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13. ABSTRACT

This report describes the test procedures and the results of tests on the physical properties of rail, tie and fastener. The properties obtained are the bending rigidity of the tie, bending rigidity of the rail in both the vertical and lateral planes, and the fastener resistance to rotation about the vertical axis. The component tests were run on two rail sections, 115 lb RE and 136 lb RE, on 7"x9"x8½" gum ties and on three fastener configurations on the two different rail sections.

The tests were conducted at the Association of American Railroads (AAR) Track Structures Dynamic Test Facility in Chicago, Illinois.

14. SUBJECT TERMS
Rail Properties
Tie Properties
Track Components
Track Fastener Properties

15. AVAILABILITY STATEMENT
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EXECUTIVE SUMMARY

This report presents the test procedures, data reduction techniques and results for the component property tests, conducted between January and May, 1979 at the Association of American Railroad's Track Structure Dynamic Test Facility in Chicago, Illinois. This work was performed under Federal Railroad Administration Contract: DOT-FR-30038. The components tested were the same as used in the construction of the test track at the Dynamic Test Facility, and included two sizes of rail, fasteners and hardwood crossties that are widely used in the railroad industry.

Two rail sections (115 RE and 136 RE) were tested to determine the bending stiffness in the vertical and lateral planes. Each test rail was supported in a simple fashion at both ends, and subjected to incrementally increasing loads. Vertical loads were applied along the centerline of the rail heads, and lateral loads applied along the neutral axis in the web area. The corresponding rail deflections were measured at four locations, and the bending stiffness calculated from simple beam theory. The test results were in agreement with predicted theoretical values.

Five hardwood crossties were tested to determine the vertical and lateral bending stiffness, using procedures identical to those for the rail bending tests. The average bending stiffness of each tie was then calculated, using simple beam theory and a least-squares method.

The resistance of fasteners (mounted on wooden crossties) to rotation about the longitudinal rail axis (under applied lateral loading conditions) was determined. Three different types of

fasteners, attached to 115 RE and 136 RE rail sections, were evaluated. Fastener stiffness was determined for both two and four cut spikes, and a Pandrol clip with two lockspikes. Each fastener's rotational resistance was determined from the moment-rotation curves, and averaging the results from three test for each fastener configuration. The results were in agreement with previously published data.

METRIC CONVERSION FACTORS

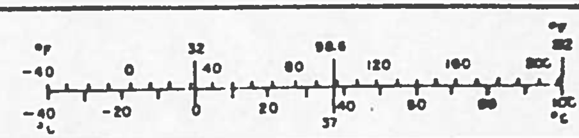
Approximate Conversions to Metric Measures

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



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1. INTRODUCTION

The objective of this portion of the laboratory test program is to determine physical and structural properties of typical track components in use in railroad track systems.

The need for these track component properties became apparent during the development of analytical models for the description of the track system behavior, which was done under task 1 of the contract. It was found that necessary component property data was either unavailable or available but of questionable reliability. As investigators proceed, in future tests, to examine and attempt to quantify the track structure's behavior the need for this data will once again became evident.

In order to fill the voids in certain areas of basic component properties and to clarify the existing results a set of test was conducted at the Association of American Railroad, Track Structure Dynamic Test Facility, Chicago, Illinois. For most part, the tests were unique except for certain tests for which data from previous work were questionable.

The results of these component property tests together with a description of the individual test set ups and procedures are described in this report.

2. REQUIRED COMPONENT PROPERTIES

In identifying the track and component property test requirements, a set of seven characteristics was defined which are important descriptors of the track structure. These characteristics include:

(1) Vertical track modulus
(2) Lateral foundation stiffness
  a) without vertical load
  b) with vertical load
(3) Bending stiffness of the rail
  a) vertical
  b) lateral
  c) torsional
(4) Vertical bending stiffness of the tie
(5) Fastener resistance to rotation
  a) about vertical axis
  b) about longitudinal axis
  c) about transverse axis
(6) Rotational joint stiffness
(7) Soil properties
  a) ballast
  b) subballast
  c) subgrade

These supplmental tests fall into three basic categories:

(1) Tests which can be incorporated within the track portion of test program. These include tests (1) and (2).

(2) Tests which must be carried out on separate test fixtures and which are independent of the test track. These tests (3) - (6) will be described in this report.

(3) Tests which must be carried out in an independent laboratory facility (7).

For the second category of tests, a special test fixture was constructed at the AAR Track Structures Dynamic Test Facility and between April and June, 1978, the following tests were performed using the special test fixture:

1) Vertical bending stiffness of a 7" x 9" x 8'-6" hardwood cross-tie
2) Vertical bending stiffness of 115 RE rail and 136 RE rail
3) Lateral bending stiffness of 115 RE rail and 136 RE rail
4) Fastener resistance to rotation about vertical axis

3. BENDING STIFFNESS OF WOOD CROSS-TIES

3.1 Objective.

The objective of this test was to determine the bending stiffness (EI) of hardwood cross-ties. Additionally, the modulus of elasticity (E) of the hardwood tie was determined and compared with known material values.

3.2 Test Description.

Five new 7" deep x 9" wide x 8½', untreated prebored hardwood (gum) cross-ties were selected. Each tie was tested by simply supporting it in the supplemental test fixture over foot span and applying a vertical load at mid span. The test set up is shown in Figure 1a. Tie moisture content was 13-18%.

Deflection of each tie was measured at 4 locations along the tie, mid-span, quarter-span, and two eighth-span points. (Figure 1b). Deflections were measured with 2" displacement transducers. Jack loading force was measured with a 3,000 psi pressure transducer installed in the hydraulic pressure line.

The vertical load was applied in 1,000 lb increments to a maximum of 5,000 lbs. This loading cycle was repeated 5 times. The wood tie was then inverted (top surface down) and the loading sequence repeated 5 times.

A second set of tests, to determine the tie bending stiffness in the lateral plane was then conducted. The gum cross-tie was placed on its side, with the deflection instrumentation similar to that described for the vertical bending tests.

Loads were then applied at mid span in 1,000 lb increments to a maximum of 5,000 lbs.

The test series was repeated for each of the five ties. In both sets of tests, data was recorded on both magnetic and paper tape. A description of the data reduction procedure is given in Appendix A.

Measurements were taken of the tie cross-sectional area at each of the instrumented sections so that the local moment of inertia could be subsequently calculated.

3.3 Results.

The results of a typical tie vertical bending test are given in Table 1.

The bending stiffnesses of the ties were determined from beam theory, for a simple supported beam, using the relations:

$$EI = \frac{PL^3}{48d} \quad \text{at mid span}$$

$$EI = \frac{11PL^3}{768d} \quad \text{at } L/4$$

$$EI = \frac{47PL^3}{6144d} \quad \text{at } L/8$$

Where:

EI = Bending Stiffness of tie ($lb\text{-}in^2$)

d = Deflection of the beam (inches)

L = Span between simple supports (inches)

P = Concentrated force applied at mid-span (lbs)

Note, from Figure 2, the linearity of the load - deflection relationship for the tie bending, indicating that the use of linear elastic beam theory is valid.

The average stiffness of all ties in the vertical plane was found to be:

$EI = 350.8 \times 10^6$ lb - in.^{2}

Using the individual cross-section moment of inertias to determine modulus of elasticity for each tie, and averaging these values, the average modulus of elasticity was then found to be:

$E = 1.54 \times 10^6$ psi.

For the inverted ties, the results for a typical vertical bending stiffness are given in Table 2.

The average stiffness, (vertical) for all ties was found to be:

$EI = 322.1 \times 10^6$ lb - in.^{2}

and a corresponding modulus of elasticity;

$E = 1.42 \times 10^6$ psi.

The range of modulus for gum hardwood with 12% moisture contents is 1.2×10^6 psi. to 1.49×10^6 psi. {1}

The experimental values of the modulus of elasticity appears to fall within this range.

The results for the bending stiffness of a typical tie in the lateral plane (i.e., with the tie on its side) are given in Table 3.

The average stiffness for all ties was found to be:

$EI = 552.5 \times 10^6$ lb - in.^{2} and a modulus of elasticity $E = 1.45 \times 10^6$psi.

The results of these tests are summarized in Table 4.

TABLE 1 BENDING STIFFNESS OF WOOD TIE

LOAD (LB)	@ L/2 DEFLC. (IN)	@ L/2 EI (LB-IN^2)	@ L/2 E (PSI)	@ L/4 DEFLC. (IN)	@ L/4 EI (LB-IN^2)	@ L/4 E (PSI)	@ L/3 DEFLC. (IN)	@ L/3 EI (LB-IN^2)	@ L/3 E (PSI)	@ L/3 DEFLC. (IN)	@ L/3 EI (LB-IN^2)	@ L/3 E (PSI)
		TEST 240										
1422.7	.0738	0.357E+09	0.148E+07	.0487	0.372E+09	0.143E+07	.0299	0.324E+09	0.119E+07	.0344	0.281E+09	0.129E+07
2097.9	.1047	0.371E+09	0.154E+07	.0684	0.390E+09	0.150E+07	.0409	0.349E+09	0.128E+07	.0467	0.305E+09	0.140E+07
3038.3	.1561	0.360E+09	0.149E+07	.1026	0.377E+09	0.145E+07	.0600	0.344E+09	0.126E+07	.0681	0.303E+09	0.139E+07
4027.0	.2101	0.355E+09	0.147E+07	.1353	0.379E+09	0.146E+07	.0782	0.350E+09	0.129E+07	.0889	0.308E+09	0.141E+07
4979.5	.2556	0.361E+09	0.150E+07	.1638	0.387E+09	0.149E+07	.0928	0.365E+09	0.134E+07	.1055	0.321E+09	0.147E+07
		TEST 240										
1338.3	.0731	0.339E+09	0.141E+07	.0476	0.358E+09	0.138E+07	.0295	0.308E+09	0.113E+07	.0337	0.270E+09	0.124E+07
2109.9	.1116	0.350E+09	0.145E+07	.0738	0.364E+09	0.140E+07	.0435	0.330E+09	0.121E+07	.0496	0.289E+09	0.133E+07
3128.7	.1630	0.355E+09	0.147E+07	.1059	0.373E+09	0.143E+07	.0618	0.344E+09	0.126E+07	.0703	0.303E+09	0.139E+07
4051.1	.2149	0.349E+09	0.145E+07	.1389	0.371E+09	0.143E+07	.0802	0.343E+09	0.126E+07	.0903	0.305E+09	0.140E+07
4949.3	.2564	0.357E+09	0.148E+07	.1643	0.384E+09	0.147E+07	.0931	0.351E+09	0.133E+07	.1054	0.319E+09	0.147E+07
		TEST 240										
1296.1	.0689	0.348E+09	0.144E+07	.0457	0.361E+09	0.139E+07	.0276	0.319E+09	0.117E+07	.0319	0.276E+09	0.127E+07
2134.1	.1090	0.363E+09	0.150E+07	.0725	0.375E+09	0.144E+07	.0420	0.346E+09	0.127E+07	.0486	0.299E+09	0.137E+07
2984.1	.1524	0.360E+09	0.150E+07	.1010	0.376E+09	0.145E+07	.0581	0.349E+09	0.129E+07	.0663	0.306E+09	0.140E+07
3990.8	.2052	0.360E+09	0.149E+07	.1327	0.383E+09	0.147E+07	.0758	0.358E+09	0.131E+07	.0864	0.314E+09	0.144E+07
4919.2	.2493	0.365E+09	0.151E+07	.1606	0.390E+09	0.150E+07	.0901	0.371E+09	0.136E+07	.1026	0.326E+09	0.150E+07
		TEST 240										
1501.1	.0817	0.340E+09	0.141E+07	.0540	0.354E+09	0.136E+07	.0336	0.304E+09	0.112E+07	.0373	0.274E+09	0.126E+07
2140.1	.1106	0.358E+09	0.149E+07	.0738	0.369E+09	0.142E+07	.0444	0.328E+09	0.120E+07	.0489	0.298E+09	0.137E+07
3032.3	.1559	0.358E+09	0.148E+07	.1043	0.370E+09	0.142E+07	.0613	0.335E+09	0.124E+07	.0677	0.305E+09	0.140E+07
4063.1	.2132	0.353E+09	0.146E+07	.1387	0.373E+09	0.143E+07	.0802	0.344E+09	0.127E+07	.0892	0.310E+09	0.142E+07
4943.3	.2555	0.358E+09	0.149E+07	.1658	0.380E+09	0.146E+07	.0943	0.355E+09	0.131E+07	.1051	0.320E+09	0.147E+07
		TEST 240										
1326.3	.0731	0.336E+09	0.139E+07	.0491	0.344E+09	0.132E+07	.0303	0.298E+09	0.109E+07	.0339	0.266E+09	0.122E+07
2122.0	.1096	0.359E+09	0.149E+07	.0734	0.368E+09	0.141E+07	.0443	0.326E+09	0.120E+07	.0487	0.296E+09	0.136E+07
3074.5	.1587	0.359E+09	0.149E+07	.1052	0.372E+09	0.143E+07	.0617	0.339E+09	0.124E+07	.0679	0.308E+09	0.141E+07
4027.0	.2105	0.354E+09	0.147E+07	.1373	0.373E+09	0.144E+07	.0794	0.345E+09	0.127E+07	.0880	0.311E+09	0.143E+07
4967.4	.2576	0.357E+09	0.148E+07	.1670	0.379E+09	0.146E+07	.0947	0.357E+09	0.131E+07	.1058	0.319E+09	0.147E+07

AVERAGE STIFFNESS = 0.35547E+09
STANDARD DEVIATION OF THE SAMPLE = 0.79475E+07
STANDARD DEVIATION = 0.77869E+07

TABLE 2 BENDING STIFFNESS OF WOOD TIE (UPSIDE DOWN)

	@ L/2			@ L/4			@ L/3			@ L/8		
LOAD (LB)	DEFLC. (IN)	EI $(LB-IN^2)$	E (PSI)	DEFLC. (IN)	EI $(LB-IN^2)$	E (PSI)	DEFLC. (IN)	EI $(LB-IN^2)$	E (PSI)	DEFLC. (IN)	EI $(LB-IN^2)$	E (PSI)
		TEST 240										
916.3	.0528	0.321E+09	0.133E+07	.0396	0.295E+09	0.113E+07	.0288	0.216E+09	0.795E+06	.0252	0.247E+09	0.114E+07
2140.1	.1271	0.312E+09	0.129E+07	.0859	0.317E+09	0.122E+07	.0604	0.241E+09	0.885E+06	.0551	0.259E+09	0.119E+07
3014.2	.1774	0.315E+09	0.130E+07	.1192	0.322E+09	0.124E+07	.0813	0.252E+09	0.926E+06	.0749	0.274E+09	0.126E+07
4087.3	.2301	0.329E+09	0.136E+07	.1535	0.339E+09	0.130E+07	.1006	0.276E+09	0.101E+07	.0939	0.296E+09	0.136E+07
4949.3	.2734	0.335E+09	0.139E+07	.1805	0.349E+09	0.134E+07	.1157	0.291E+09	0.107E+07	.1100	0.306E+09	0.140E+07
		TEST 240										
916.3	.0524	0.324E+09	0.134E+07	.0397	0.294E+09	0.113E+07	.0296	0.210E+09	0.773E+06	.0259	0.241E+09	0.110E+07
2061.7	.1218	0.313E+09	0.130E+07	.0848	0.310E+09	0.119E+07	.0593	0.236E+09	0.868E+06	.0547	0.256E+09	0.118E+07
3104.6	.1785	0.322E+09	0.134E+07	.1196	0.330E+09	0.127E+07	.0821	0.257E+09	0.944E+06	.0762	0.277E+09	0.127E+07
3996.8	.2241	0.330E+09	0.137E+07	.1501	0.339E+09	0.130E+07	.0992	0.274E+09	0.101E+07	.0926	0.293E+09	0.135E+07
4925.2	.2721	0.335E+09	0.139E+07	.1799	0.349E+09	0.134E+07	.1154	0.290E+09	0.107E+07	.1103	0.304E+09	0.139E+07
		TEST 240										
1290.1	.0478	0.500E+09	0.207E+07	.0330	0.498E+09	0.191E+07	.0187	0.469E+09	0.172E+07	.0223	0.393E+09	0.181E+07
2128.0	.0760	0.519E+09	0.215E+07	.0534	0.507E+09	0.195E+07	.0297	0.487E+09	0.179E+07	.0334	0.433E+09	0.199E+07
3050.4	.1054	0.536E+09	0.222E+07	.0719	0.540E+09	0.208E+07	.0401	0.517E+09	0.190E+07	.0441	0.470E+09	0.216E+07
3912.4	.1331	0.544E+09	0.226E+07	.0882	0.565E+09	0.217E+07	.0487	0.546E+09	0.201E+07	.0546	0.437E+09	0.224E+07
4901.1	.1637	0.554E+09	0.230E+07	.1071	0.583E+09	0.224E+07	.0588	0.567E+09	0.209E+07	.0658	0.506E+09	0.233E+07
		TEST 240										
916.3	.0515	0.329E+09	0.137E+07	.0376	0.310E+09	0.119E+07	.0260	0.240E+09	0.880E+06	.0281	0.222E+09	0.102E+07
2073.8	.1219	0.315E+09	0.131E+07	.0835	0.316E+09	0.121E+07	.0560	0.252E+09	0.925E+06	.0569	0.248E+09	0.114E+07
2941.9	.1698	0.321E+09	0.133E+07	.1119	0.335E+09	0.129E+07	.0755	0.265E+09	0.973E+06	.0746	0.268E+09	0.123E+07
4002.9	.2241	0.331E+09	0.137E+07	.1472	0.346E+09	0.133E+07	.0952	0.286E+09	0.105E+07	.0946	0.238E+09	0.132E+07
4858.9	.2661	0.338E+09	0.140E+07	.1733	0.357E+09	0.137E+07	.1094	0.302E+09	0.111E+07	.1102	0.300E+09	0.133E+07
		TEST 240										
1308.2	.0805	0.301E+09	0.125E+07	.0583	0.286E+09	0.110E+07	.0403	0.221E+09	0.811E+06	.0394	0.226E+09	0.104E+07
2067.7	.1233	0.311E+09	0.129E+07	.0850	0.310E+09	0.119E+07	.0580	0.242E+09	0.890E+06	.0566	0.248E+09	0.114E+07
3002.1	.1722	0.323E+09	0.134E+07	.1144	0.334E+09	0.128E+07	.0783	0.261E+09	0.958E+06	.0755	0.270E+09	0.124E+07
4045.1	.2276	0.329E+09	0.136E+07	.1502	0.343E+09	0.132E+07	.0981	0.280E+09	0.103E+07	.0953	0.239E+09	0.132E+07
4919.2	.2703	0.337E+09	0.140E+07	.1772	0.353E+09	0.136E+07	.1125	0.297E+09	0.109E+07	.1111	0.301E+09	0.133E+07

