FEARS STRUCTURAL ENGINEERING LABORATORY

ROOF SYSTEMS BEHAVIOR

Progress Report

SIMPLE SPAN Z-PURLIN TESTS
WITH VARIOUS RESTRAINT SYSTEMS

ADDENDUM

by

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PREFACE

An investigation of the effect of various restraint systems on the behavior of single span C- and Z-purlin supported conventional roof systems is being conducted at the Fears Structural Engineering Laboratory, University of Oklahoma. A progress report "Simple Span Z-Purlin Tests with Various Restraint Systems" was issued in February 1982. Data from one additional test and the results of a series of diaphragm action tests are reported here. Chapter and section numbers correspond to numbering used in the original report. Errata for the original report is contained in Appendix J.

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INTRODUCTION

Results of nine single span, gravity loaded Z-purlin tests are described in the original report. Lateral restraint was provided using combinations of torsional restraint braces at the rafter lines and intermediate lateral restraints. In all tests, the purlin top flanges faced in the same direction. Since publication of this report, one additional flexure test has been conducted with the purlin top flanges opposing. The complete test matrix is shown in Table 1A.

The purpose and configuration of the additional Z-purlin flexure test is as follows:

Test VII. 19 ft. 7½ in. simple span; two Z-purlins; gravity loading; torsional restraint; flanges opposed.

Purpose:

To determine the effect of purlin orientation on purlin strength. To determine the magnitude of torsional restraint forces for flanges opposed.

Configuration:

Torsional restraint provided at the rafter location; no other restraint provided.

Details of the test set-up are as shown in Figure 1(a) and 1(d) in the original report, except the Z-purlins were oriented with the top flanges of both purlins pointing inward (opposing). All other details were identical to Test III. The purlins used in this test were cold-formed from the same coil in a continuous operation as those used in the previously reported tests. Results are presented in Section 3.7A of this Addendum.

Table 1A

Z-Section Test Matrix

Parameter / Test	Intermediate Bracing @¼ Pt.	Torsional Restraint @ Rafter	Panel Shear Stiffness Q	Torsional Restraint F	Remarks
I	X	X	X	X	Base Test
II	X*	X	X*		Greased top Flg.
III		X	X	X	
IV	X		X	X	
V		X		X	No side lap fasteners
VI		X	X	X	Same as III except panel connections reinforced
VII		X	X	X	Same as III except with flanges opposing

*Intermediate braces @ 2'-0" o.c.

Additional coupon test results for samples taken from a failed purlin in each test series are reported in Section 2.5 of this Addendum. Predicted failure loads for these purlins using the constrained bending assumption, AISI criteria with factors of safety removed, and the measured yield stress are found in Appendix I.

Results of cantilever diaphragm tests are also reported herein. The diaphragm tests were conducted in five series with purpose and configuration as follows:

Series A. Five 3 ft. 0 in. wide by 10 ft. 0 in. long panels; three Z-purlins spaced at 4 ft. 10½ in.; side lap fasteners at intermediate laps only and spaced at 30 in. on-center; panel to purlin fasteners at 12 in. on-center.

Purpose:

To determine diaphragm shear strength and shear stiffness using the standard configuration.

Configuration:

Standard.

Series B. Five 3 ft. 0 in. wide by 10 ft. 0 in. long panels; three Z-purlins spaced at 4 ft. 10½ in.; no side lap fasteners; panel to purlin fasteners at 12 in. on center.

Purpose:

To determine diaphragm shear strength and shear stiffness if side lap fasteners are not used.

Configuration:

Same as Series A except no side lap fasteners.

Series C. Five 3 ft. 0 in. wide by 10 ft. 0 in. long panels; two Z-purlins spaced at 5 ft. 0 in. centered on panels; side lap fasteners at intermediate laps only and spaced at 30 in. on-center; panel to purlin fasteners at 12 in. on-center.

Purpose:

To determine diaphragm shear strength and shear stiffness for flexure test configuration.

Configuration:

Similar to flexure Tests I, III, IV and VII.

Series D. Five 3 ft. 0 in. wide by 10 ft. 0 in. long panels; two Z-purlins spaced at 5 ft. 0 in. centered on panels; no side lap fasteners; panel to purlin fasteners at 12 in. on-center.

Purpose:

To determine diaphragm shear strength and shear stiffness for flexure test configuration without sidelap fasteners.

