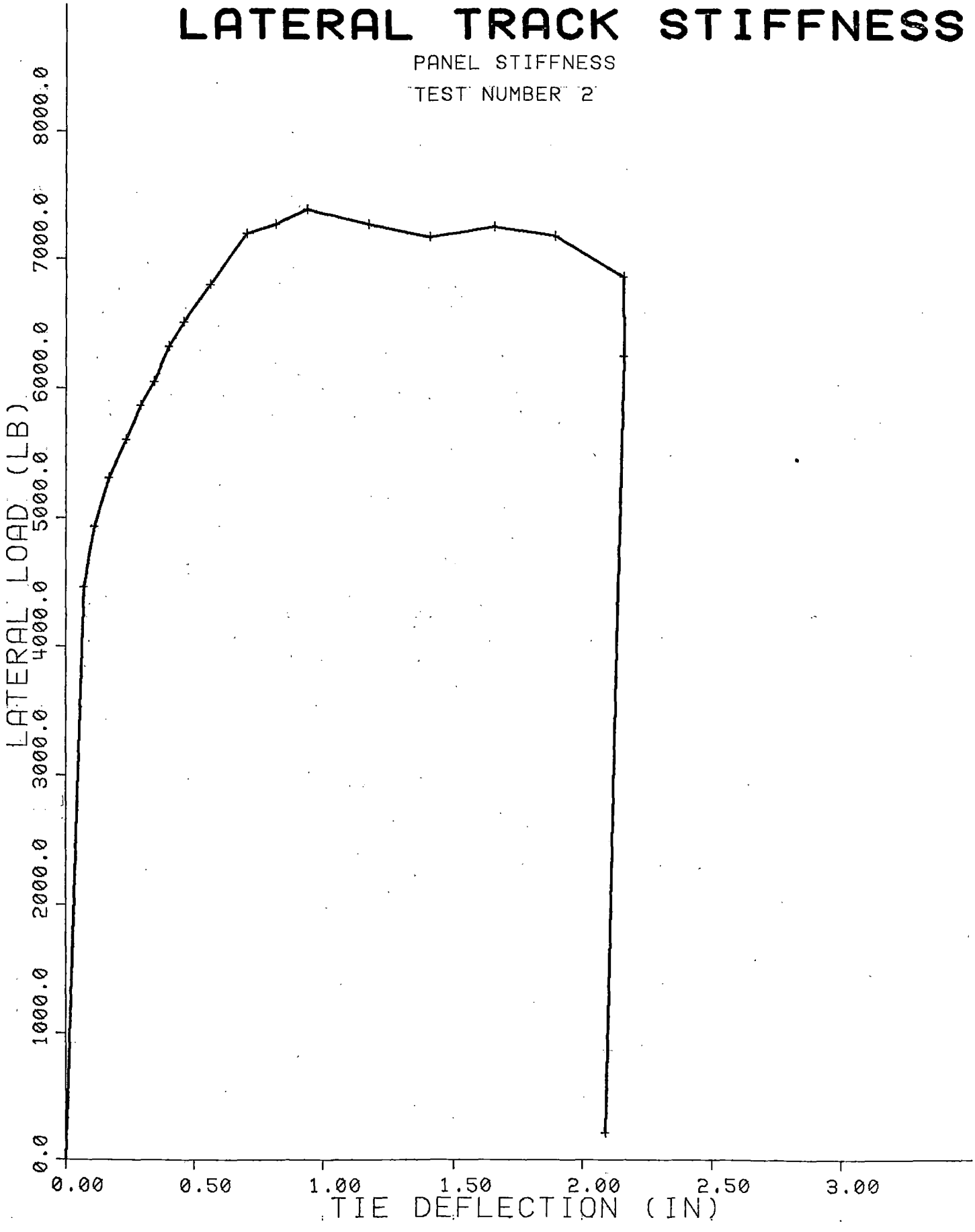
tie spacing - 19.5 in.