AVERAGE STIFFNESS = 0.36499E+09
STANDARD DEVIATION OF THE SAMPLE = 0.83730E+08
STANDARD DEVIATION = 0.82038E+08

TABLE 3 BENDING STIFFNESS OF WOOD TIE (LATERAL)

LOAD (LB)	@ L/2 DEFLC. (IN)	@ L/2 EI ($LB-IN^2$)	@ L/2 E (PSI)	@ L/4 DEFLC. (IN)	@ L/4 EI ($LB-IN^2$)	@ L/4 E (PSI)	@ L/3 DEFLC. (IN)	@ L/3 EI ($LB-IN^2$)	@ L/3 E (PSI)	@ L/3 DEFLC. (IN)	@ L/3 EI ($LB-IN^2$)	@ L/3 E (PSI)
		TEST 240										
1193.6	.0403	0.548E+09	0.227E+07	.0262	0.580E+09	0.223E+07	.0159	0.510E+09	0.187E+07	.0189	0.429E+09	0.197E+07
2122.0	.0786	0.500E+09	0.207E+07	.0544	0.497E+09	0.191E+07	.0301	0.479E+09	0.176E+07	.0345	0.418E+09	0.192E+07
3122.7	.1071	0.540E+09	0.224E+07	.0730	0.545E+09	0.209E+07	.0403	0.527E+09	0.194E+07	.0451	0.471E+09	0.216E+07
4039.0	.1359	0.547E+09	0.227E+07	.0908	0.566E+09	0.218E+07	.0501	0.543E+09	0.201E+07	.0552	0.489E+09	0.224E+07
4991.5	.1684	0.549E+09	0.228E+07	.1099	0.578E+09	0.222E+07	.0602	0.564E+09	0.207E+07	.0682	0.498E+09	0.228E+07
		TEST 240										
1308.2	.0488	0.496E+09	0.206E+07	.0330	0.505E+09	0.194E+07	.0190	0.468E+09	0.172E+07	.0225	0.395E+09	0.181E+07
2134.1	.0781	0.506E+09	0.210E+07	.0549	0.495E+09	0.190E+07	.0310	0.468E+09	0.172E+07	.0345	0.421E+09	0.193E+07
3068.5	.1088	0.522E+09	0.217E+07	.0740	0.528E+09	0.203E+07	.0418	0.499E+09	0.183E+07	.0459	0.455E+09	0.209E+07
4002.9	.1388	0.534E+09	0.221E+07	.0921	0.553E+09	0.213E+07	.0517	0.526E+09	0.193E+07	.0571	0.477E+09	0.219E+07
4377.0	.1575	0.539E+09	0.224E+07	.1096	0.567E+09	0.218E+07	.0610	0.544E+09	0.200E+07	.0679	0.438E+09	0.224E+07
		TEST 240										
1290.1	.0478	0.500E+09	0.207E+07	.0330	0.498E+09	0.191E+07	.0187	0.469E+09	0.172E+07	.0223	0.393E+09	0.181E+07
2128.0	.0760	0.519E+09	0.215E+07	.0534	0.507E+09	0.195E+07	.0297	0.487E+09	0.179E+07	.0334	0.433E+09	0.199E+07
3050.4	.1054	0.536E+09	0.222E+07	.0719	0.540E+09	0.208E+07	.0401	0.517E+09	0.190E+07	.0441	0.470E+09	0.216E+07
3912.4	.1331	0.544E+09	0.226E+07	.0882	0.565E+09	0.217E+07	.0487	0.546E+09	0.201E+07	.0545	0.437E+09	0.224E+07
4901.1	.1637	0.554E+09	0.230E+07	.1071	0.583E+09	0.224E+07	.0588	0.557E+09	0.208E+07	.0558	0.506E+09	0.233E+07

AVERAGE STIFFNESS = 0.52901E+09
STANDARD DEVIATION OF THE SAMPLE = 0.19515E+03
STANDARD DEVIATION = 0.18854E+08

Summary of Results

Wood Tie Bending Stiffness Tests *

Tie Position	EI** lb-in^2	Standard Deviation (EI)	E** psi	Standard Deviation (E)
Normal-Vertical	350.76×10^6	35.0×10^6	1.54×10^6	$.16 \times 10^6$
Inverted-Vertical	322.1×10^6	20.2×10^6	1.42×10^6	$.08 \times 10^6$
On-Side-Lateral	552.5×10^6	58.2×10^6	1.45×10^6	$.13 \times 10^6$

* Range for gum hardwood with 12% moisture content:
$1.20 \times 10^6 - 1.49 \times 10^6$ psi

** Average for five ties , with five load series per tie.

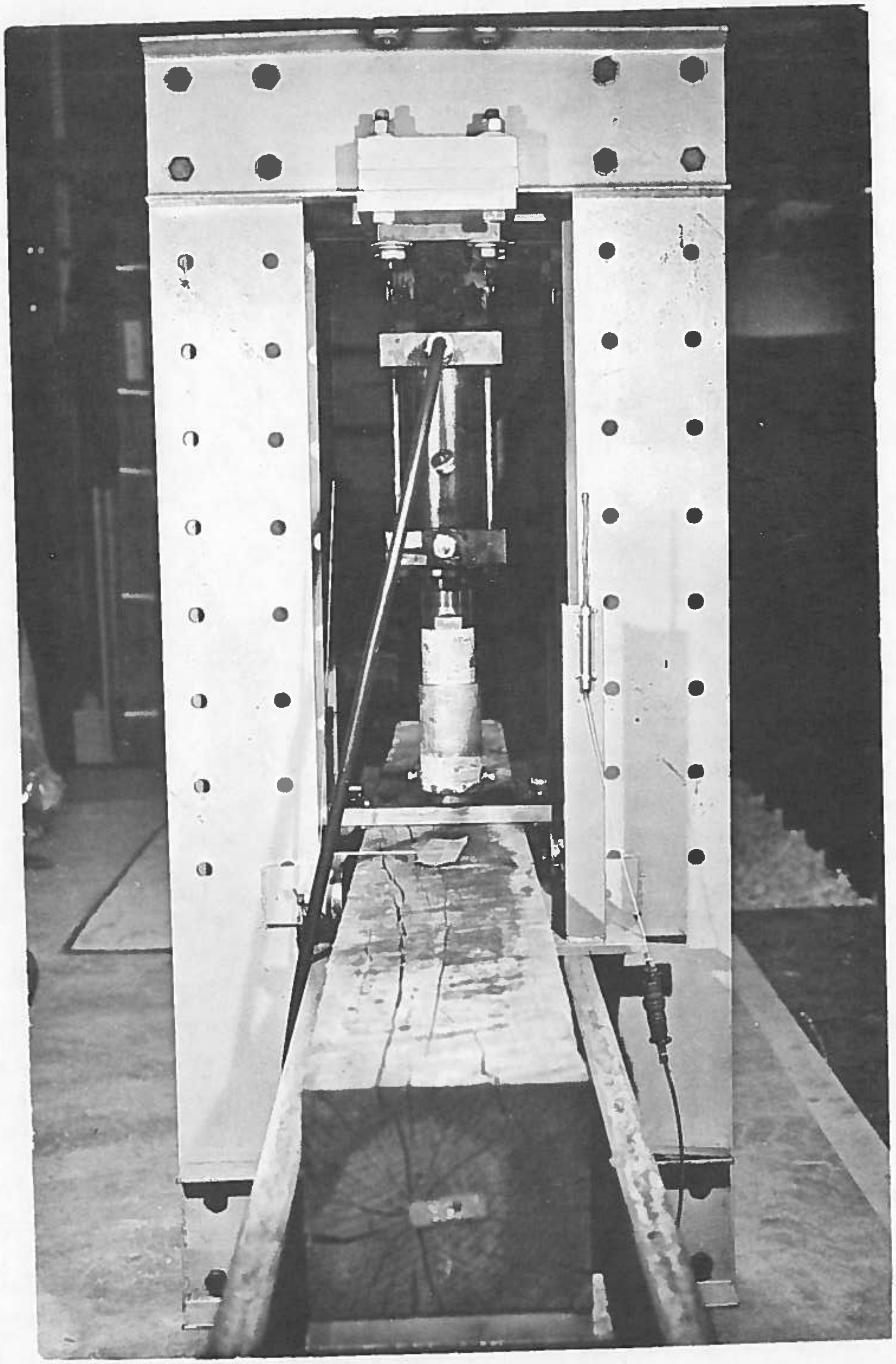
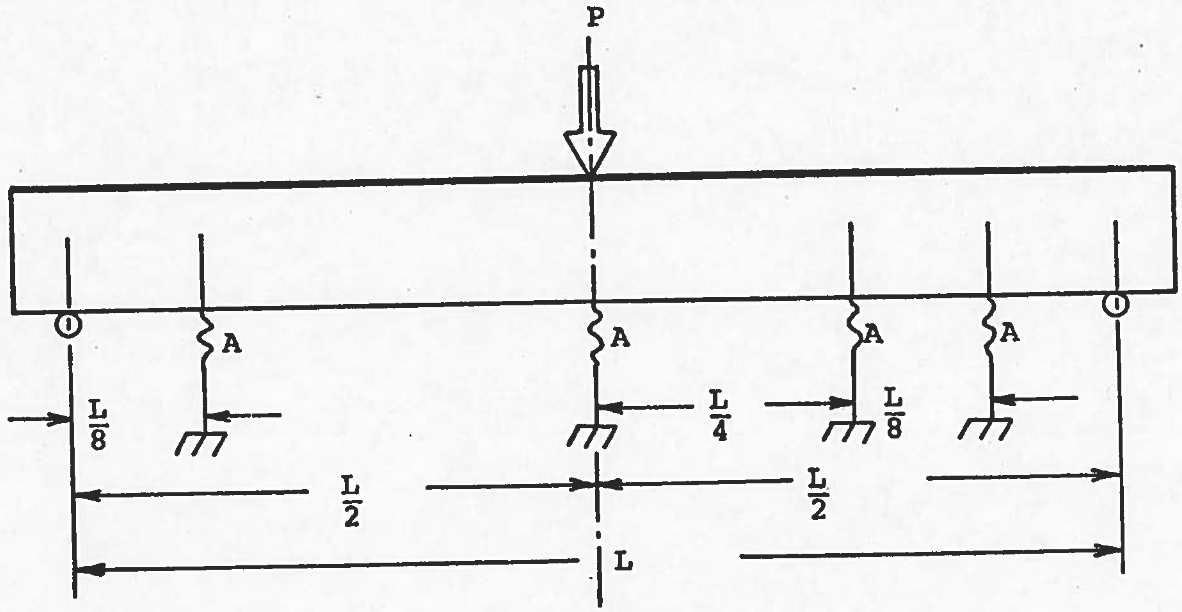


Figure 1a - Wood Tie Bending Test



L = 96 in. ; tie length = 102 in.

A - Bourns Model 80294 - 2" displacement transducers on tie centerline.

P - Force applied at center line of tie.

FIGURE 1b GENERAL ARRANGEMENT FOR ESTABLISHING BENDING STIFFNESS OF WOOD TIE.

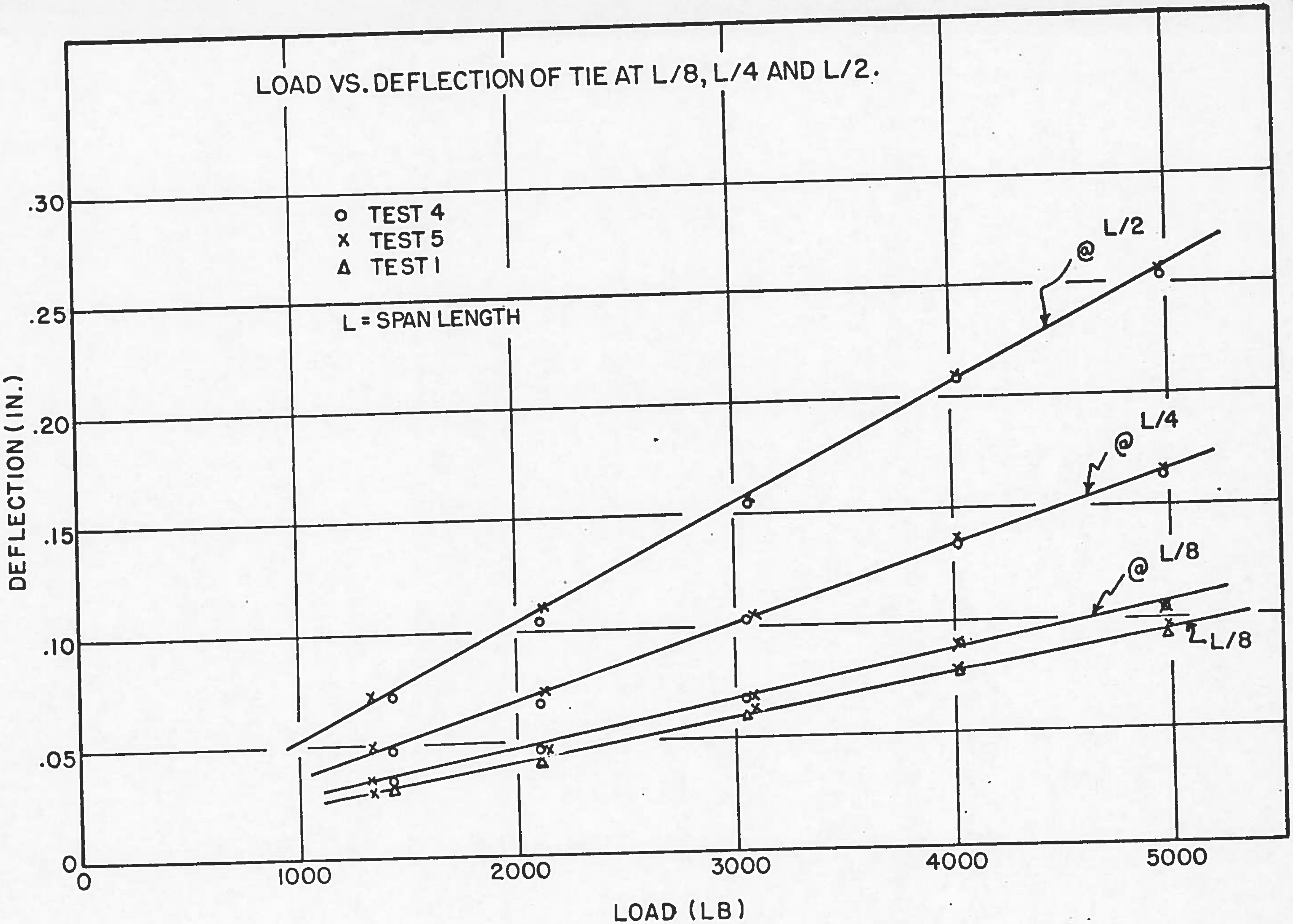


FIGURE 2. WOOD TIE: LOAD VS. DEFLECTION

4. BENDING STIFFNESS OF RAIL SECTION

4.1 Objective

The objective of this test was to determine the bending stiffness (EI) of a rail section in both the vertical and lateral planes. Using the known modulus of elasticity of steel {1},, the moments of inertia can then be determined.

4.2 Vertical Bending

4.2.1 Test Description

A 9 ft. section of Standard Carbon 115 RE rail was selected. The rail was simply supported, over an 8 ft. span as illustrated in Figure 3, and shown in Figure 4.

Deflection of the rail was measured at 4 locations; mid-span, quarter span, and two eighth-span points. (Figure 3). Four 2" displacement transducers were used to measure deflection and a 3,000 psi pressure transducer in the hydraulic pressure line was used to measure jack loading force. Vertical displacement transducers and a sample mounting configuration are illustrated in Figure 5.

A vertical load was applied at mid-span in 5 kips increments from 5 kips to 25 kips. This loading cycle was repeated 5 times. Data was recorded on both magnetic and paper tape. Data reduction procedure is described in Appendix A.

The test procedure was then repeated for a 9 ft section of Standard Carbon 136 RE rail.

4.2.2 Results

The results of the rail vertical bending tests are given in Tables 5a and 5b.

The bending rigidity of the rail was determined from simple (linear-elastic) beam theory for a simply supported beam, using the relations:

$$EI = \frac{PL^3}{48d} \quad \text{at mid span}$$

$$EI = \frac{11PL^3}{768d} \quad \text{at } L/4$$

$$EI = \frac{47PL^3}{6144d} \quad \text{at } L/8$$

Note, from Figure 6, the linearity of the load deflection relationship for the vertical rail section, indicating that the use of linear elastic beam theory is valid.

The average vertical bending stiffness of the rail section was found to be:

$EI\ (115\ RE) = 1884 \times 10^6$ lb-in^2

$EI\ (136\ RE) = 2626 \times 10^6$ lb-in^2

Using an Elastic modulus of rail steel

$E = 29 \times 10^6$ psi

The vertical moment of inertia, (i.e., with respect to a horizontal axis through the centroid) was found to be

$I\ (115\ RE) = 64.9$ in^4

$I\ (136\ RE) = 90.54$ in^4

This compares well with published values of 65.6 in^4 [2] and 64.3 in^4 [3] for 115 RE rail and 94.9 in^4 [2] and 96.4 in^4 [3] for 136 RE rail.

4.3. Lateral Bending

4.3.1. Test Description

A 9 ft. section of standard carbon 115 RE rail was selected. The rail was simply supported, over a 8 ft. span, with the vertical axis of the rail section resting in the horizontal plane. This arrangement is illustrated in Figure 7 and shown in Figure 8.

Deflection of the rail was measured at four locations; midspan, quarter span and two eighth span points. Instrumentation was similar to that of the rail vertical bending test.

A vertical load was applied at mid span, at the neutral axis, as shown in Figure 7. The rail was loaded in 1 kip increments from 1.5 kips to 5.5 kips. This loading cycle was repeated 5 times.

The test procedure was then repeated for a 9 ft (2.47 m) section of standard carbon 136 RE rail.

Data was recorded on both magnetic and paper tape and reduced per Appendix A.

4.3.2 Results

The results of the rail horizontal bending tests are given in Tables 6a and 6b. The bending rigidity of the rail was determined form simple (linear-elastic) beam theory for a simply supported beam. Figure 9 shows the linear relationship between the applied load and the rail deflection.