Configuration:

Similar to flexure Test V.

Series E. Five 3 ft. 0 in. wide by 10 ft. 0 in. long panels; two Z-purlins spaced at 5 ft. 0 in. centered on panels; side lap fasteners at intermediate laps spaced at 30 in. on-center; side lap fasteners at edge channels spaced at 6 in. on-center; panel to purlin fasteners at 12 in. on-center.

Purpose:

To determine diaphragm shear strength and shear stiffness for flexure test configurations with sidelap fasteners and reinforced panel-to-purlin connection at the rafter locations.

Configuration:

Similar to flexure Test VI.

Details of the test set-up are given in Section 2.5 and results in Section 3.8 of this Addendum.

Finally, fastener shear tests were conducted. Test details are given in Section 2.5 and results in Section 3.8 of this Addendum.

CHAPTER II

TEST DETAILS

2.5 Supplementary Tests

Diaphragm Tests. Cantilever diaphragm tests were conducted in accordance with the procedures given in "Notes on Steel Diaphragms", by James M. Fisher dated April 23, 1982. The test set-up is shown in Figure 10. Load was applied using a hydraulic ram and manual pump. The load was monitored with a load cell and associated instrumentation. Horizontal displacements of the load frame and upper right corner of the diaphragm were measured using displacement transducers. Displacements at the support locations were measured using dial gages. All readings were recorded to the nearest 0.001 in. Corrections were made to measured horizontal displacements using the procedure outlined in the referenced paper.

The loading procedure consisted of a preload and a final load applied in increments. A preload of approximately 10% of the estimated ultimate load was first applied to remove initial system movement. The diaphragm was then loaded to failure in increments of approximately 10% of the estimated failure load. Displacement readings were recorded at all increments.

All tests were conducted using five 3 ft. 0 in. wide by 10 ft. 0 in. long panels. Three tests were conducted using the "standard" configuration shown in Figure 7 with purlins spaced at 4 ft. 10½ in. The remaining four tests were conducted using two purlins spaced at 5 ft. 0 in. with the panel cantilevering 2 ft. 6 in. each side of the purlins. Load was applied in the plane of the web of the upper purlin. This configuration was used to more closely

represent the diaphragm stiffness of the flexural test set-up.

Results of the seven tests are discussed in Section 3.8.

Fastener Shear Tests. Fastener shear tests were conducted using 1.35 in. wide strips sheared from randomly selected panels. The strips were connected using two fasteners spaced 2 in. on-center. Edge distance in the direction of loading was maintained at 1 in. Tensile load was applied in line with the fasteners using a universal testing machine. An initial load of 0.3 kips was first applied and then released. The specimens were than loaded to failure with slowly increasing load. Only load at rupture and failure mode were recorded.