* not sure - ran off test paper

LATERAL TRACK STIFFNESS
PANEL STIFFNESS
TEST MUMBER 2

LOAD (LB)		TIE DEFLECTION (IN)				
2N	2S	4S	3S	2S	1S	0
4315.9	4612.1	0.0534	0.0570	0.0620	0.0775	0.0764
4773.0	5097.6	0.1010	0.1033	0.1083	0.1251	0.1217
5137.9	5493.6	0.1698	0.1701	0.1707	0.1883	0.1790
5419.0	5800.2	0.2685	0.2619	0.2553	0.2715	0.2546
5679.0	6060.0	0.3259	0.3199	0.3116	0.3303	0.3104
5851.0	6255.9	0.3873	0.3804	0.3693	0.3885	0.3661
6098.4	6554.0	0.4488	0.4427	0.4301	0.4508	0.4265
6278.8	6745.7	0.5123	0.5060	0.4910	0.5119	0.4856
6538.8	7056.5	0.6271	0.6195	0.6034	0.6236	0.5945
6886.9	7503.7	0.7784	0.7650	0.7457	0.7696	0.7376
6991.8	7550.5	0.8842	0.8722	0.8531	0.8827	0.8528
7092.5	7674.0	1.0099	0.9199	0.9727	1.0030	0.9737
6928.9	7614.4	1.3187	0.9199	1.2431	1.2666	1.2288
6811.4	7525.0	1.5606	0.9198	1.4764	1.5036	1.4674
6891.1	7610.2	1.8368	0.9197	1.7359	1.7583	1.7208
6803.1	7559.1	2.1091	0.9197	1.9903	2.0027	1.9651
6463.3	7252.4	2.3499	2.3090	2.2529	2.2532	2.2237
5897.1	6605.1	2.3708	2.3217	2.2629	2.2587	2.2275
159.4	272.6	2.3452	2.2905	2.2148	2.1980	2.1700

2N	2S	1N	2N	4N	6N	8N
4315.9	4612.1	0.0690	0.0796	0.0910	0.0523	0.0175
4773.0	5097.6	0.1123	0.1208	0.1292	0.0806	0.0354
5137.9	5493.6	0.1669	0.1708	0.1751	0.1142	0.0572
5419.0	5800.2	0.2355	0.2331	0.2305	0.1529	0.0862
5679.0	6060.0	0.2895	0.2858	0.2805	0.1949	0.1202
5851.0	6255.9	0.3425	0.3345	0.3255	0.2305	0.1450
6098.4	6554.0	0.4010	0.3882	0.3764	0.2734	0.1786
6278.8	6745.7	0.4566	0.4439	0.4234	0.3130	0.2098
6538.8	7056.5	0.5590	0.5405	0.5144	0.3930	0.2749
6886.9	7503.7	0.6989	0.6766	0.6486	0.5223	0.3927
6991.8	7550.5	0.8130	0.7944	0.7679	0.6439	0.5109
7092.5	7674.0	0.9352	0.9199	0.8916	0.7646	0.6241
6928.9	7614.4	1.1724	1.1455	1.1091	0.9619	0.7955
6811.4	7525.0	1.4074	1.3851	1.3407	1.1898	1.0208
6891.1	7610.2	1.6549	1.6313	1.5773	1.4158	1.2363
6803.1	7559.1	1.8916	1.8657	1.8049	1.6312	1.4544
6463.3	7252.4	2.1538	2.1302	2.0685	1.8942	1.7294
5897.1	6605.1	2.1566	2.1323	2.0703	1.8981	1.7362
159.4	272.6	2.0910	2.0665	2.0017	1.8978	1.7166


LATERAL TRACK STIFFNESS
PANEL STIFFNESS
TEST NUMBER 2
LATERAL LOAD (LB)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
TIE DEFLECTION (IN)