The average horizontal bending stiffness of the rail sections was found to be:

$$EI\ (115\ RE) = 333.2 \times 10^6\ lb\text{-}in^2$$

$$EI\ (136\ RE) = 483.7 \times 10^6\ lb\text{-}in^2$$

Using an elastic modulus of rail steel, $E = 29 \times 10^6$ psi the lateral moment of inertia (i.e., with respect to a vertical axis through the centroid) was found to be:

$$I\ (115\ RE) = 11.48\ in^4,\ I\ (136\ RE) = 16.68\ in^4$$

This compares with the published values of 10.9 in^4 and 10.35 [3] for 115 RE rail and 14,7 in^4 and 15.91 in^4 [3] for 136 RE rail.

The results of the vertical and lateral tests are summarized in Table 7.

TABLE 5A VERTICAL BENDING OF 115 RE RAIL

AD 3)	@ L/2 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/4 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/8 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/8 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})
		TEST 235										
5.5	.0511	0.180E+10	0.620E+02	.0403	0.157E+10	0.541E+02	.0168	0.201E+10	0.693E+02	.0272	0.124E+10	0.423E+02
1.3	.0969	0.183E+10	0.631E+02	.0721	0.169E+10	0.583E+02	.0331	0.197E+10	0.678E+02	.0438	0.149E+10	0.513E+02
2.4	.1410	0.190E+10	0.655E+02	.1041	0.177E+10	0.610E+02	.0474	0.207E+10	0.715E+02	.0612	0.161E+10	0.554E+02
).3	.1857	0.192E+10	0.663E+02	.1356	0.181E+10	0.624E+02	.0625	0.210E+10	0.723E+02	.0783	0.167E+10	0.577E+02
5.1	.2295	0.194E+10	0.671E+02	.1653	0.186E+10	0.640E+02	.0763	0.215E+10	0.741E+02	.0941	0.174E+10	0.601E+02
		TEST 235										
5.7	.0499	0.178E+10	0.614E+02	.0396	0.154E+10	0.531E+02	.0166	0.196E+10	0.677E+02	.0272	0.120E+10	0.413E+02
1.7	.0958	0.187E+10	0.643E+02	.0717	0.171E+10	0.591E+02	.0329	0.199E+10	0.688E+02	.0438	0.150E+10	0.517E+02
1.9	.1400	0.190E+10	0.654E+02	.1039	0.176E+10	0.606E+02	.0472	0.207E+10	0.712E+02	.0612	0.159E+10	0.549E+02
5.9	.1954	0.192E+10	0.661E+02	.1355	0.180E+10	0.621E+02	.0625	0.209E+10	0.719E+02	.0786	0.166E+10	0.572E+02
5.7	.2293	0.195E+10	0.672E+02	.1649	0.185E+10	0.639E+02	.0760	0.215E+10	0.741E+02	.0942	0.173E+10	0.593E+02
		TEST 235										
?.3	.0407	0.179E+10	0.618E+02	.0393	0.154E+10	0.530E+02	.0167	0.196E+10	0.675E+02	.0258	0.127E+10	0.437E+02
7.9	.0951	0.187E+10	0.645E+02	.0723	0.171E+10	0.589E+02	.0330	0.200E+10	0.689E+02	.0440	0.150E+10	0.517E+02
3.9	.1409	0.191E+10	0.660E+02	.1046	0.177E+10	0.611E+02	.0476	0.208E+10	0.717E+02	.0614	0.161E+10	0.556E+02
5.5	.1855	0.193E+10	0.665E+02	.1358	0.181E+10	0.624E+02	.0625	0.210E+10	0.725E+02	.0784	0.168E+10	0.578E+02
1.0	.2290	0.195E+10	0.672E+02	.1655	0.185E+10	0.639E+02	.0762	0.215E+10	0.741E+02	.0942	0.174E+10	0.600E+02
		TEST 235										
.3	.0508	0.183E+10	0.632E+02	.0406	0.158E+10	0.544E+02	.0159	0.202E+10	0.698E+02	.0260	0.132E+10	0.453E+02
.9	.0962	0.186E+10	0.643E+02	.0722	0.171E+10	0.589E+02	.0331	0.199E+10	0.686E+02	.0439	0.150E+10	0.517E+02
7.5	.1419	0.192E+10	0.661E+02	.1050	0.178E+10	0.614E+02	.0475	0.210E+10	0.725E+02	.0619	0.161E+10	0.556E+02
5.8	.1859	0.191E+10	0.659E+02	.1360	0.180E+10	0.619E+02	.0627	0.209E+10	0.717E+02	.0796	0.166E+10	0.572E+02
).0	.2290	0.195E+10	0.671E+02	.1656	0.185E+10	0.638E+02	.0762	0.215E+10	0.741E+02	.0942	0.174E+10	0.599E+02
		TEST 235										
1.7	.0507	0.175E+10	0.603E+02	.0401	0.152E+10	0.524E+02	.0168	0.194E+10	0.668E+02	.0261	0.125E+10	0.430E+02
1.0	.0967	0.186E+10	0.641E+02	.0724	0.171E+10	0.589E+02	.0330	0.200E+10	0.690E+02	.0440	0.150E+10	0.517E+02
).2	.1420	0.191E+10	0.657E+02	.1053	0.177E+10	0.609E+02	.0477	0.208E+10	0.718E+02	.0617	0.161E+10	0.555E+02
.6	.1865	0.192E+10	0.663E+02	.1365	0.180E+10	0.622E+02	.0627	0.210E+10	0.724E+02	.0797	0.167E+10	0.577E+02
'.9	.2288	0.195E+10	0.671E+02	.1655	0.185E+10	0.638E+02	.0762	0.215E+10	0.740E+02	.0942	0.174E+10	0.599E+02

AVRAGE STIFFNESS = 0.18840E+10
STANDAR DEVIATION OF THE SAMPLE = 0.57029E+08
STANDAR DEVIATION = 0.55876E+08

TABLE 5B VERTICAL BENDING OF 136 RE RAIL

AD S)	@ L/2 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/4 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/8 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})	@ L/8 DEFLECTION (IN)	EI (LB-IN ^{2})	I (IN ^{4})
		TEST 236										
).5	.0343	0.260E+10	0.898E+02	.0252	0.247E+10	0.852E+02	.0116	0.287E+10	0.989E+02	.0157	0.212E+10	0.731E+02
.1	[illegible]	0.257E+10	0.889E+02	.0506	0.247E+10	0.852E+02	.0253	0.254E+10	0.910E+02	.0318	0.210E+10	0.724E+02
.6	[illegible]	0.262E+10	0.905E+02	.0739	0.255E+10	0.880E+02	.0353	0.277E+10	0.957E+02	.0466	0.216E+10	0.745E+02
.4	.1372	0.267E+10	0.920E+02	.0966	0.260E+10	0.893E+02	.0458	0.293E+10	0.101E+03	.0600	0.224E+10	0.772E+02
.3	[illegible]	0.270E+10	0.933E+02	.1191	0.265E+10	0.915E+02	.0557	0.303E+10	0.105E+03	.0737	0.229E+10	0.790E+02
		TEST 236										
.3	.0345	0.262E+10	0.904E+02	.0257	0.243E+10	0.837E+02	.0114	0.292E+10	0.101E+03	.0155	0.215E+10	0.741E+02
.0	.0707	0.257E+10	0.887E+02	.0513	0.244E+10	0.840E+02	.0253	0.264E+10	0.910E+02	.0319	0.209E+10	0.722E+02
.1	.1045	0.263E+10	0.907E+02	.0746	0.254E+10	0.875E+02	.0351	0.290E+10	0.965E+02	.0466	0.217E+10	0.748E+02
.3	.1368	0.268E+10	0.926E+02	.0970	0.250E+10	0.898E+02	.0454	0.297E+10	0.102E+03	.0599	0.225E+10	0.776E+02
.5	.1704	0.260E+10	0.927E+02	.1199	0.263E+10	0.906E+02	.0557	0.302E+10	0.104E+03	.0739	0.229E+10	0.785E+02
		TEST 236										
.0	.0350	0.264E+10	0.909E+02	.0250	0.245E+10	0.844E+02	.0113	0.285E+10	0.982E+02	.0157	0.216E+10	0.744E+02
.6	[illegible]	0.261E+10	0.898E+02	.0510	0.247E+10	0.853E+02	.0254	0.265E+10	0.914E+02	.0313	0.212E+10	0.731E+02
.1	.1052	0.258E+10	0.891E+02	.0751	0.249E+10	0.858E+02	.0368	0.271E+10	0.935E+02	.0469	0.213E+10	0.734E+02
.0	[illegible]	0.268E+10	0.923E+02	.0970	0.260E+10	0.897E+02	.0450	0.299E+10	0.103E+03	.0600	0.224E+10	0.774E+02
.6	.1700	0.271E+10	0.933E+02	.1190	0.266E+10	0.915E+02	.0550	0.307E+10	0.106E+03	.0740	0.229E+10	0.787E+02

AVRAGE STIFFNESS = 0.26387E+10
STANDAR DEVIATION OF THE SAMPLE = 0.44714E+08
STANDAR DEVIATION = 0.43103E+08

TABLE 6A LATERAL BENDING OF 115 RE RAIL

LOAD	@ L/2 DEFLECTION	EI	I	@ L/4 DEFLECTION	EI	I	@ L/8 DEFLECTION	EI	I	@ L/8 DEFLECTION	EI	I
(LB)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)
		TEST 235										
1368.4	.0716	0.352E+09	0.121E+02	.0499	0.348E+09	0.120E+02	.0267	0.347E+09	0.120E+02	.0267	0.347E+09	0.120E+02
2249.6	.1210	0.343E+09	0.118E+02	.0842	0.338E+09	0.117E+02	.0453	0.336E+09	0.116E+02	.0449	0.339E+09	0.117E+02
3327.7	.1844	0.333E+09	0.115E+02	.1279	0.330E+09	0.114E+02	.0688	0.327E+09	0.113E+02	.0680	0.331E+09	0.114E+02
4587.6	.2568	0.329E+09	0.114E+02	.1748	0.333E+09	0.115E+02	.0964	0.322E+09	0.111E+02	.0942	0.330E+09	0.114E+02
5708.9	.3154	0.333E+09	0.115E+02	.2094	0.345E+09	0.119E+02	.1168	0.331E+09	0.114E+02	.1142	0.338E+09	0.117E+02
		TEST 235										
1563.8	.0913	0.336E+09	0.116E+02	.0638	0.330E+09	0.114E+02	.0340	0.331E+09	0.114E+02	.0336	0.335E+09	0.116E+02
2327.0	.1257	0.341E+09	0.118E+02	.0875	0.337E+09	0.116E+02	.0477	0.330E+09	0.114E+02	.0467	0.337E+09	0.116E+02
3436.2	.1882	0.337E+09	0.116E+02	.1311	0.332E+09	0.115E+02	.0711	0.327E+09	0.113E+02	.0698	0.333E+09	0.115E+02
4720.2	.2622	0.332E+09	0.114E+02	.1786	0.335E+09	0.115E+02	.0988	0.323E+09	0.111E+02	.0966	0.331E+09	0.114E+02
5847.6	.3229	0.334E+09	0.115E+02	.2142	0.346E+09	0.119E+02	.1197	0.331E+09	0.114E+02	.1170	0.338E+09	0.117E+02
		TEST 235										
1597.5	.0866	0.340E+09	0.117E+02	.0612	0.331E+09	0.114E+02	.0326	0.332E+09	0.114E+02	.0327	0.331E+09	0.114E+02
2447.5	.1320	0.342E+09	0.118E+02	.0917	0.339E+09	0.117E+02	.0507	0.327E+09	0.113E+02	.0494	0.335E+09	0.115E+02
3568.8	.1972	0.334E+09	0.115E+02	.1370	0.330E+09	0.114E+02	.0747	0.323E+09	0.111E+02	.0737	0.328E+09	0.113E+02
4738.3	.2645	0.330E+09	0.114E+02	.1803	0.333E+09	0.115E+02	.1001	0.320E+09	0.110E+02	.0976	0.329E+09	0.113E+02
5793.3	.3215	0.332E+09	0.115E+02	.2134	0.344E+09	0.119E+02	.1197	0.328E+09	0.113E+02	.1167	0.336E+09	0.116E+02
		TEST 235										
1537.2	.0832	0.341E+09	0.117E+02	.0579	0.336E+09	0.116E+02	.0308	0.338E+09	0.116E+02	.0316	0.329E+09	0.114E+02
2477.7	.1350	0.338E+09	0.117E+02	.0939	0.334E+09	0.115E+02	.0516	0.325E+09	0.112E+02	.0507	0.331E+09	0.114E+02
3683.4	.2034	0.334E+09	0.115E+02	.1417	0.329E+09	0.114E+02	.0768	0.325E+09	0.112E+02	.0760	0.328E+09	0.113E+02
4774.5	.2657	0.331E+09	0.114E+02	.1811	0.334E+09	0.115E+02	.1004	0.322E+09	0.111E+02	.0982	0.329E+09	0.113E+02
5889.8	.3254	0.334E+09	0.115E+02	.2161	0.345E+09	0.119E+02	.1207	0.330E+09	0.114E+02	.1185	0.336E+09	0.116E+02
		TEST 235										
1247.9	.0761	0.302E+09	0.104E+02	.0523	0.302E+09	0.104E+02	.0279	0.303E+09	0.104E+02	.0280	0.302E+09	0.104E+02
2405.3	.1350	0.328E+09	0.113E+02	.0931	0.327E+09	0.113E+02	.0510	0.319E+09	0.110E+02	.0499	0.326E+09	0.112E+02
3611.0	.2048	0.325E+09	0.112E+02	.1416	0.323E+09	0.111E+02	.0769	0.318E+09	0.110E+02	.0755	0.324E+09	0.112E+02
4666.0	.2659	0.323E+09	0.112E+02	.1802	0.328E+09	0.113E+02	.1000	0.316E+09	0.109E+02	.0974	0.324E+09	0.112E+02
5805.4	.3264	0.328E+09	0.113E+02	.2157	0.341E+09	0.118E+02	.1205	0.326E+09	0.112E+02	.1182	0.332E+09	0.115E+02

AVRAGE STIFFNESS = 0.33323E+09
STANDAR DEVIATION OF THE SAMPLE = 0.88072E+07
STANDAR DEVIATION = 0.86292E+07

TABLE 6B LATERAL BENDING OF 136 RE RAIL

LOAD	@ L/2 DEFLECTION	EI	I	@ L/4 DEFLECTION	EI	I	@ L/8 DEFLECTION	EI	I	@ L/8 DEFLECTION	EI	I
(LB)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)	(IN)	$(LB\text{-}IN^2)$	(IN^4)
		TEST 236										
1202.9	.0456	0.494E+09	0.170E+02	.0320	0.484E+09	0.157E+02	.0164	0.504E+09	0.174E+02	.0187	0.442E+09	0.152E+02
2236.5	.0859	0.487E+09	0.168E+02	.0600	0.479E+09	0.165E+02	.0320	0.480E+09	0.166E+02	.0340	0.452E+09	0.156E+02
3456.9	.1363	0.475E+09	0.164E+02	.0951	0.469E+09	0.161E+02	.0510	0.466E+09	0.161E+02	.0517	0.459E+09	0.158E+02
4619.2	.1834	0.474E+09	0.164E+02	.1285	0.465E+09	0.160E+02	.0679	0.470E+09	0.162E+02	.0693	0.461E+09	0.159E+02
5756.9	.2299	0.471E+09	0.162E+02	.1596	0.466E+09	0.161E+02	.0849	0.469E+09	0.162E+02	.0866	0.459E+09	0.158E+02
		TEST 236										
1162.0	.0435	0.500E+09	0.172E+02	.0305	0.490E+09	0.159E+02	.0155	0.515E+09	0.178E+02	.0190	0.443E+09	0.153E+02
2341.6	.0907	0.483E+09	0.167E+02	.0639	0.472E+09	0.163E+02	.0343	0.469E+09	0.162E+02	.0356	0.452E+09	0.156E+02
3497.9	.1376	0.476E+09	0.164E+02	.0961	0.463E+09	0.161E+02	.0513	0.469E+09	0.162E+02	.0525	0.457E+09	0.157E+02
4537.2	.1790	0.474E+09	0.164E+02	.1252	0.466E+09	0.161E+02	.0666	0.465E+09	0.161E+02	.0690	0.455E+09	0.157E+02
5775.2	.2297	0.470E+09	0.162E+02	.1599	0.465E+09	0.160E+02	.0847	0.468E+09	0.162E+02	.0859	0.457E+09	0.157E+02
		TEST 236										
1097.8	.0380	0.540E+09	0.186E+02	.0267	0.529E+09	0.182E+02	.0131	0.576E+09	0.199E+02	.0140	0.539E+09	0.186E+02
2201.5	.0955	0.482E+09	0.166E+02	.0600	0.472E+09	0.163E+02	.0320	0.473E+09	0.163E+02	.0322	0.472E+09	0.162E+02
3427.8	.1329	0.493E+09	0.157E+02	.0929	0.475E+09	0.164E+02	.0497	0.474E+09	0.153E+02	.0493	0.475E+09	0.165E+02
4642.4	.1911	0.480E+09	0.165E+02	.1270	0.470E+09	0.162E+02	.0670	0.476E+09	0.164E+02	.0677	0.471E+09	0.162E+02
5687.6	.2273	0.468E+09	0.161E+02	.1580	0.463E+09	0.160E+02	.0839	0.465E+09	0.161E+02	.0839	0.466E+09	0.161E+02

AVRAGE STIFFNESS = 0.48374E+09
STANDAR DEVIATION OF THE SAMPLE = 0.17375E+08
STANDAR DEVIATION = 0.16796E+08

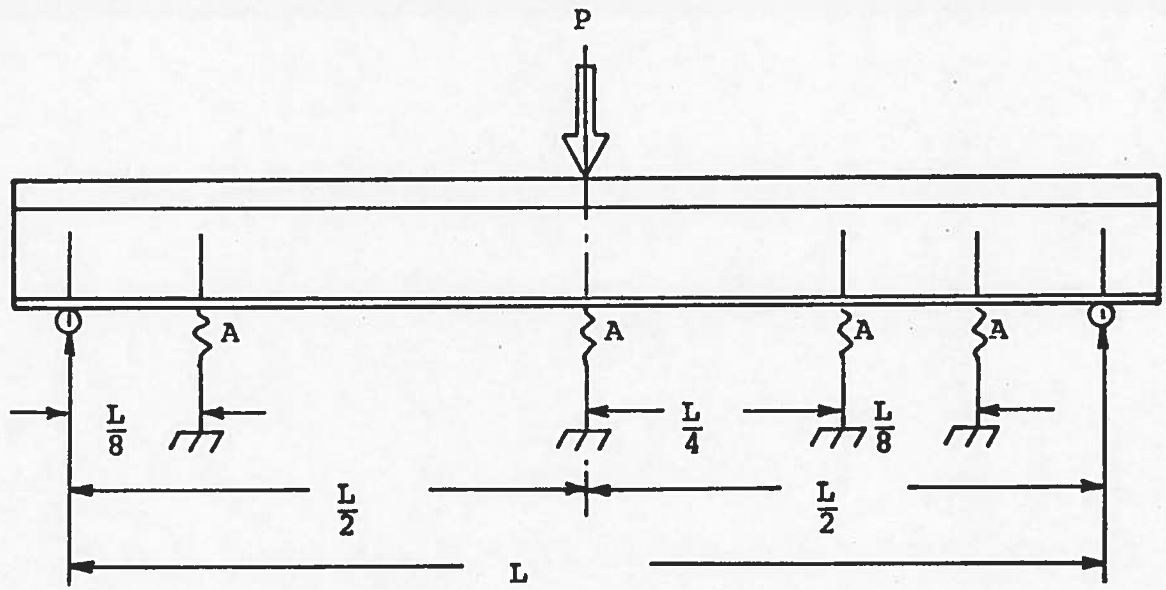
TABLE 7

SUMMARY OF RESULTS

RAIL BENDING STIFFNESS TESTS

	EI	Standard deviation	I*	AREA Value {2}	Calculated Value {3}
Vertical (115RE)	1884.4×10^6 lb-in^2	57×10^6 lb-in^2	64.9 in^4	65.6 in^4	64.3 in^4
Lateral (115 RE)	333.2×10^6 lb-in^2	8.8×10^6 lb-in^2	11.48 in^4	10.9 in^4	10.35 in^4
Vertical (136 RE)	2626×10^6 lb-in^2	44.49×10^6 16-in^2	90.54 in^4	94.9 in^4	96.4 in^4
Lateral (136 RE)	483.7×10^6 lb-in^2	17.37×10^6 lb-in^2	16.68 in^4	14.7 in^4	15.91 in^4

*E = 29×10^6 psi



L = 96 in. Sample rail length = 108 in.