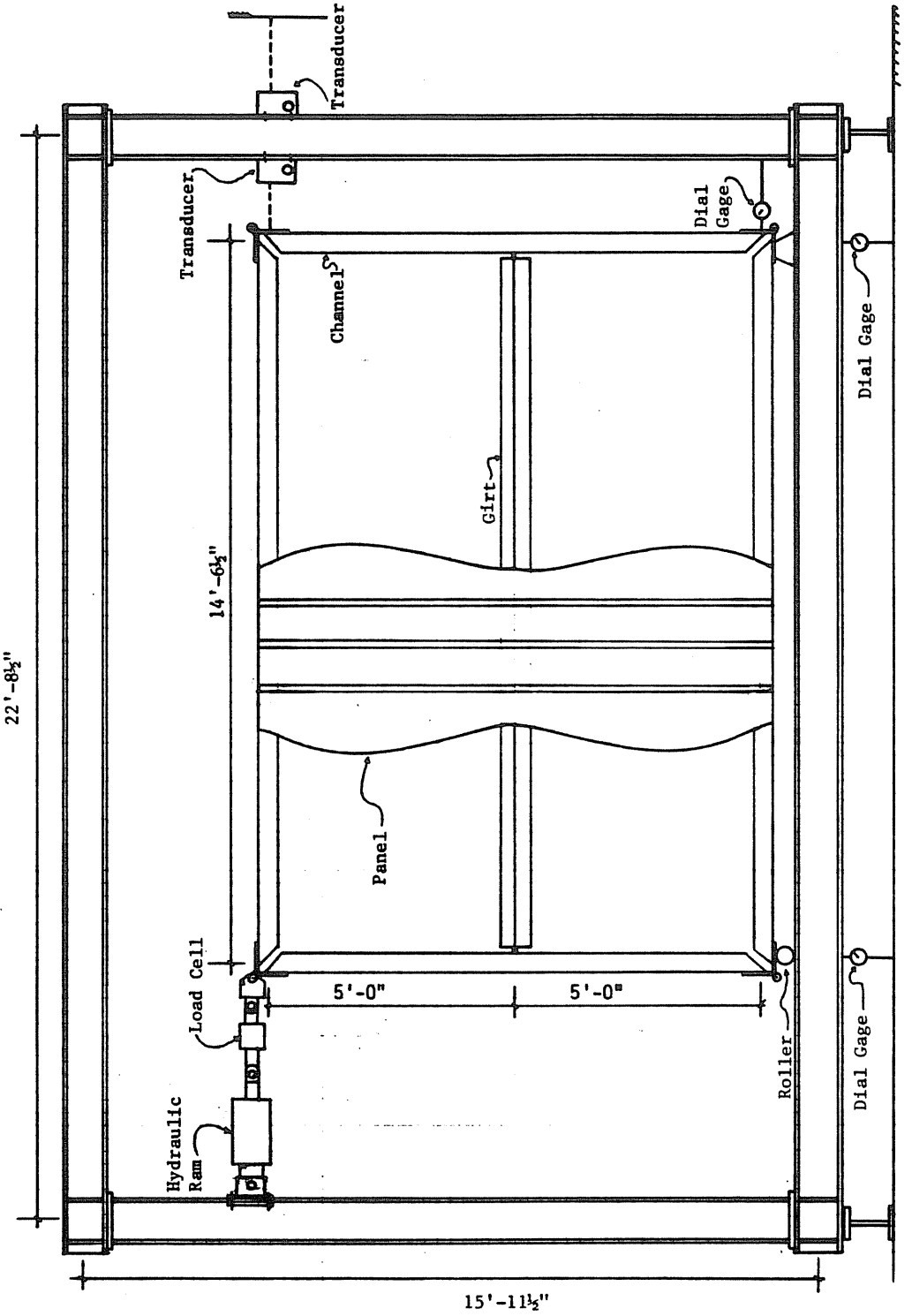


Figure 10. Diaphragm Test Set-up

CHAPTER III

TEST RESULTS

3.7A Test VII

Test VII was identical to Test III except with the top flanges of both purlins facing inward. Results are shown in Appendix G. Failure occurred at a load of 257.4 plf per purlin (versus 193.6 plf for Test III) by local buckling of the flange/web near the centerline of the internal purlin (purlin nearer the support joist). The predicted failure load using the constrained bending assumption and AISI criteria with factor of safety removed was 331.2 plf for an assumed yield stress of 56.0 ksi (for comparison with results in the original report) and 343.6 plf for the measured yield stress of 57.9 ksi.

Measured vertical deflections exceeded predicted values as shown in Figure G.5. Deflections were consistent between purlins and were linear until near failure. Figures G.6 and G.7 show inconsistency between brace forces at the rafter locations. Brace forces at the north end were generally in compression and those at the south end in tension. Relative to other tests, the magnitude of the brace forces was very low. Total brace force as a percent of gravity load on each purlin was less than 1%. Measured strains were consistent with the constrained bending assumption, Figures G.8 and G.9. Maximum lateral displacement at midspan before failure was less than 0.5 in., Figure G.10.

3.8 Results of Supplementary Tests

Coupon Tests. Tensile coupon test results for samples cut from the web of the failed test purlin are given in Table 5A. (Coupon test results shown

in Table 5 of the original report are for coupons cut from plain material). Measured yield stresses varied from 56.85 to 63.66 ksi with an average yield stress of 58.86 ksi. Excluding 63.66 ksi, the average value is 57.90 ksi which will be used in all calculations.

Cantilever Diaphragm Tests. Results for seven cantilever diaphragm tests are given in Table 8. Load versus deflection plots are found in Appendix H. Tests were conducted in five categories, A through E. Series A used standard test procedures. Series B was identical to Series A except sidelap fasteners were not installed. Series C, D and E were conducted using configurations similar to that used in the single span tests, e.g. purlin spacing at 5 ft. 0 in. and 10 ft. 0 in. long panels, and will be referred to as parameter tests. Series C represents Tests I, III, IV and VII, Series D represents Test V (no sidelap fasteners), and Series E represents Test VI (reinforced panel at the rafter lines). Shear strength varied from 771 to 2040 lb/ft and shear stiffness from 917 to 5429 lb/in.