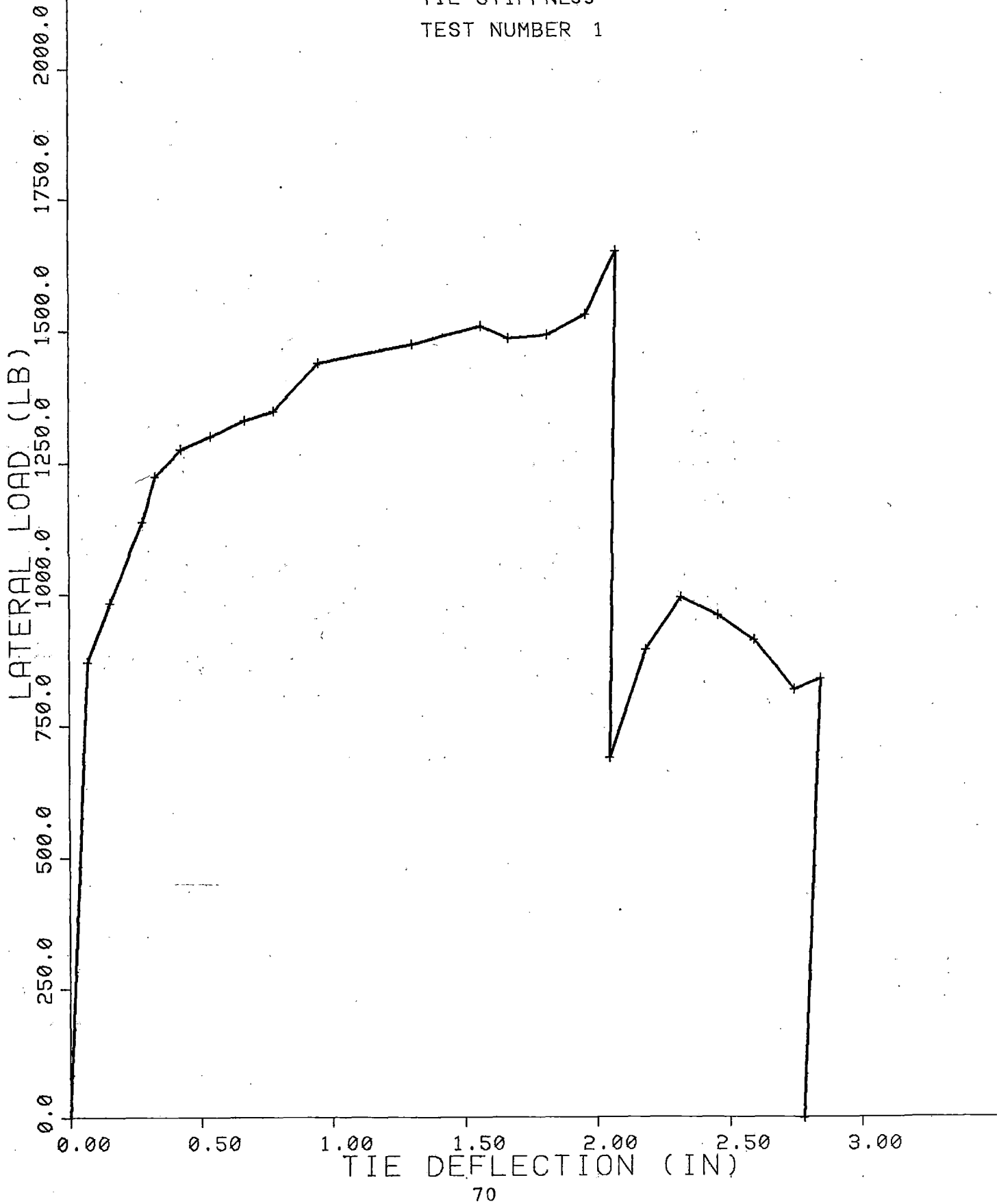
LATERAL TRACK STIFFNESS
SINGLE TIE STIFFNESS
TEST NUMBER 1

LOAD (LB)	DEFLECTION (IN)
870.5	0.0690
983.1	0.1553
1137.9	0.2791
1224.3	0.3291
1274.6	0.4278
1300.1	0.5429
1330.2	0.6731
1347.0	0.7836
1438.8	0.9531
1472.3	1.3048
1507.8	1.5639
1485.0	1.6690
1491.7	1.8174
1529.9	1.9627
1649.9	2.0768
688.9	2.0519
893.3	2.1879
992.5	2.3205
959.0	2.4581
910.7	2.5951
817.6	2.7483
837.7	2.8472
-0.7	2.7800