A - Bourns Model 80294 - 2" displacement transducers on rail center line.

P - Force applied on centerline of rail head.

FIGURE 3 - GENERAL ARRANGEMENT for ESTABLISHING VERTICAL STIFFNESS (EI) of RAIL.

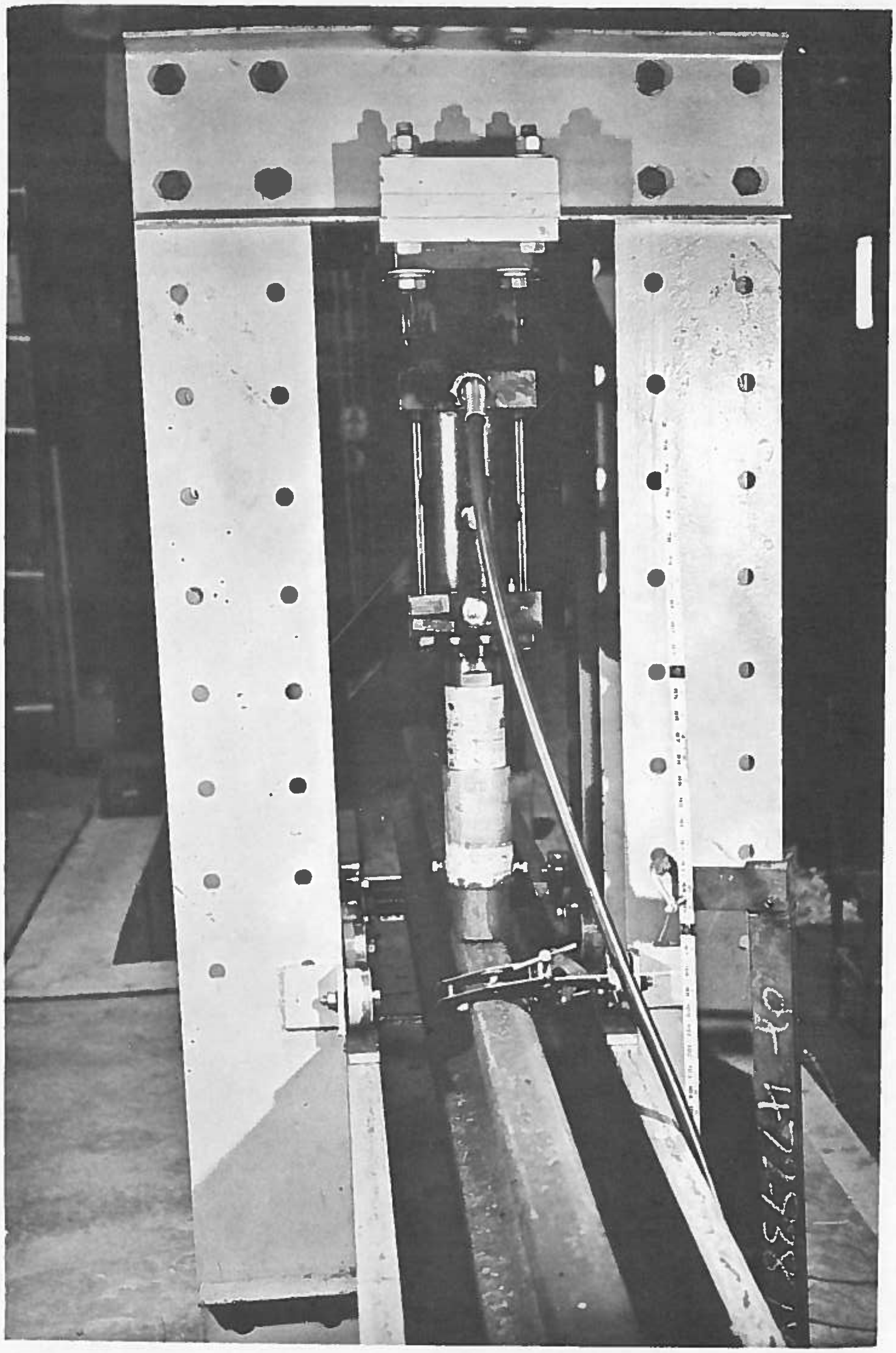


Figure 4 - Rail Vertical Bending Test

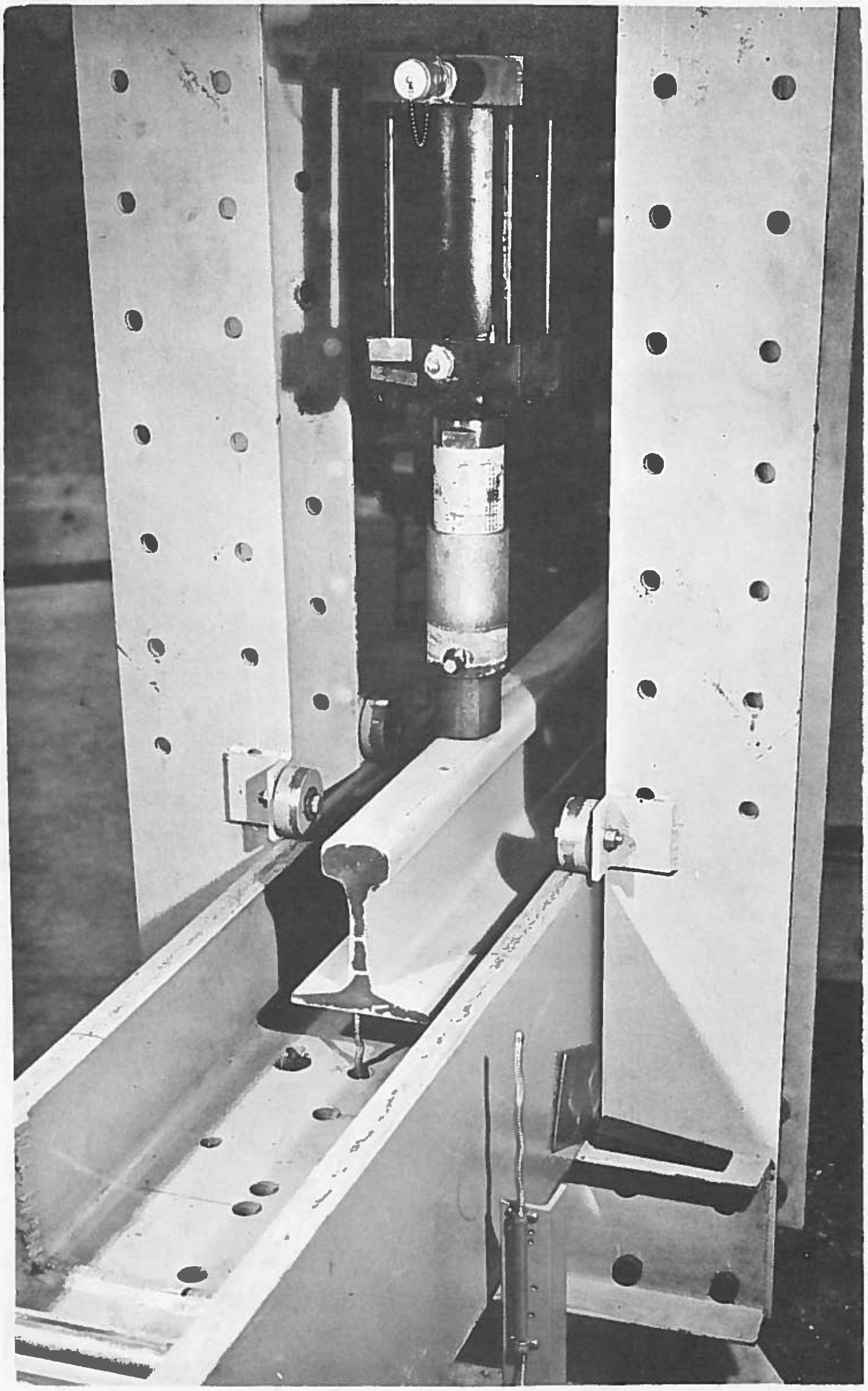


Figure 5 - Rail Displacement Transducers
Mounted in Test Fixture

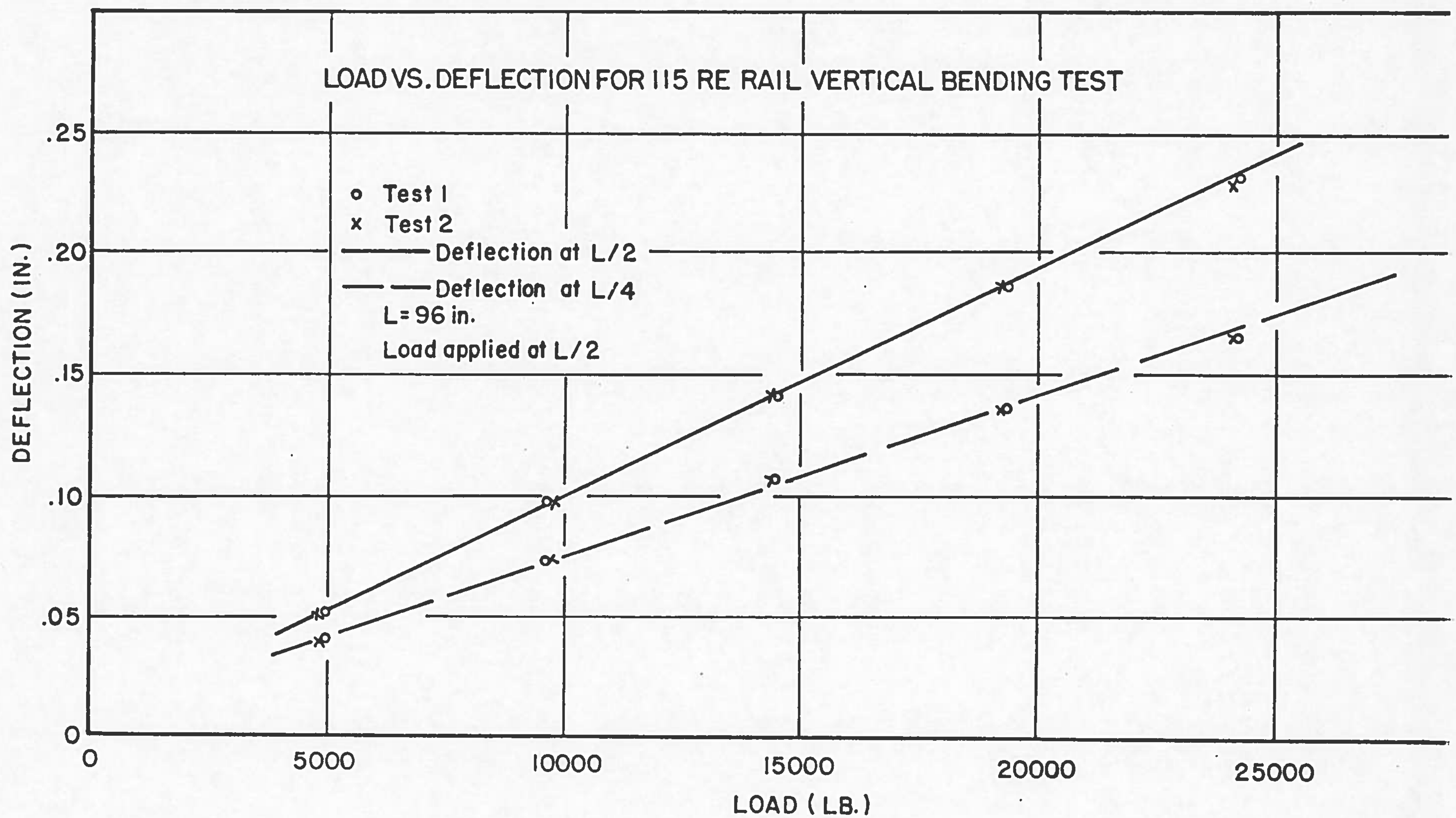
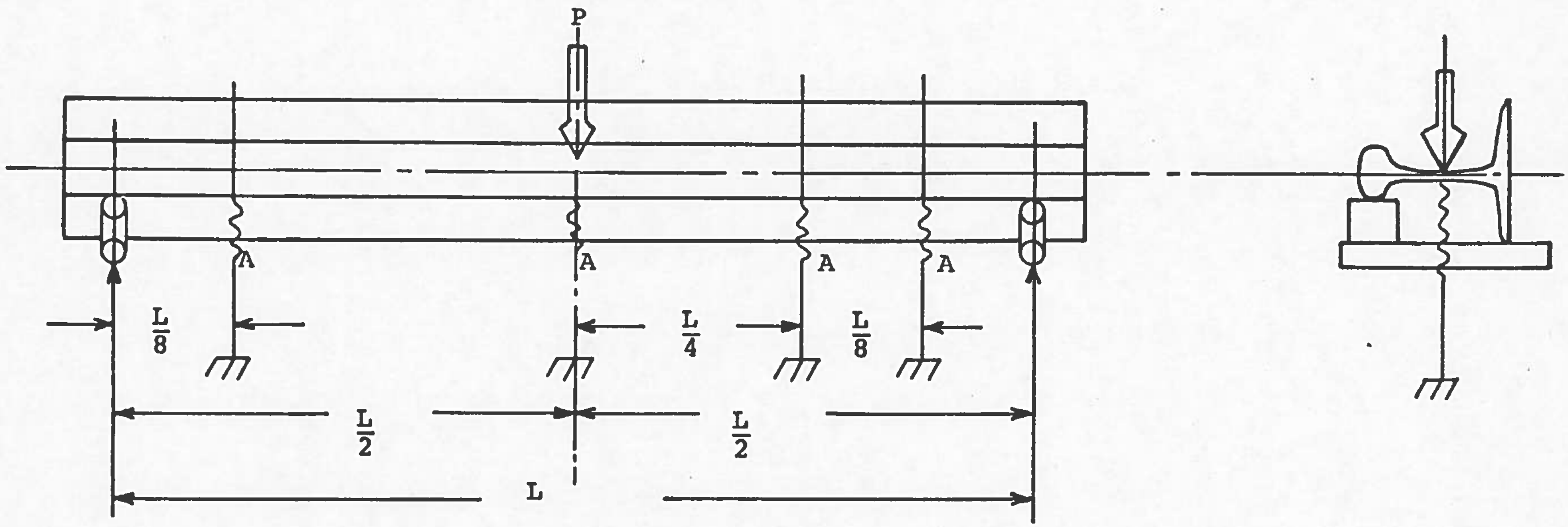

LOAD VS. DEFLECTION FOR 115 RE RAIL VERTICAL BENDING TEST
o Test 1
x Test 2
Deflection at L/2
Deflection at L/4
L = 96 in.
Load applied at L/2
DEFLECTION (IN.)
.25
.20
.15
.10
.05
0
0
5000
10000
15000
20000
25000
LOAD (LB.)

FIGURE 6



L = 96 in.; Sample rail length = 108 in.

A - Bourns Model 80294 - 2" displacement transducers

P - Force applied on neutral axis

FIGURE 7 - GENERAL ARRANGEMENT for ESTABLISHING LATERAL STIFFNESS (EI) of RAIL.