In the standard tests, Series A and B, the shear strength was found to be 43% less when sidelap fasteners were not used, however, the shear stiffness decreased only 14%. For the parametric tests, the shear strength decreased 48% and the shear stiffness decreased 30% when sidelap fasteners were not used. Reinforcement of the panel edges had little effect on shear strength, but significantly effected shear stiffness (261%).

Fastener Shear Tests. Fastener shear test results are given in Table 9. Two tests were conducted; the average failure load was 695 lb. Failure was by shear out of the panel material in the direction of loading.

Table 5A

Tensile Coupon Test Results

Material Location		Test No.	Thickness (in.)	Width (in.)	Yield Stress (ksi)	Ultimate Stress (ksi)	Elongation %
Type	Test						
Purlin	I	1	0.094	0.491	57.27	69.85	37.5
	II	2	0.091	0.491	57.02	70.38	37.5
	III	3	0.090	0.492	56.85	71.01	34.5
	IV	4	0.090	0.501	59.42	70.73	37.0
	V	5	0.090	0.496	63.66*	71.14	34.0
	VII	6	0.090	0.498	58.93	70.76	32.5
		Avg.			57.90	70.65	35.5
Sheet		1	0.090	0.489	63.97	71.33	31.0
		2	0.090	0.486	62.27	70.68	29.5
		3	0.090	0.487	62.64	71.30	33.5
		Avg.			62.96	71.10	31.1
Panel	I	1	0.019	0.426	53.63	62.07	31.0
	II	2	0.019	0.424	52.61	60.47	31.5
	VII	3	0.020	0.497	45.92	-	27.5
		4	0.020	0.488	51.04	58.33	26.5
		Avg.			50.80	60.29	29.1

*Not included in average

Table 8

Cantilever Diaphragm Test Results

Series	Test No.	Side Lap Fasteners	Purlin Spacing	P_u (lbs)	Δ_{max} (in.)	S_u (lb/ft)	$0.4P_u$ (lbs)	D' (in.)	D_b' (in.)	G' (lb/in)
A	1	yes	9'-9"	3200	2.083	219.0	1280	0.700		
	2	yes	9'-9"	3558	2.739	243.5	1423	0.950		
	Avg.			3379		231.2	1352	0.825	0.00324	1071
B	1	no	9'-9"	1927	3.006	131.9	771	0.550	0.00185	917
C	1	yes	5'-0"	3620	2.156	247.7	1448	0.670		
	2	yes	5'-0"	4264	1.508	290.7	1751	0.413		
	Avg.			3942		269.2	1577	0.542	0.00197	979
D	1	no	5'-0"	2680	1.208	182.7	1072	0.154		
	2	no	5'-0"	2600	1.548	177.3	1040	0.337		
	Avg.			2640		180.0	1056	0.246	0.00132	1447
E	1	yes*	5'-0"	5000	0.514	340.9	2000	0.126	0.00250	5429

*With additional reinforcement at the rafter lines.

Notes: P_u = Maximum applied load
Δ_{max} = Maximum horizontal deflection
S_u = Shear strength
D' = Deflection at $0.4P_u$ (corrected)
D_b' = Bending deflection of cantilever beam
G' = Shear stiffness

Table 9
Fastener Shear Test Results

Test	Plate Width (in.)	Thickness (in.)	Ultimate Load (lbs)	Failure Mode
1	1.35	0.0237	720	Shear Out
2	1.35	0.0218	670	Shear Out
Avg.			695	

CHAPTER IV

SUMMARY AND OBSERVATIONS

A summary of the ten Z-purlin flexure test results is given in Table 4A. Comparison of results at load levels of 99 and 165 plf per purlin is given in Tables 6A and 7A, respectively. Results of seven cantilever diaphragm tests are found in Table 8. Both standard configuration and configurations representing parameters in the flexure test program were tested. Results of tensile coupon tests and fastener shear strength tests are given in Tables 5A and 9, respectively.

The following observations are made as the result of the additional tests:

1. Use of the average measured yield stress for determining predicted strength increased predicted failure load 0.4% to 4.9%.