LATERAL TRACK STIFFNESS

TIE STIFFNESS

TEST NUMBER 1



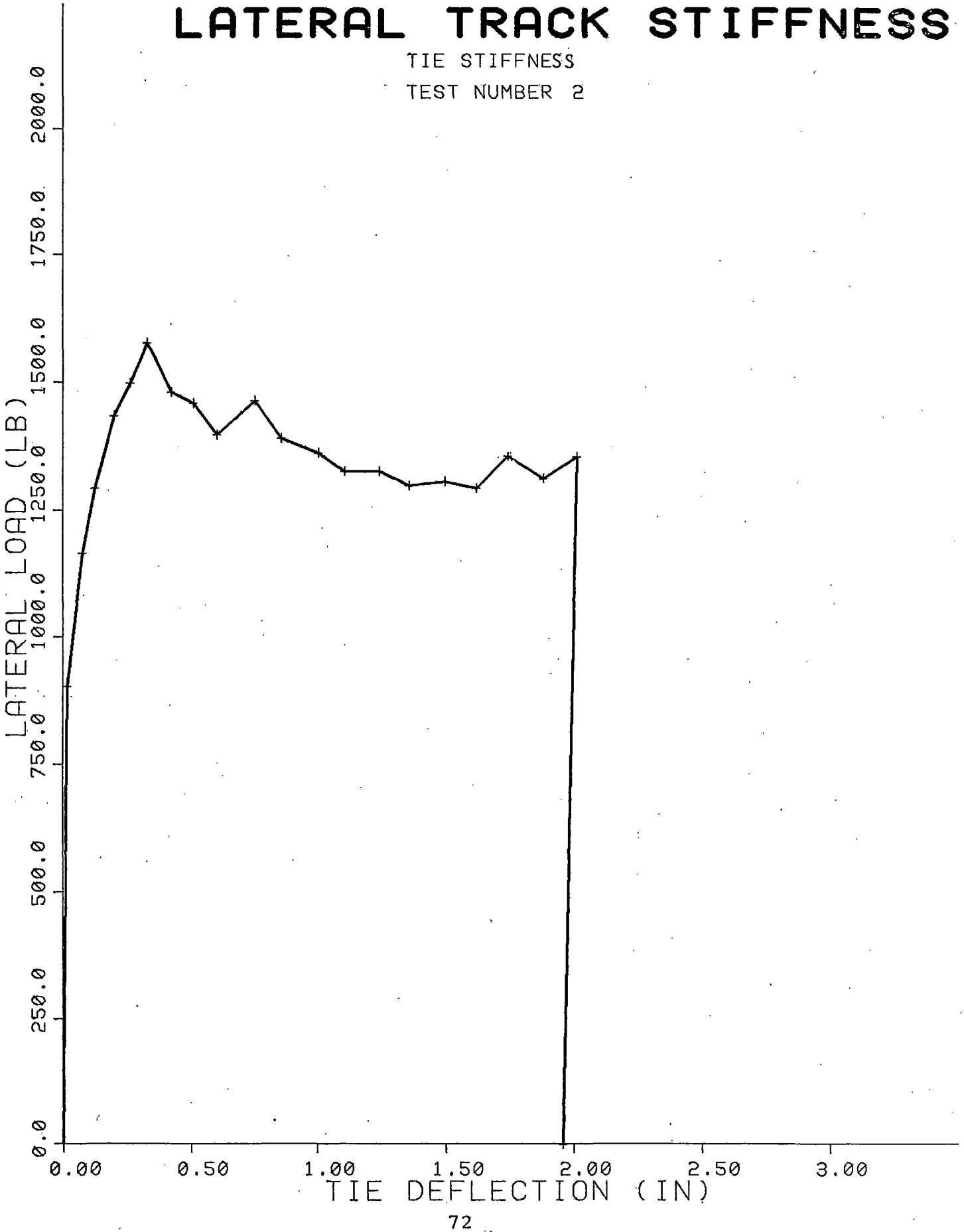
LATERAL TRACK STIFFNESS
SINGLE TIE STIFFNESS
TEST NUMBER 2

LOAD (LB)	DEFLECTION (IN)
0.0	0.0000
902.7	0.0179
1164.7	0.0786
1292.0	0.1247
1433.4	0.2008
1497.7	0.2613
1576.1	0.3298
1479.6	0.4233
1458.9	0.5108
1397.2	0.6036
1463.6	0.7525
1391.2	0.8565
1363.0	1.0057
1326.9	1.1085
1326.2	1.2424
1298.7	1.3569
1306.1	1.4951
1293.4	1.6187
1356.3	1.7394
1312.8	1.8812
1355.0	2.0130
-0.7	1.9572

LATERAL TRACK STIFFNESS

TIE STIFFNESS

TEST NUMBER 2



Laboratory Investigation of Lateral Track Shift (Interim Report), 1980
US DOT, FRA, J Choros, AM Zarembski, I Gitlin