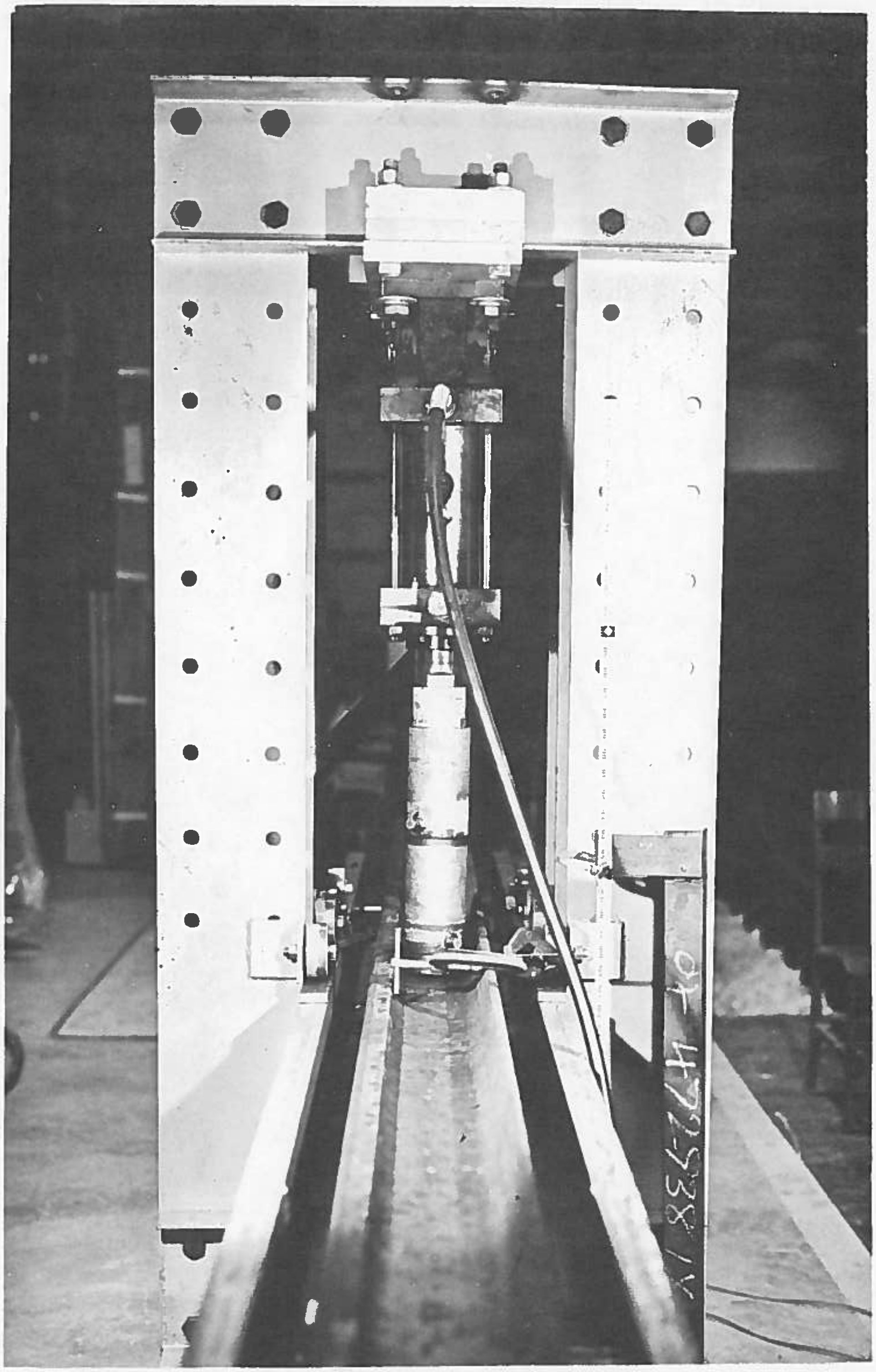


Figure 8 - Rail Horizontal Bending Test

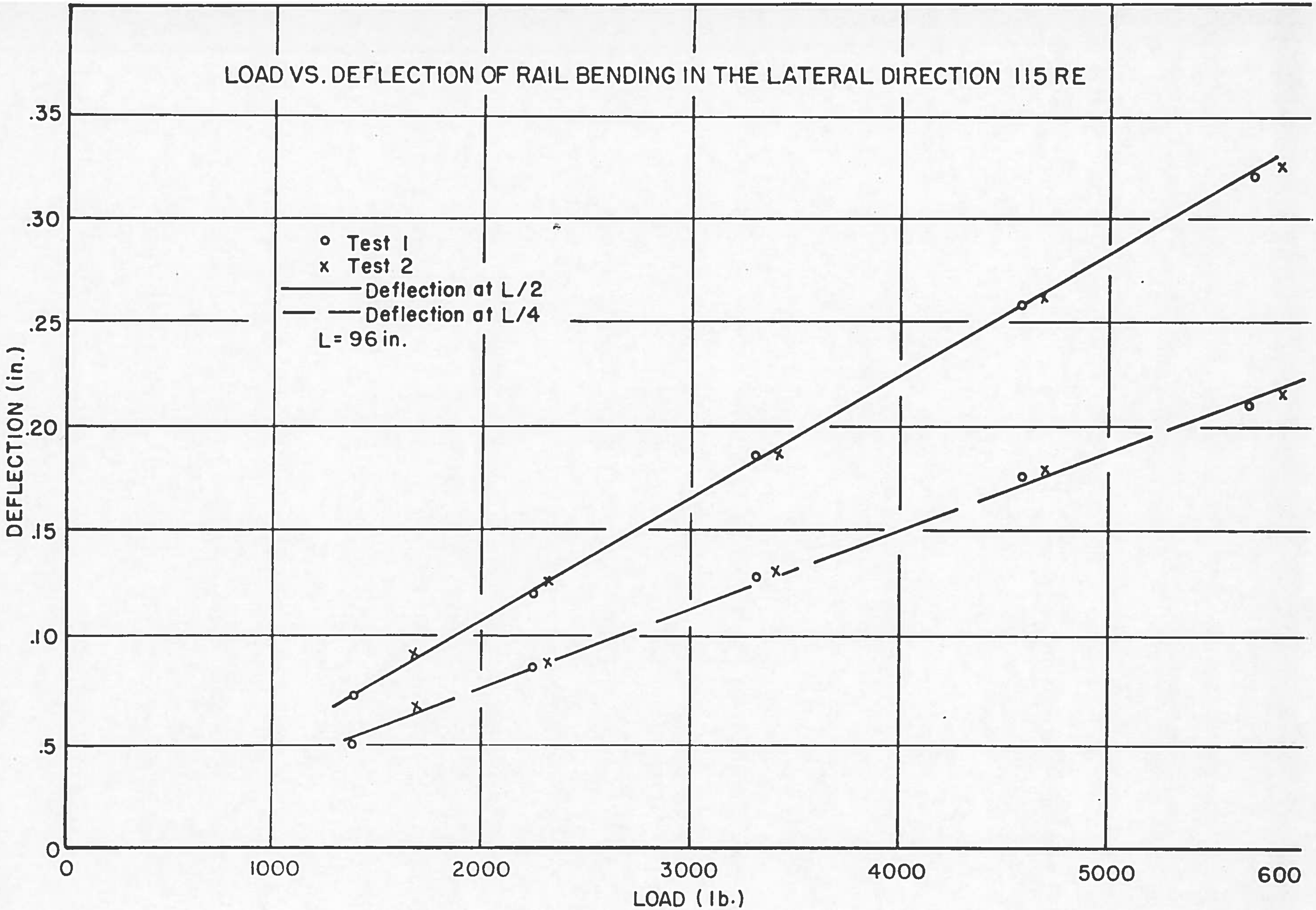

LOAD VS. DEFLECTION OF RAIL BENDING IN THE LATERAL DIRECTION 115 RE
o Test 1
x Test 2
Deflection at L/2
Deflection at L/4
L = 96 in.
DEFLECTION (in.)
.35
.30
.25
.20
.15
.10
.5
0
0
1000
2000
3000
4000
5000
600
LOAD (lb.)

FIGURE 9

5. FASTENER RESISTANCE

ROTATION ABOUT VERTICAL AXIS

5.1 Objective

The objective of this test series was to determine the resistance of several different fastener configurations to rotation of the rail about the vertical axis. These values were to be obtained for two rail sizes, 115 RE and 136 RE for the following tie-fastener configurations:

(1) Wood Tie - 2 cut spikes per plate

(2) Wood Tie - 4 cut spikes per plate

(3) Wood Tie - Pandrol fasteners with 2 lock spikes

5.2 Test Description

A 30 inch section of rail was mounted on a 54 inch section of wood tie, with the fastener configuration under investigation and an appropriate tie plate. (Described in Figure 11).

The rail-tie segment was mounted in the test fixture, as shown in Figure 10. A torsional load about the vertical axis, i.e., in the plane of the tie, was applied as illustrated in Figure 11. Deflections reference to the tie were measured using deflection transducers at the base and head of the rail, in the four locations shown in Figure 11. The applied load was measured with pressure transducer located in the hydraulic lines. A typical arrangement of loading jacks and deflection transducers is shown in Figure 12.

The torsional load was applied by two opposing lateral jacks located 12 inches from the center of the fastening system on opposite sides of the tie. The load was applied in 2,000 in-lbs increments until a rail base displacement of .25 in was recorded. At the conclusion of the loading cycle, the tie and fasteners were replaced and the test repeated. For each fastener configuration and rail size, this test series was repeated three times. Each test utilized a fresh tie segment and new fasteners.

All three fastener systems investigated were tested with both 115 RE and 136 RE rail. Conventional shouldered tie plates were used for the cut spike tests (Figure 10) while the special Pandrol tie plates, with two hold down lock spikes, were used for the Pandrol fastener tests (Figure 13)

At the conclusion of each test, the fasteners and ties were inspected for damage. Figure 14 shows a typical set of fasteners and ties , after the conclusion of the fastener resistance tests. In all cases, the damage to both ties and fasteners was minimal.

Data was recorded during the test, on both magnetic and paper tape and reduced in the manner described in Appendix A..

3 Results

The results of the fastener resistance tests were obtained in the tabular form shown in Table 8, and 9 giving deflection and rotation at both the rail head and rail base. In examining the respective data, it was noted that there was little significant difference between the rotation measured at the rail head and at the rail base(figure 15), indicating that no significant rail rotation or web bending was occuring. This agreed with visual observations conducted during the testing and resulted in the decision to utilize only the rail base rotations for the calculation of the torsional resistance of the fasteners.

The results of the individual fastener resistance tests are given in Figures 16 through 21, in the form of applied torque - rail rotation curves. Each figure contains all three repetitions of the test for the given fastener configuration and rail size.

In order to obtain a single value for fastener torsional resistance, the slope of the linear portion of the curves in Figures 16 through 21 were examined. The resulting values for fastener torsional stiffness are given in Table 9. Note the significant increase in fastener resistance that is obtained from increasing the cut spike configuration from 2 spikes per plate to 4 spikes per plate.

In order to more fully understand the significance of these results, the applied torque - rotation curves of Figures 16 - 21 are compared to the generalized torque - rotations curves for wood tie rail fasteners suggested by D. P. McConnell (4).

In his report, McConnell presents the two types of generalized applied torque - rotation curves illustrated in Figure 22. Curve OAD" represents the rotational response of the tie plate under the action of a continuously increasing torque, applied directly to the plate. Curve OACD represents the response of the entire rail fastener assembly to this applied torque, as measured by the rotation of the rail.

Thus, in curve OACD, segment OA represents the frictional resistance between the base of rail and the tie plate. At point A, this resistance is overcome and the rail slides on the plate until point C, where the rail base contacts the shoulder of the tie plate. Beyond this point, the system experiences the resistance of the fastener-tie configuration which is depicted by segment CD.

For the cut spike tests described in this report, measurements commenced with an initial applied torque of approximately 2,000 in-lbs. Since all tests were conducted in the absence of vertical load, the frictional resistance between the rail base and the tie plate was low, and consequently overcome with the initial torque.

Consequently, the test results shown in Figures 16 - 19 correspond to curve segment CD, which represents the resistance of the tie-fastener assembly itself.

In the case of the Pandrol fasteners, it was noted that the elastic nature of the Pandrol clips resulted in an initial applied torque to the rail. This pre-torque forced the base of the rail into contact with the tie plate shoulders even in the absence of an externally applied torque. Since there can be no relative motion between the rail and the tie plate, the Pandrol fastener assembly response corresponds to the response of the tie plate, illustrated by curve OD" of Figure 22, and the test results shown in Figures 20 and 21 confirm this behavior.

TABLE 9 FASTENER TEST 2 136 RE RAIL 2 SPIKES

MOMENT (IN-LB)	DEFLECTION (IN)				ROTATION X 10E-2 (RAD)	
	D1	D2	D3	D4	BASE	HEAD
3537.1	0.0028	0.0033	0.0024	0.0024	0.04952	0.05429
5761.8	0.0070	0.0080	0.0053	0.0054	0.11714	0.12762
8322.5	0.0115	0.0137	0.0104	0.0105	0.20857	0.23048
10931.3	0.0178	0.0207	0.0175	0.0182	0.33619	0.37047
13636.2	0.0311	0.0338	0.0303	0.0324	0.58476	0.63047
16228.9	0.0569	0.0586	0.0548	0.0592	1.06377	1.12186
18965.8	0.0877	0.0873	0.0832	0.0904	1.62748	1.69222
21414.5	0.1122	0.1132	0.1039	0.1132	2.05780	2.15586
23959.3	0.1783	0.1796	0.1454	0.1582	3.08188	3.21603
27192.3	0.2090	0.2073	0.1610	0.1738	3.52235	3.62793
29577.0	0.2228	0.2218	0.1710	0.1843	3.74872	3.86569
32105.8	0.2364	0.2356	0.1822	0.1957	3.98456	4.10531
34746.6	0.2501	0.2506	0.1949	0.2089	4.23556	4.37340
37419.4	0.2651	0.2661	0.2084	0.2229	4.50647	4.65378
39740.1	0.2890	0.2929	0.2333	0.2500	4.97019	5.16588
42284.9	0.3327	0.3368	0.2730	0.2935	5.76219	5.99566
45565.9	0.4040	0.4135	0.3298	0.3554	6.97723	7.30981
80.0	0.3142	0.3217	0.2412	0.2461	5.28460	5.40236

TABLE 8 FASTENER TEST 2 115 RE RAIL 2 SPIKES

MOMENT (IN-LB)	DEFLECTION (IN)				ROTATION X 10E-2 (RAD)	
	D1	D2	D3	D4	BASE	HEAD
3121.0	0.0141	0.0134	0.0151	0.0123	0.27809	0.24476
5793.8	0.0265	0.0231	0.0283	0.0221	0.52190	0.43047
8354.5	0.0398	0.0333	0.0421	0.0326	0.77998	0.62761
10979.3	0.0531	0.0438	0.0555	0.0438	1.03425	0.83427
13796.2	0.0650	0.0554	0.0681	0.0562	1.26755	1.06282
16485.0	0.0768	0.0673	0.0792	0.0692	1.48560	1.29993
18917.8	0.0883	0.0792	0.0907	0.0824	1.70460	1.53893
21622.6	0.1009	0.0925	0.1026	0.0965	1.93785	1.79981
24215.4	0.1146	0.1069	0.1157	0.1121	2.19298	2.08541
26728.1	0.1272	0.1206	0.1290	0.1270	2.43952	2.35766
29000.8	0.1440	0.1407	0.1469	0.1467	2.76977	2.73646
32169.8	0.1640	0.1635	0.1666	0.1696	3.14753	3.17132
34858.6	0.1835	0.1872	0.1877	0.1949	3.53377	3.63744
37419.4	0.2100	0.2202	0.2152	0.2276	4.04731	4.26218
39404.0	0.2523	0.2814	0.2747	0.2958	5.01484	5.49162
43037.1	0.3143	0.3519	0.3299	0.3566	6.12756	6.73741
45389.8	0.3746	0.4290	0.3920	0.4326	7.28802	8.18737
0.0	0.2186	0.2430	0.2198	0.2455	4.17281	4.64903