2. The ratio of actual to predicted failure loads varied from 0.65 to 0.76, excluding Tests II and II-A. These tests are excluded because the intermediate brace restraint system failed or was not effective.

3. The highest ratios of actual to predicted loads were obtained in Tests VI and VII, 0.76 and 0.75, respectively. Effective diaphragm stiffness for these tests is greater than for all other tests.

4. Significant shear strength and shear stiffness is available even if sidelap fasteners are not installed as shown by cantilever diaphragm test Series B and D.

5. Panel to purlin connection near the diaphragm ends significantly

effects shear strength and stiffness (cantilever diaphragm test Series E versus other series) and purlin strength. Failure in Tests III and V was attributed to panel to purlin connection strength near the rafter line at actual load to predicted load ratios of 0.60 and 0.62, respectively. When the connection was reinforced, Test VI, the ratio increased to 0.76.

6. AISI design criteria with the constrained bending assumption are not adequate for the design of Z-purlins with sloping lips (nominally 45^{o}) and top flange lateral restraint with or without intermediate lateral braces.

Table 4A

Summary of Test Results

Test No.	AISI/Constrained Bending (plf) F_y = 57.9 ksi	Actual Failure Load (plf) (Actual/Predicted)	Failure Mode	Remarks
I	334.6	219.9 (0.66)	Local buckling of flange and/or web.	Initial failure was end bearing; purlins were repaired.
I-A	317.7	226.1 (0.71)	Local buckling of flange and/or web.	
II	311.9	132.0 (0.42)	Purlins rolled over.	Intermediate brace restraint system failed.
II-A	300.2	135.3 (0.45)	Purlins rolled over.	Several intermediate braces carried no load.
II-B	290.2	188.2 (0.65)	Tension flange lateral buckling	Outside two intermediate braces in compression.
III	321.8	193.6 (0.60)	Center portion of the purlin rolled.	Panel to purlin connection failed near support.
IV	306.8	231.0 (0.75)	Local buckling of the flange and/or web.	North end of the purlins were rolled toward west, (Fig. 1(d))
V	309.6	191.9 (0.62)	Purlins rolled.	Panel to purlin connection failed near supports.
VI	304.3	230.0 (0.76)	Local buckling of the top flange and/or web.	Panel to purlin connection was reinforced.
VII	343.6	257.4 (0.75)	Local buckling of the top flange and/or web of interior purlin.	Tests with flanges facing each other.

Note: If failure occurred during a load increment, the failure load was calculated assuming the partial increment was uniformly distributed. Symmetry of loading was maintained during the application of load increments.

Table 6A
Comparison of Results at 99 plf per Purlin

Test No.	Inter-mediate Bracing	Torsional Restraint	Shear Stiff-ness	Torsional Stiffness	Midspan Vertical Deflection Exterior (in.)	$\frac{\Delta m}{\Delta c}$	Measured Restraint Force as a % of Support Load		Lateral Displace-ment of Top Flange (Exterior) (in.)	Max. Stress	
							Exterior One Purlin	Interior Two Purlin		Tension (ksi)	Comp. (ksi)
I	yes	yes	yes	yes	0.96	1.14	NA	NA	0.46	18.1	19.2
I-A	yes	yes	yes	yes	0.89	1.00	16.7	38.6	0.04	NA	NA
II	yes	yes	yes*	no	1.02	1.18	NA	NA	0.10	19.0	20.0
II-A	yes	yes	yes*	no	0.81	0.85	NA	NA	0.13	NA	NA
II-B	yes	yes	yes*	no	1.00	1.02	18.0	29.0	0.05	NA	NA
III	no	yes	yes	yes	0.85	0.99	15.5	48.5	0.01	18.1	17.5
IV	yes	no	yes	yes	0.96	1.03	21.0	31.0	0.15	18.8	41.1
V	no	yes	no	yes	0.98	1.07	24.5	48.5	0.05	27.9	17
VI	no	yes	yes	yes	0.89	0.98	8.0	33.9	0.11	NA	NA
VII**	no	yes	yes	yes	0.94	1.14	0.16	1.2	0.12	17.9	17.7

Note: Δm = measured deflection for exterior purlin

Δc = constrained bending deflection for exterior purlin

N.A. = not measured, invalid or erratic

* = provided by intermediate braces at 2'-0 o.c.

** = flanges were facing (opposed)

Table 7A

Comparison of Results at 165 plf

Test No.	Inter-mediate Bracing	Torsional Restraint at Rafter	Shear Stiff-ness	Torsional Stiffness	Midspan Vertical Deflection Exterior (in.)	$\frac{\Delta m}{\Delta c}$	Measured Restraint Force as a % of Support Load		Lateral Displace-ment of Top Flange (Exterior) (in.)	Max. Stresses	
							Exterior One Purlin	Interior Two Purlin		Tension (ksi)	Comp. (ksi)
I	yes	yes	yes	yes	1.53	1.09	NA	NA	0.46	30.0	31.2
I-A	yes	yes	yes	yes	1.51	1.02	18.9	41.8	0.05	NA	NA
II	yes	yes	yes*	no	NA	NA	NA	NA	NA	NA	NA
II-A	yes	yes	yes*	no	NA	NA	NA	NA	NA	NA	NA
II-B	yes	yes	yes*	no	1.53	0.93	17.0	39.0	0.09	NA	NA
III	no	yes	yes	yes	1.42	0.99	20.3	57.1	0.08	56.0	56.0
IV	yes	no	yes	yes	1.66	1.07	21.1	37.3	0.29	32.4	46.3
V	no	yes	no	yes	1.72	1.12	23.4	52.9	0.372	37.0	28.6
VI	no	yes	yes	yes	1.49	0.98	8.7	34.9	0.17	NA	NA
VII**	no	yes	yes	yes	1.58	1.16	0.54	0.70	0.16	30.5	31.1

Note: Δm = measured deflection for exterior purlin

Δc = constrained bending deflection for exterior purlin

NA = not measured, invalid or erratic

* = provided by intermediate braces at 2'-0 o.c.

** = flanges were facing (opposed)

APPENDIX G

TEST VII RESULTS

TEST SUMMARY

Project: MBMA Roof System Behavior

Test No.: VII-Zee

Test Date: May 14, 1982

Purpose: To determine effect of purlin orientation on purlin strength

Span(s): 19.625'

Thickness: 0.096" Moment of Inertia: 13.7 in^4

Parameters: No intermediate braces

Torsional restraint at rafter

Panel shear stiffness

Panel torsional restraint

Top flanges facing

Failure Load: 257.4 plf

Failure Mode: Local buckling of flange and/or web near midspan

Predicted Failure Loads:

Method AISI Constr. Bending x 1.67 Load 331.2 plf

Method _____ Load _____

Method _____ Load _____

Discussion:

-Failure was caused by local buckling of flange and/or web approximately one foot away from centerline of internal purlin.

-Based on an assumed yield stress of 56.0 ksi, yielding first occurred at the top lip of the external purlin at 231 plf.

-Vertical deflections were 13-18% greater than predicted from constrained bending assumption for the external purlin, for the internal purlin, deflections were 13-20% greater than predicted from the constrained bending assumption.

-Stress in the external purlin increased linearly with increasing vertical load.

-Brace forces at the south rafter were in tension at all load increments. Brace forces at the north rafter were in compression at most load increments.

-At the north rafter at 231 plf, the measured internal brace force was 71% greater than the external brace force.

-The ratio of internal to external brace forces at the north rafter varied from -2.0 to 10.0, and at the south rafter from 0.6 to 1.6.

-At 165 plf, summation of external brace forces equaled 0.54% of total vertical load on the external purlin. Summation of internal brace forces equaled 0.70% of total vertical load on the internal purlin.

-At 231 plf, summation of external brace forces equaled 0.5% of total vertical load on the external purlin. Summation of internal brace forces equaled 0.9% of total vertical load on the internal purlin.

-Bottom flange lateral displacement exceeded top flange lateral displacement, but in the opposite direction.

-Maximum lateral displacement was less than 0.5 in.