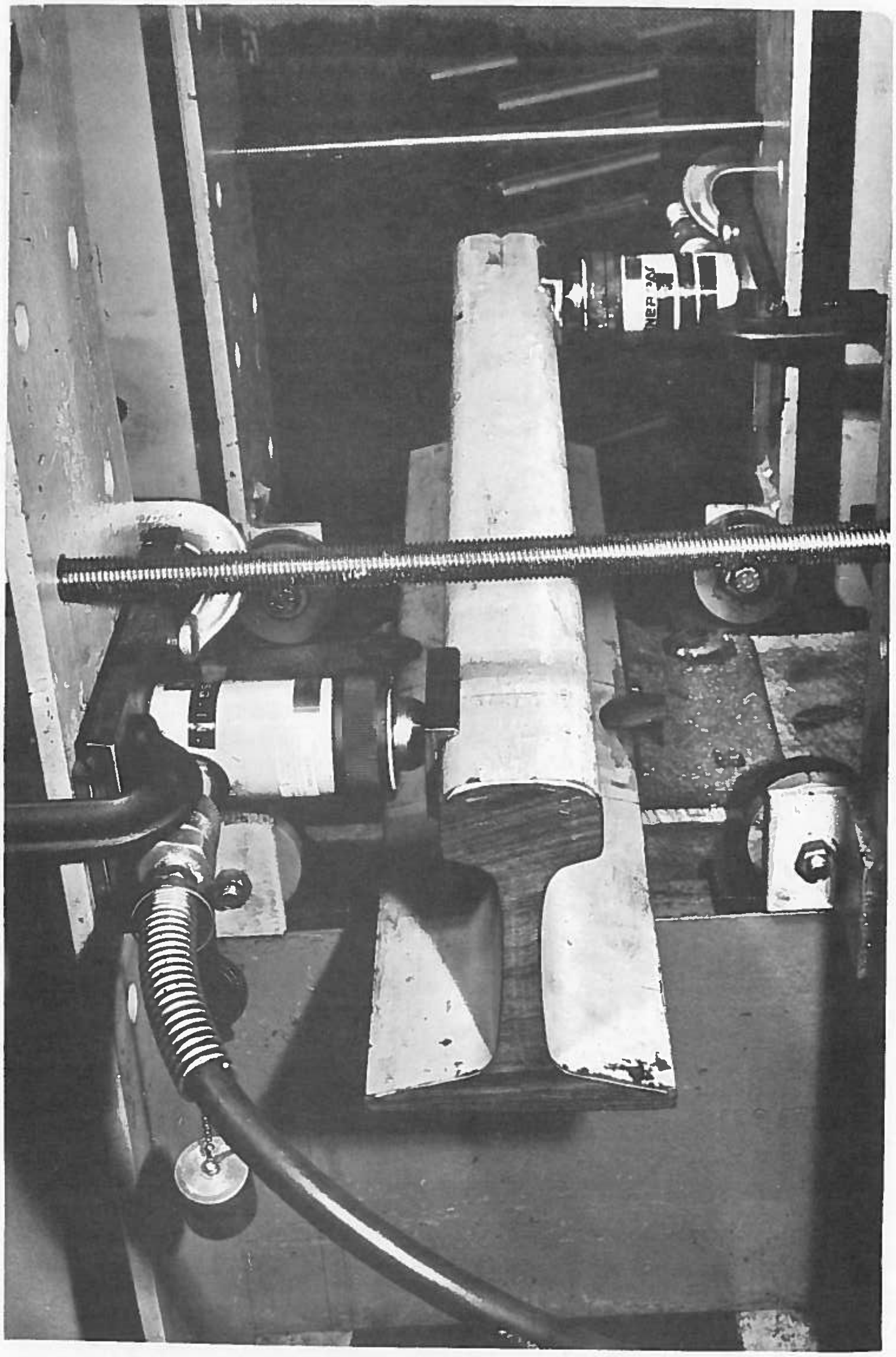
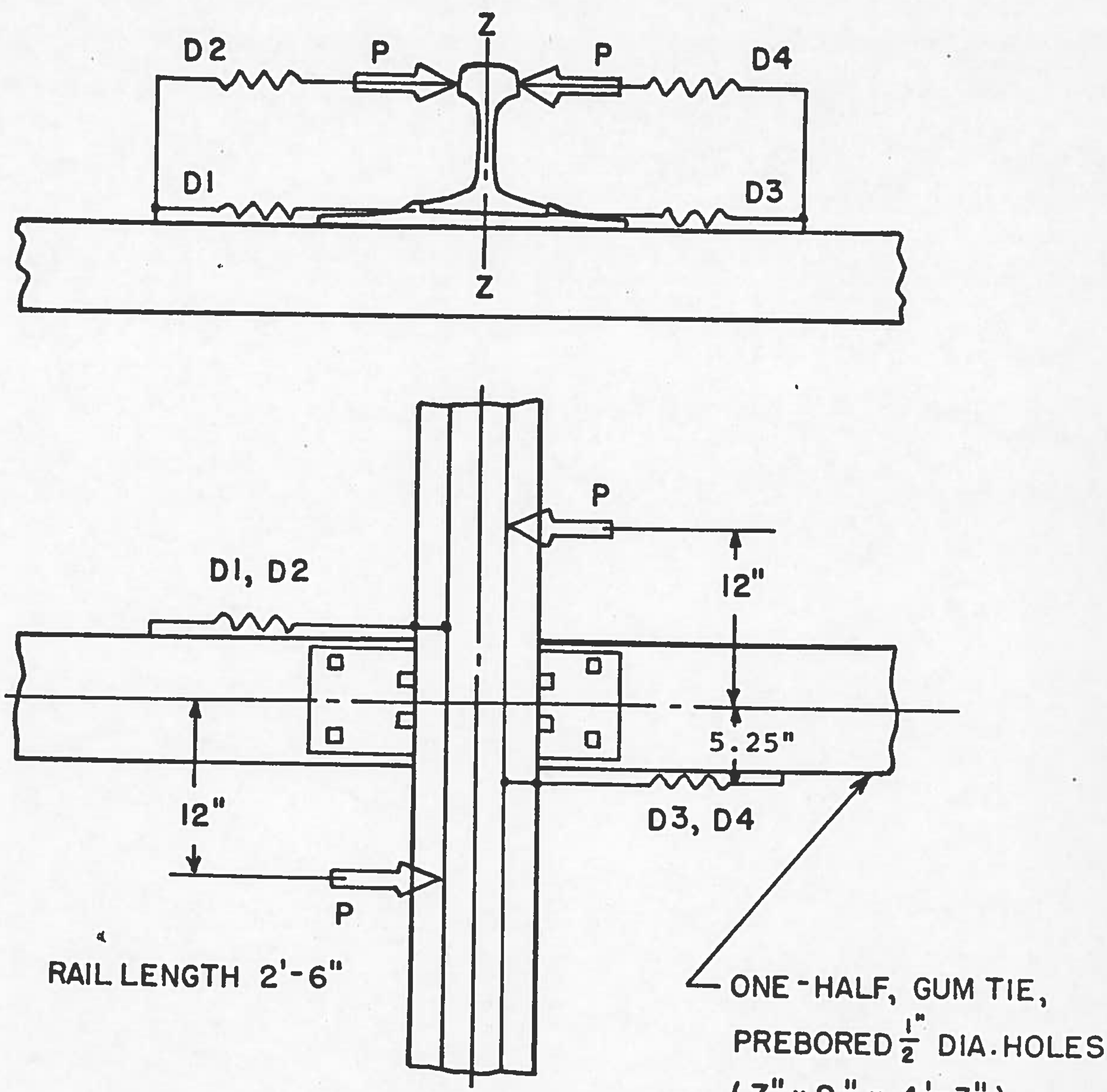


Figure 10 - Fastener Resistance About Vertical Axis. Wood Tie-Four Cut Spikes.



RAIL SIZE: 115 RE and 136 RE

TIE PLATE-AREA PLAN: No. 7, 8 Punch (115); No. 12, 8 Punch (136)

TYPE FASTENER: 2 Spikes, 4 Spikes

FIGURE 11 FASTENER STIFFNESS TEST ABOUT VERTICAL (Z) AXIS

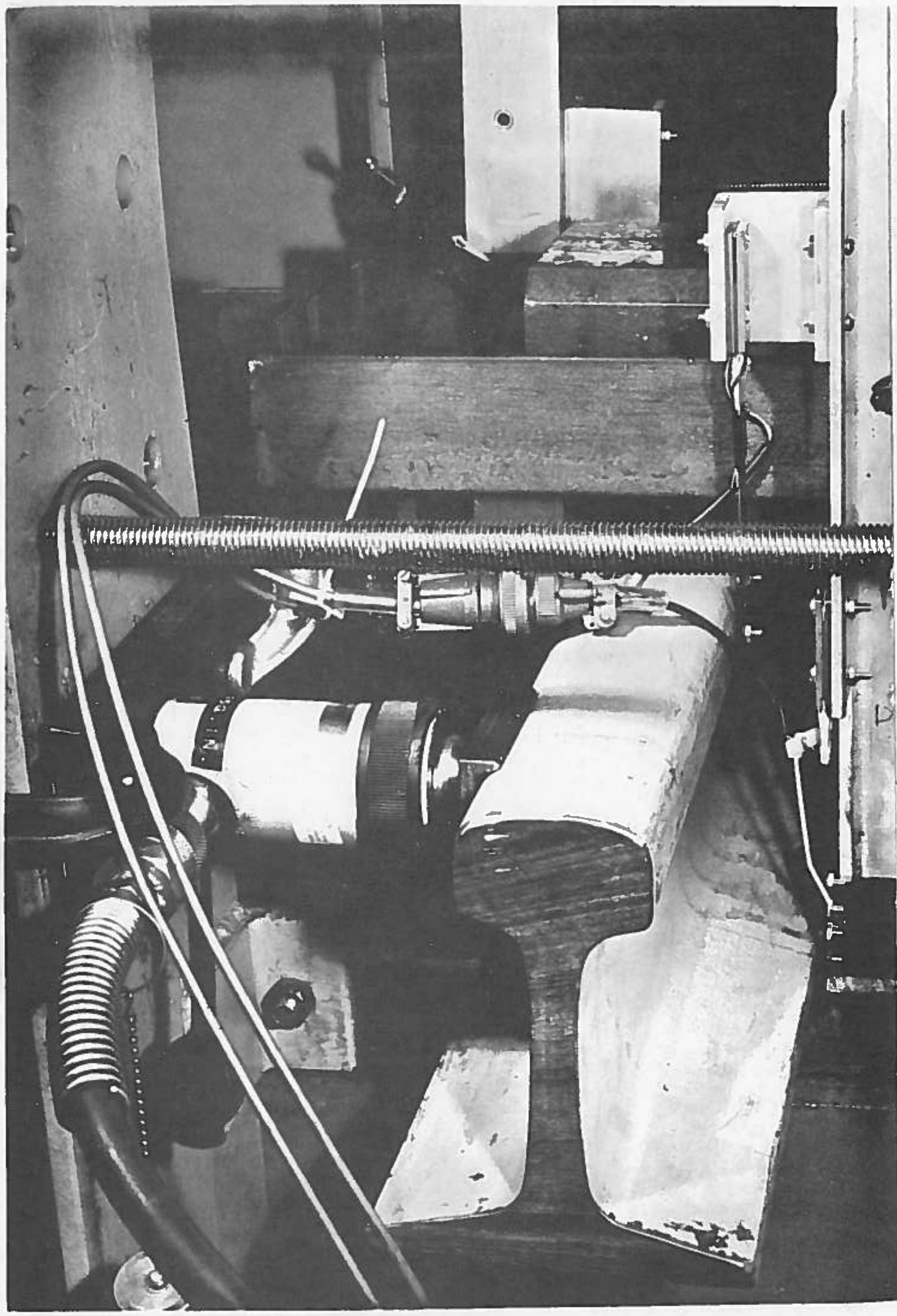


Figure 12. Deflection Transducers. Arrangement for Fastener Resistance Test.

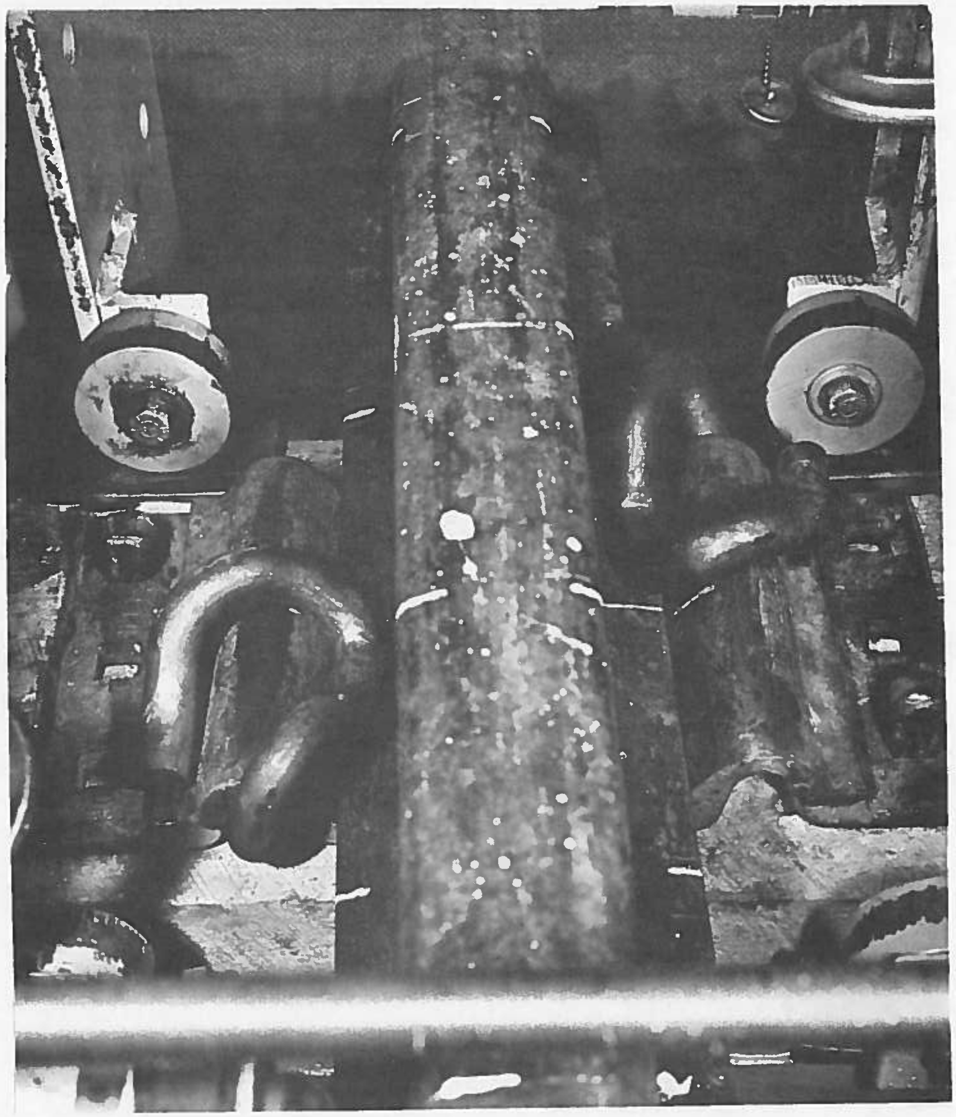


Figure 13. Fastener

Test of Pandrol Clips
With hold down lock
spikes.

Figure 14 - Examination of Tie and Fasteners
After Completion of Fastener Resistance Test

TABLE 10 SUMMARY OF RESULTS
FASTENER TORSIONAL RESISTANCE (@ BASE OF RAIL)
in-lb/rad x 10^6

TYPE OF FASTENER	TEST 1	TEST 2	TEST 3	AVERAGE	STANDARD DEVIATION
2 SPIKES 115 RE RAIL	.656	1.050	1.050	.919	.227
2 SPIKES 136 CF&I RAIL	1.139	2.013	1.260	1.471	.474
4 SPIKES 115 RE RAIL	5.320	1.925	2.713	3.319	1.78
4 SPIKES 136 CF&I RAIL	3.044	2.450	4.288	3.261	.938
PANDROL (PR601) 136 CF&I RAIL 2 LOCKSPIKES	4.317	3.646	2.625	3.529	.850
PANDROL (PR601) 136 CF&I RAIL 2 LOCKSPIKES	4.331	4.55	4.90	4.594	.287

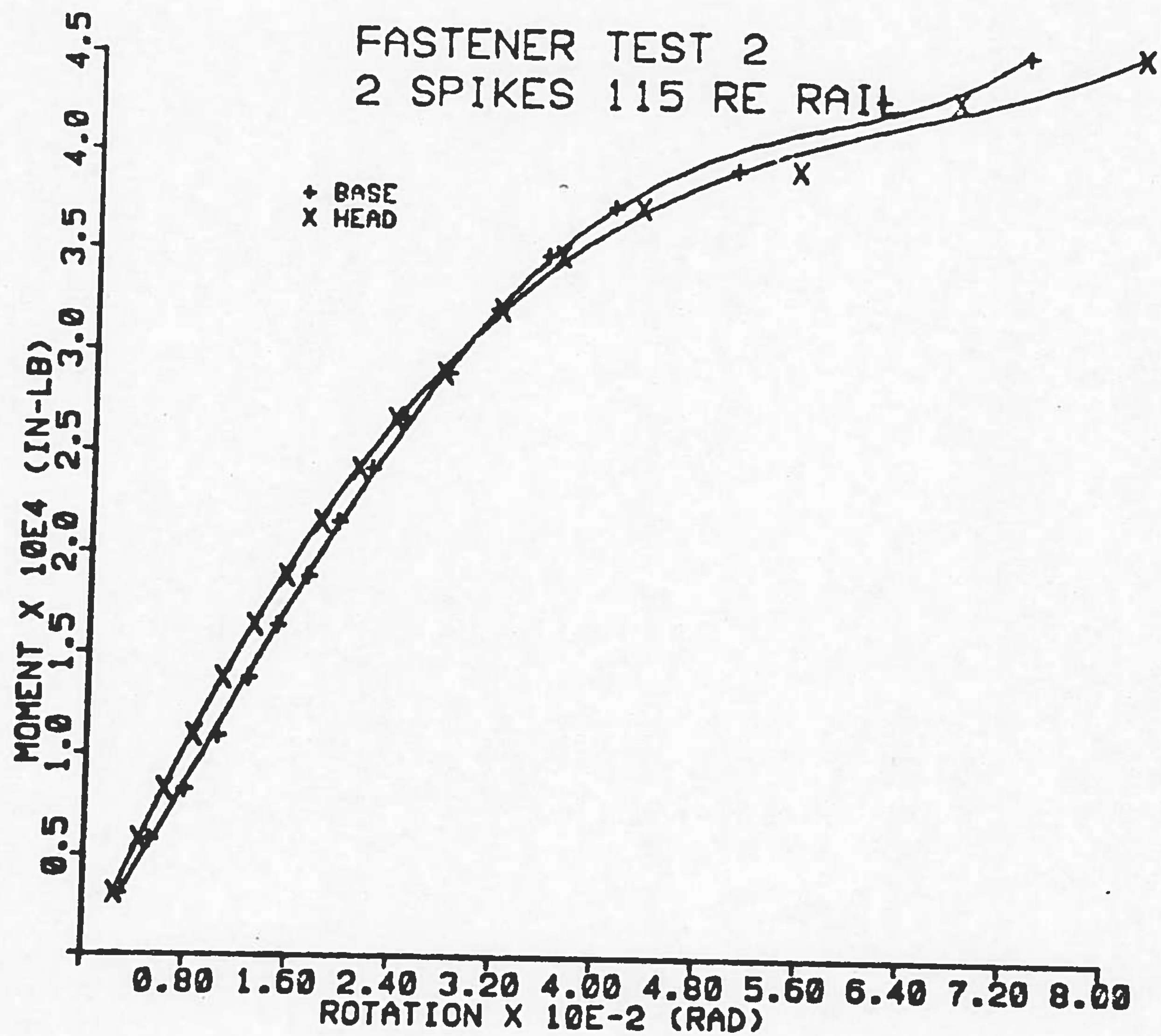

FASTENER TEST 2
2 SPIKES 115 RE RAIL
+ BASE
X HEAD
MOMENT X 10E4 (IN-LB)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 15

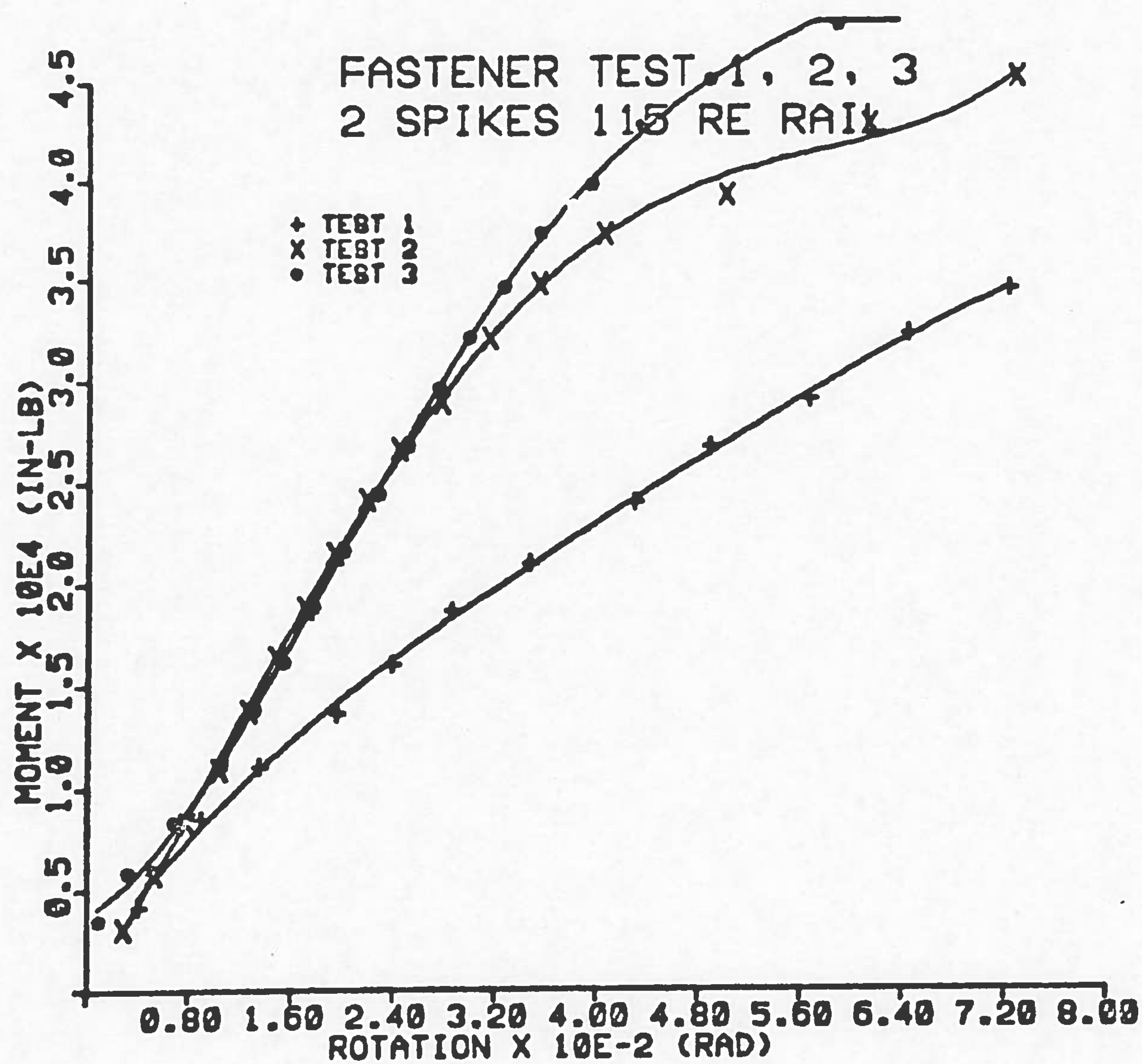

FASTENER TEST 1, 2, 3
2 SPIKES 115 RE RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 16

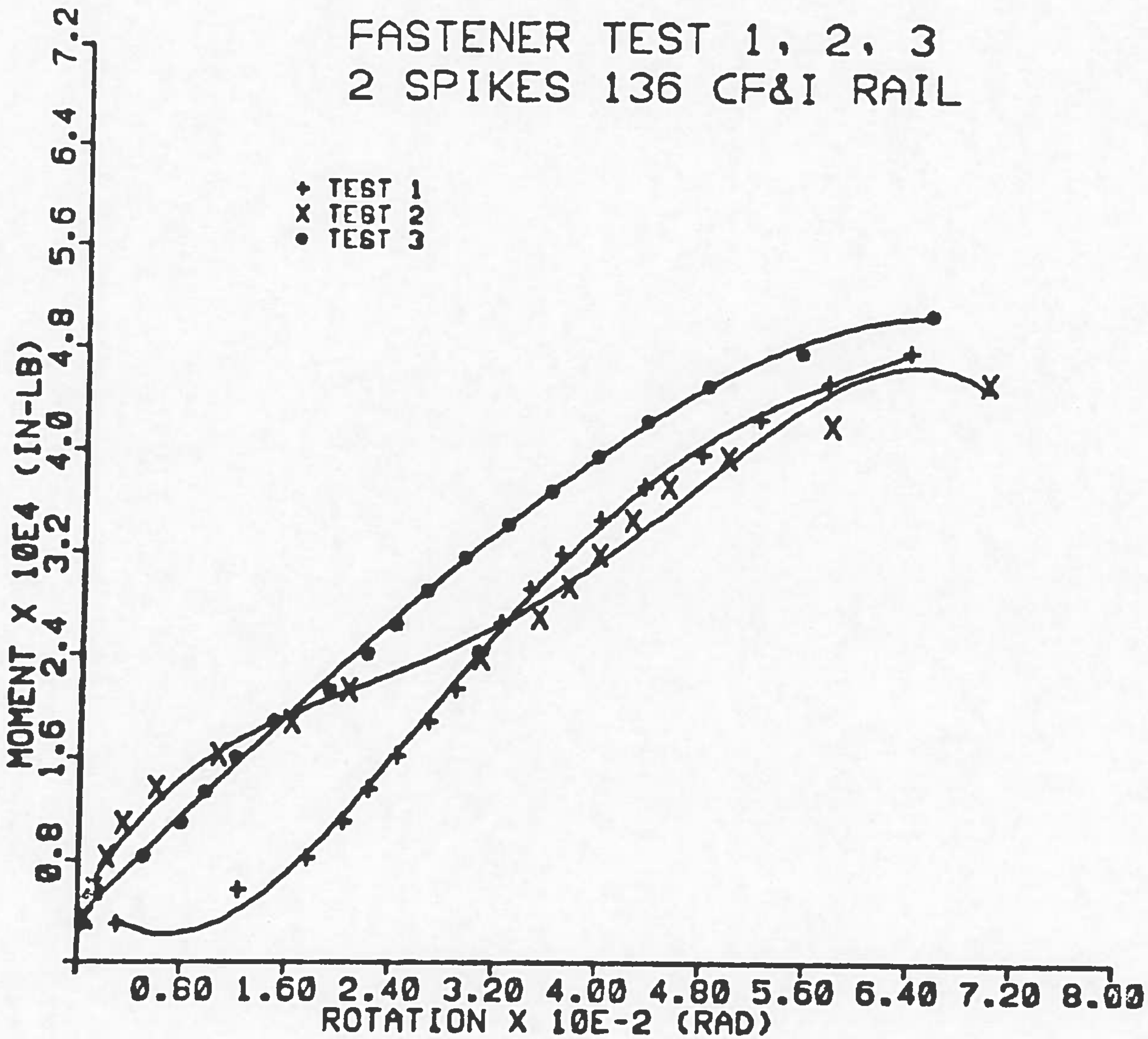

FASTENER TEST 1, 2, 3
2 SPIKES 136 CF&I RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
0.8
1.6
2.4
3.2
4.0
4.8
5.6
6.4
7.2
0.60
1.60
2.40
3.20
4.00
4.80
5.60
6.40
7.20
8.00
ROTATION X 10E-2 (RAD)

FIGURE 17

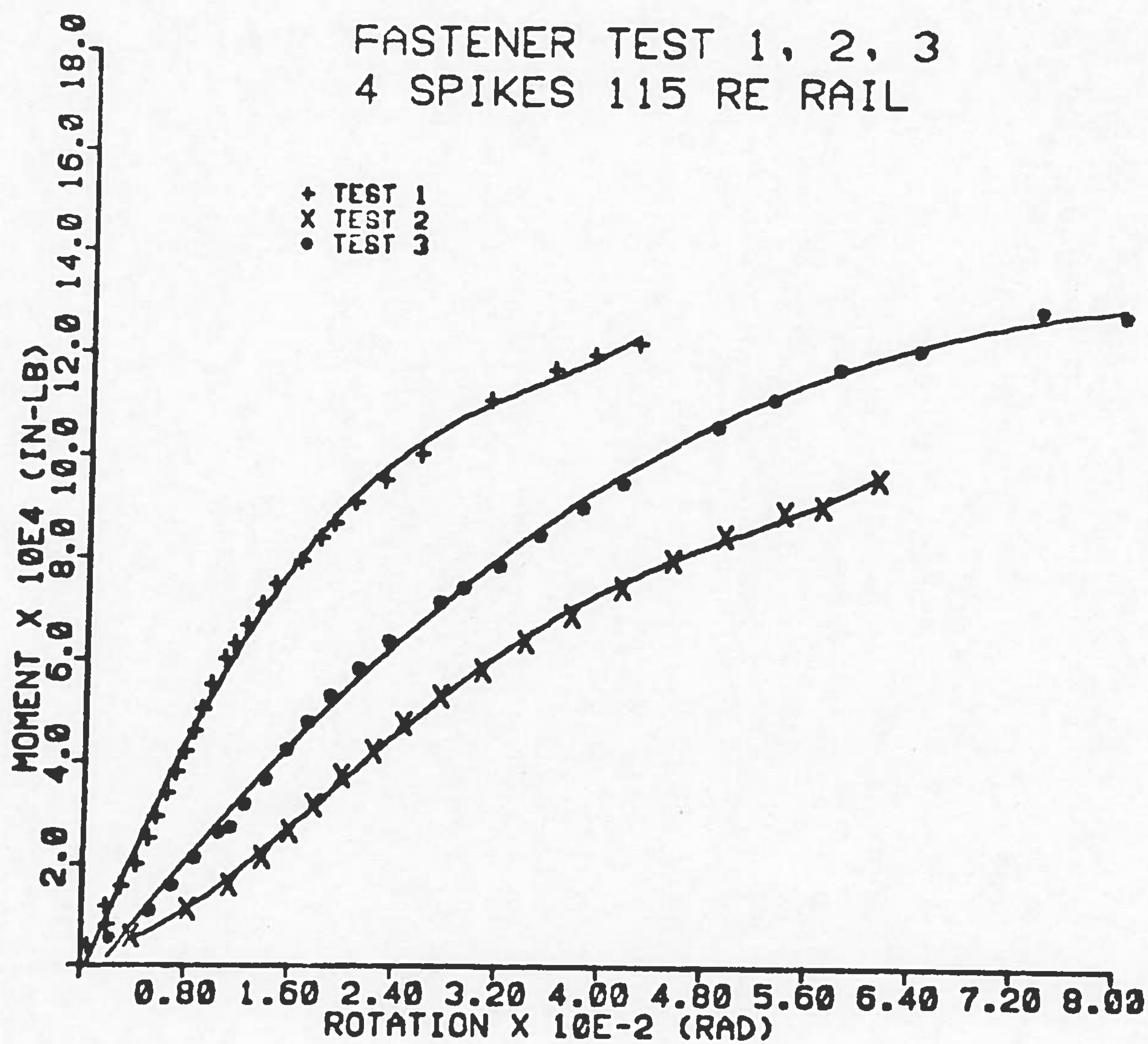

FASTENER TEST 1, 2, 3
4 SPIKES 115 RE RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 18

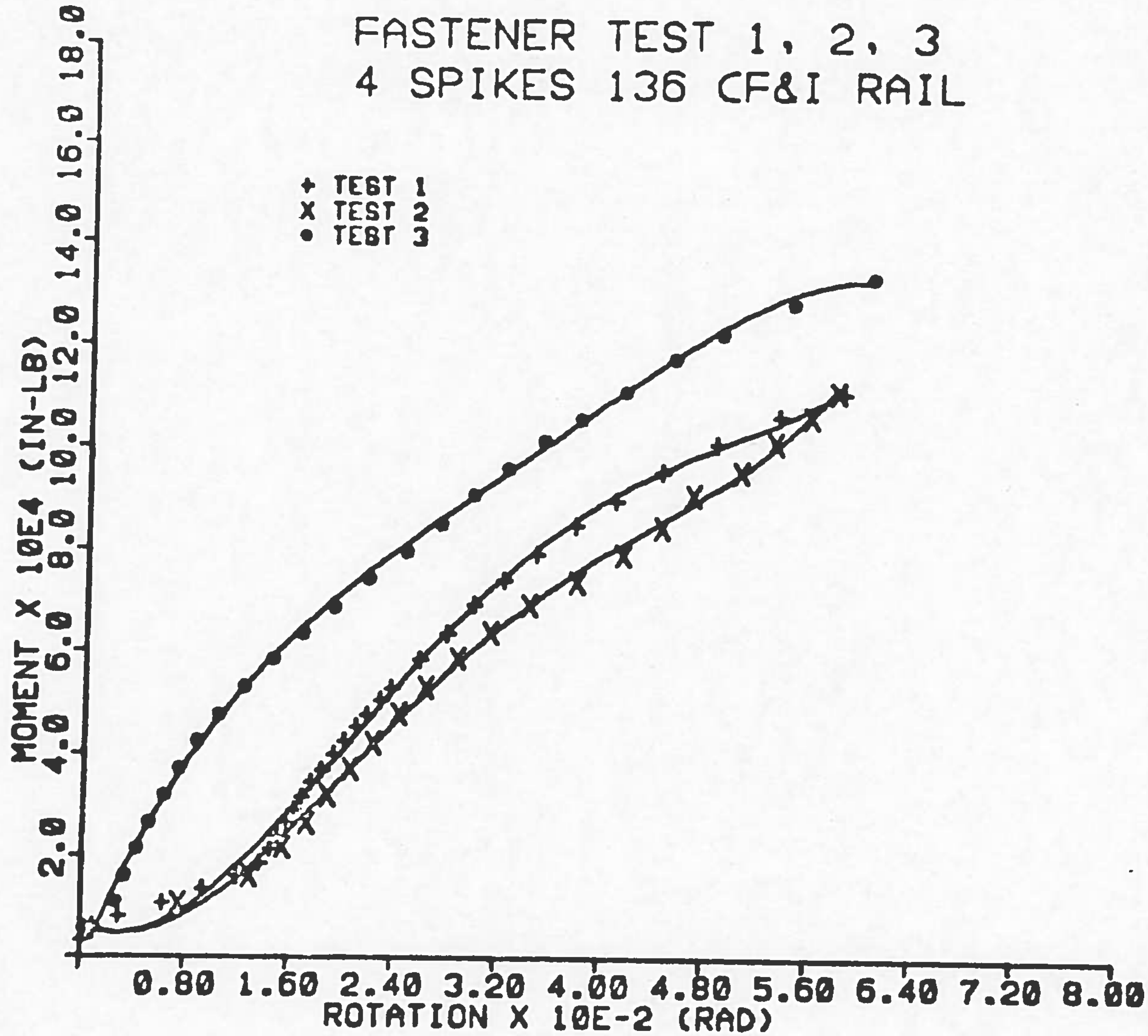

FASTENER TEST 1, 2, 3
4 SPIKES 136 CF&I RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 19

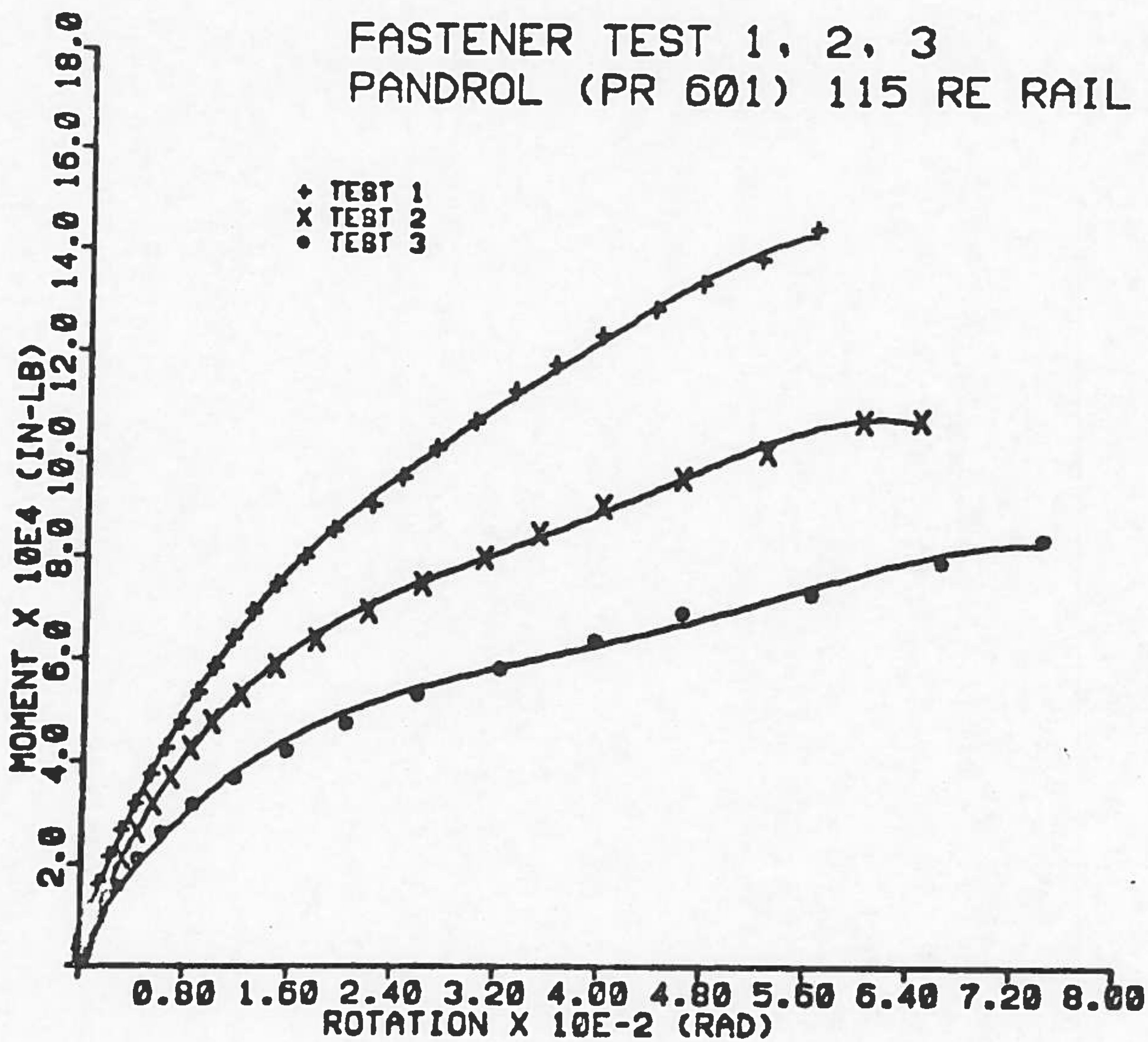

FASTENER TEST 1, 2, 3
PANDROL (PR 601) 115 RE RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 20