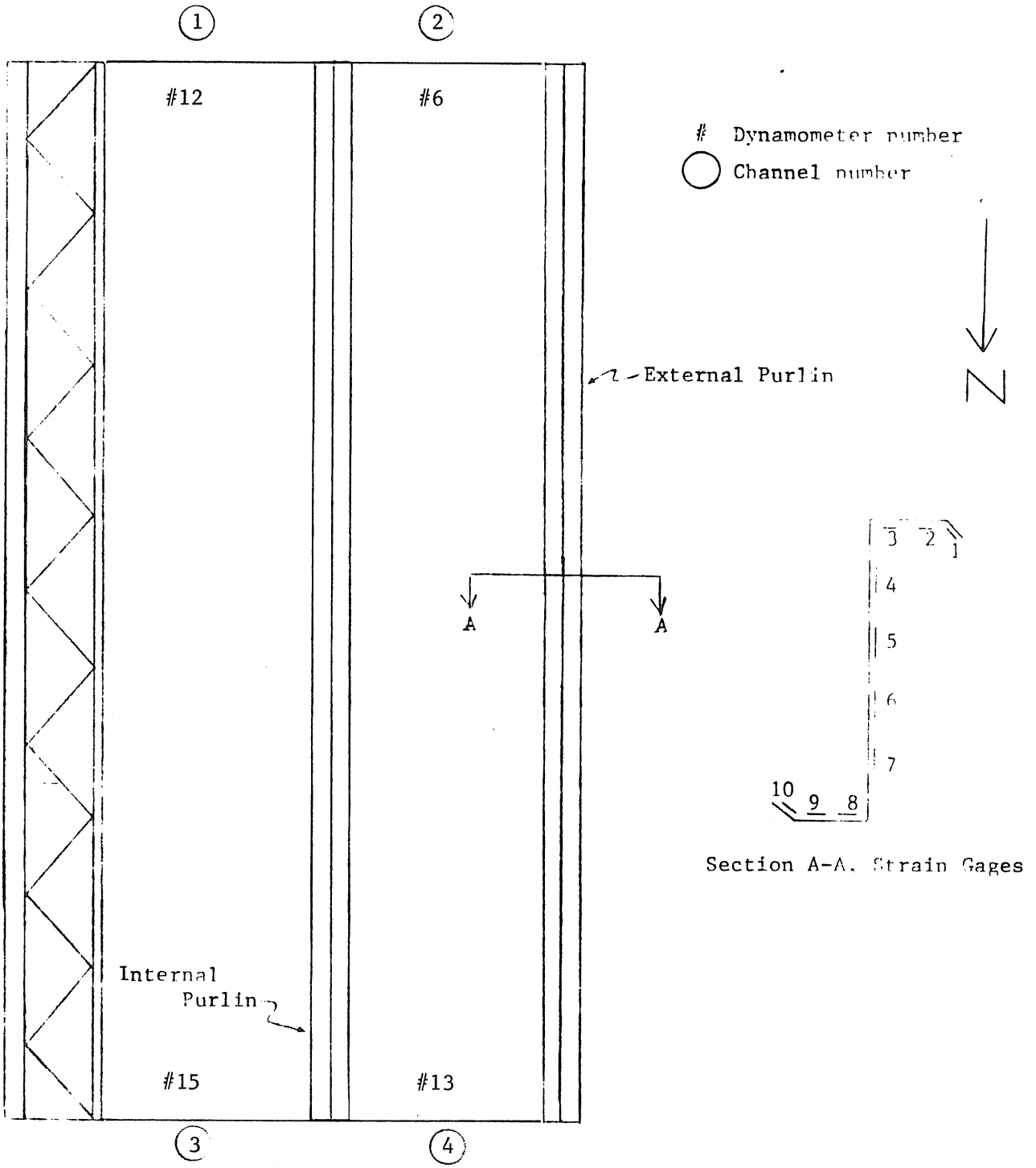
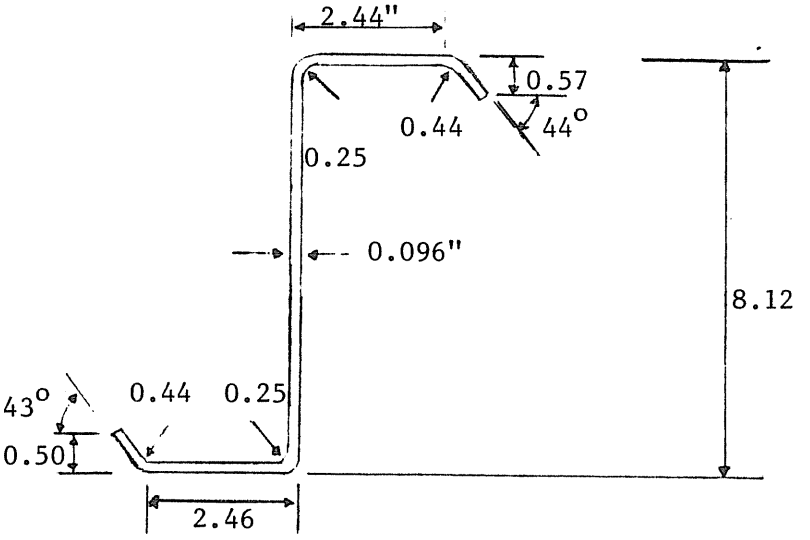
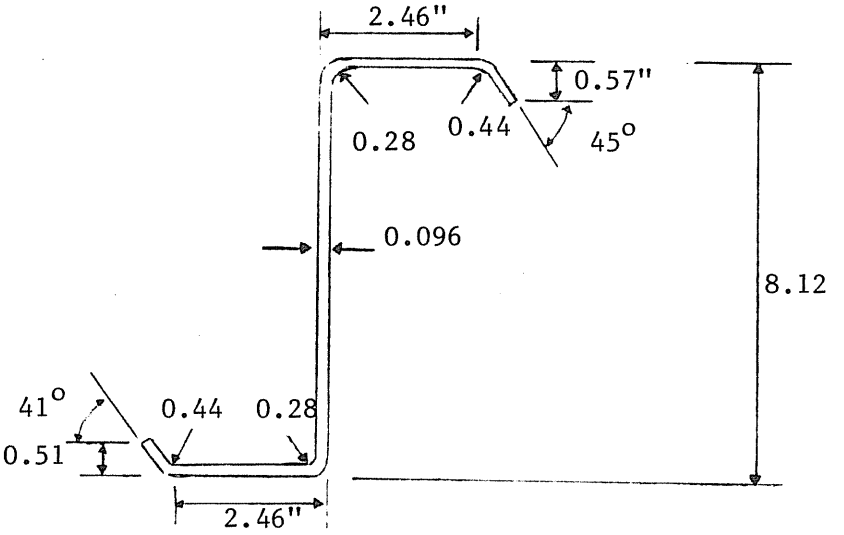