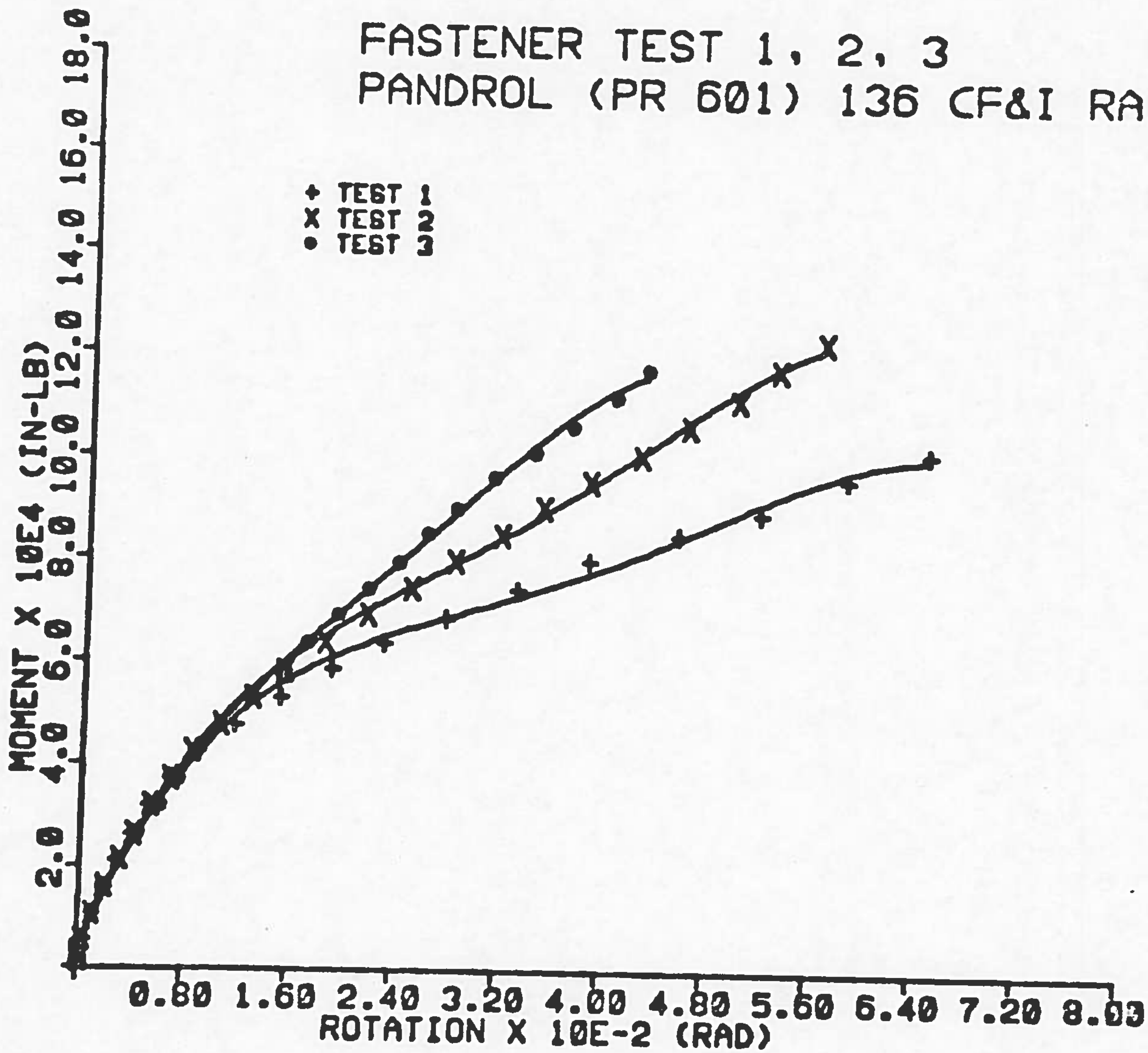
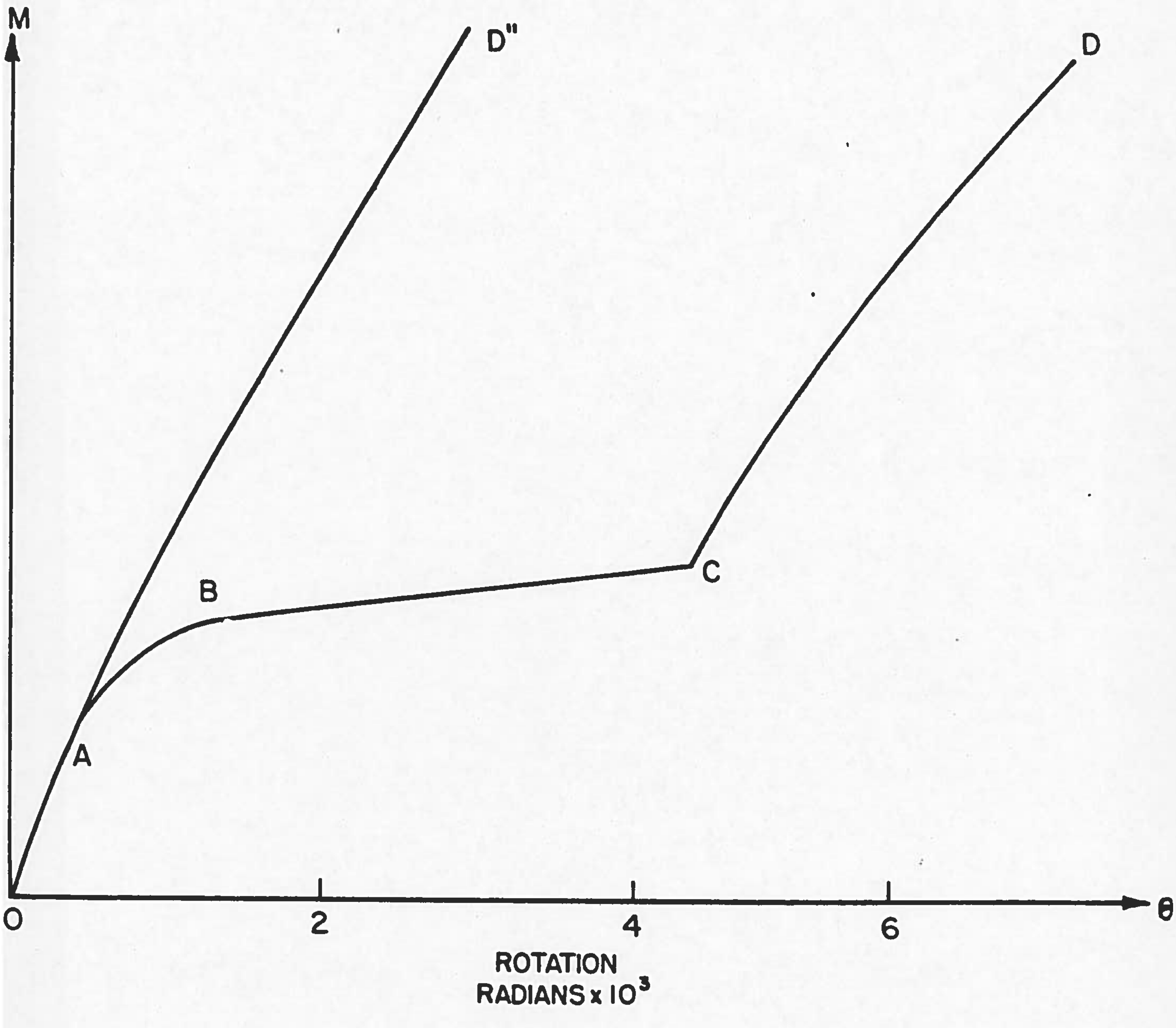

FASTENER TEST 1, 2, 3
PANDROL (PR 601) 136 CF&I RAIL
+ TEST 1
X TEST 2
• TEST 3
MOMENT X 10E4 (IN-LB)
2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0
0.80 1.60 2.40 3.20 4.00 4.80 5.60 6.40 7.20 8.00
ROTATION X 10E-2 (RAD)

FIGURE 21



TYPICAL TORQUE-ROTATION CURVE FOR WOOD TIE RAIL FASTENER

(Reference {4})

FIGURE 22

REFERENCES

1. Esbach, O.W. and Sounders, M., Handbook of Engineering Fundamentals, John Wiley and Sons, N.Y., 1975

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

3. Perlman, A.B. and Lewin, B.R., "Rail Section Properties", preliminary report to Transportation Systems Center, Cambridge, MA, July, 1977

4. McConnell, D.P., "On the Torsional Rigidity of Rail Fasteners in the Lateral Plane", Department of Transportation, Report, November, 1972

5. "Laboratory Test Plan for Mathematical Model Validation", Association of American Railroads, November, 1976, (Revised March, 1977), FRA Contract DOT-FR-30038

APPENDIX A

DATA RECORDING AND REDUCTION

All data measurements made during the conduct of the tests were recorded with the Track Structures Dynamic Test Facility Data Recording System and reduced on the Association of American Railroads DEC-20 computer system.

The Data Recording System (Fig.A.1) is made up of three major subcomponents; strain gauge signal conditioners, data scanner (with printer), and magnetic tape recorder. The signal conditioners are Electronic System Design Inc., model C-721 conditioners modified for use as displacement signal conditioners. The two data scanners are Monitor Labs Inc., model 9400 Data Loggers with paper tape recording capability.

They are capable of scanning up to 100 channels each, at a maximum rate of 2.5 channels per second. The two magnetic tape recorders are Cipher Data Products, model 70-M. Each unit is capable of recording up to 100 channels of data at three different tape densities (odd parity). The recording mode being used during the tests is industry-compatible, with the recorder set for use at 800 bpi density.

The complete Data Recording System is thus capable of monitoring up to 200 channels of test data, at a maximum rate of 2½ channels per second (per unit). All channels are recorded on magnetic and (digitized) paper tape.

All data recorded on the Data Recording System is processed on the AAR DEC-20 System. The test data is scaled, converted to engineering units, and stored in matrix table form.

At the beginning of each test, a zero reading is recorded on all active channels. This gives a reference zero and is used to determine the absolute maximum change in millvolts for each channel. These absolute maximum readings are then multiplied by the appropriate calibration factor to reduce the voltage reading to engineering units. The engineering units, together with the loads and channel number are then put into a "MxNxL" storage matrix, (M is the number of loads, N is the number of channels, and L is an identifier code) is created. For each test, a data file was stored on the disk area of the DEC-20 System. These data files are then transferred to magnetic tape through the use of existing system routines. Selected data channels, were also reduced manually from the paper tape in order to monitor the progress of the tests and to check the reduction software.

The plotting subroutines available in the DEC-20 System can then be used to plot data curves from the stored data matrices. Examples of these curves are presented in figures 16 - 21.

The plotted curves are fourth order polynomials whose coefficients have been determined through the use of a least-square fit through the data points.

Data can also be presented in the form of matrix tables, as shown in Tables 1-3.

All test data will be stored in data files, in matrix format, under the first six characters of the supplemental identification code. The format for these codes is given in Appendix B.

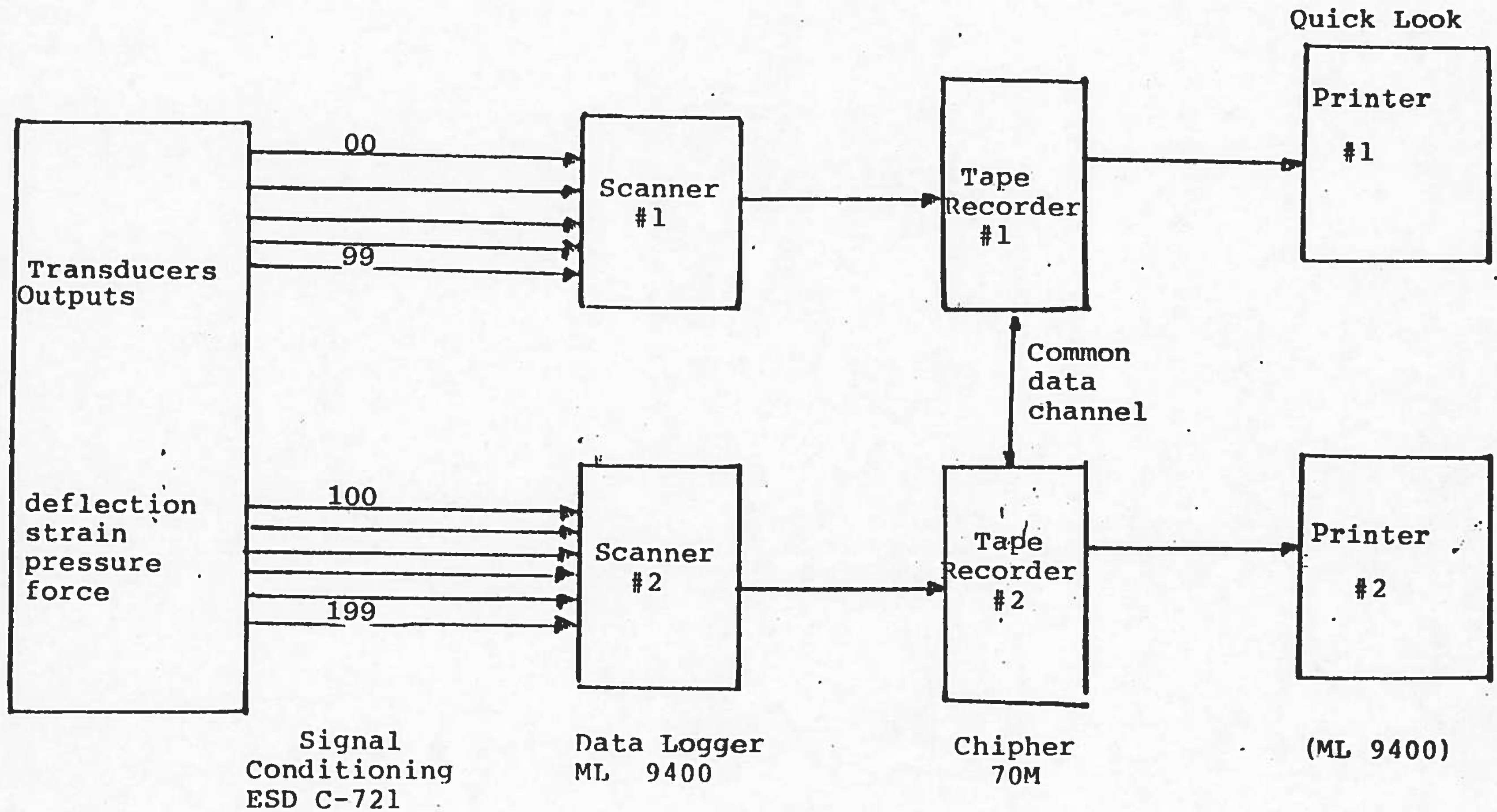


FIGURE A.1

Data Collection System

APPENDIX B - SUPPLEMENTAL TEST IDENTIFICATION CODE

The following is the procedure for labelling of all data and records for the supplemental tests.

LABELING PROCEDURE

The label of any given test in the supplemental group will consist of a ten digit number.

The ten numerical characters will be subdivided into four groups A, B, C, and W each group will consist of 1, 1, 4, and 4 characters respectively.

A B C C C C W W W W

Since this method is similar to the numbering of the main tests in the test plan*, the first character will always be 2 for the supplemental tests, so as to avoid confusion,

A = 2 Indicates Supplemental Tests

The second character will denote the number of the test varing from 1 to 7.

B Stands for the Test Number.

The test numbering is as follows:

1. Vertical track modulus
2. Lateral foundation stiffness
3. Bending stiffness of rail
4. Vertical bending stiffness of tie
5. Fastener resistance to rotation
6. Rotation stiffness of joint
7. Soil Properties

* Laboratory Test Plan for Model Validation {5}

The next four digits (CCCC) of the label will be used to to explain the parameter studies in each of the test and it will be explained for each individual test. The last four digits (WWWW), represent the applied loads or moments**

Test 1 Vertical Track Modulus

No label will be required for this test since it will be incorporated into subsequent in-track tests, however a file could be kept of the results under the #21000000.

Test 2 Lateral Foundation Stiffness

The label for this test should be 22XYZZWWWW where:

X stands for condition of track
- 1 to 8 is the degree of consolidation of the track***

Y stands for vertical loadings
- 1 is for vertical load
- 2 is without vertical load

When Y = 1

ZZ is the applied vertical load (Ø, 2Ø, 4Ø kips) otherwise it is zero

WWWW is the applied lateral load in kips

Test 3 Bending Stiffness of Rail

The label for test three is 23XZYYWWWW.

Where X stands for the direction.

- 1 vertical stiffness
- 2 lateral stiffness
- 3 torsional stiffness

Z Test Number

YY stands for rail size

- 15 115 lb RE
- 36 136 lb CF&I

WWWW is the applied load in lb when X=3 and the applied load in kips (5 to 25 kips) when X=1 or 2.

** The load or moment is always entered in such a way that the last digit in WWWW is the last digit of the load or moment.

*** The degree of consolidation will be explained in the test procedure.

Test 4 Vertical Bending Stiffness of Tie

The label for test four is 24XIZØWWWW.

Where X is position of the tie

1 is for vertical
2 is for vertical (upside down)
3 is for lateral

Z is the test number

WWWW is the applied load in lb.

Test 5 Fastener Resistance to Rotation

The label for this test is 25VXYZØWWW

Where V Test Number

X stands for the axis in question

1 is for the vertical axis
2 is for the longitudinal axis
3 is for the transverse axis

Y is type of fastener

2 is for two spikes
4 is for four spikes
5 is for screw spikes
6 is for compression clip
7 is for pandrol fastener
8 is for clip loc fastener

Z is the type of tie

1 is for wood tie
2 is for concrete tie

WWW stands for the rail size.

Test 6 Rotation Stiffness of Joint

The label for this test is 26VXØYWWWW

Where V Test Number

1 is for vertical
2 is for lateral

Y stands for the condition of joint

1 is for tight (bolt tension 2Ø,ØØØlb)
2 is for normal (bolt tension 12,ØØØlb)
3 is for loose (bolt tension 4,ØØØ)

WWWW stands for the load in kips.

The following is an example of the labelling described above. For a given label 2612Ø2ØØØ4 the following information is obtained.

Breaking the number into four groups described in the first paragraph:

A = 2
B = 6
CCCC = 12Ø2
WWWW = ØØØ4

A = 2 indicates that this is a supplemental test described in the test plan. [5] B = 6 indicates that it is the sixth test from the supplemental group, joint rotational stiffness. For this group of tests; CCCC is given as VXØY. V = 1 indicates test 1, X = 2 indicates that the joint is considered normal and bolt tension is 12,ØØØ lb. WWWW gives the applied load as 4 kips.