Figure G.1 Instrumentation Locations, Test VII



External Purlin



Internal Purlin

Figure G.2 Measured Purlin Dimensions, Test VII

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-VII-WEST(EXT.)  5/13/82
```

	TOP	BOTTOM
FLANGE(in)	2.440	2.460
LIP(in)	0.570	0.500
LIP ANGLE(deg)	44.000	43.000
RADIUS L/F(in)	0.440	0.440
RADIUS F/W(in)	0.250	0.250

TOTAL DEPTH(in)	8.12
THICKNESS(in)	0.096
YIELD STRENGTH(ksi)	56

MOMENTS OF INERTIA(in^4)		SECTION MODULI(in^3) TOP	BOTTOM
GROSS=	13.737	3.438	3.410
STRENGTH=	13.737	3.438	3.410
DEFLECTION=	13.737		

```
BE=    2.094   in
FC=   33.600   ksi
FT=   33.600   ksi
FBW=  33.596   ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
           MC=     9.626   ft-k
           MT=     9.549   ft-k
           MW=    10.401   ft-k
           MU=    15.946   ft-k (1.67*allowable)
SPAN         =    19.625   ft.
UNIFORM LOAD=   331.232   plf (1.67*allowable)
DEFLECTION   =     0.824   in./100plf
```

Figure G.3 AISI Purlin Analysis, Test VII External Purlin

```
A I S I   P U R L I N   A N A L Y S I S
                Z-SECTION
IDENTIFICATION: MBMA-VII-EAST(INT.)  5/13/82
```

	TOP	BOTTOM
FLANGE(in)	2.460	2.460
LIP(in)	0.570	0.510
LIP ANGLE(deg)	45.000	41.000
RADIUS L/F(in)	0.440	0.440
RADIUS F/W(in)	0.280	0.280

TOTAL DEPTH(in)	8.12
THICKNESS(in)	0.096
YIELD STRENGTH(ksi)	56

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	13.760	3.438	3.422
STRENGTH=	13.760	3.438	3.422
DEFLECTION=	13.760		

BE=	2.084	in
FC=	33.600	ksi
FT=	33.600	ksi
FBW=	33.596	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	9.625	ft-k
MT=	9.581	ft-k
MW=	10.483	ft-k
MU=	16.000	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	332.341	plf (1.67*allowable)
DEFLECTION =	0.822	in./100plf

Figure G.4 AISI Purlin Analysis, Test VII Internal Purlin

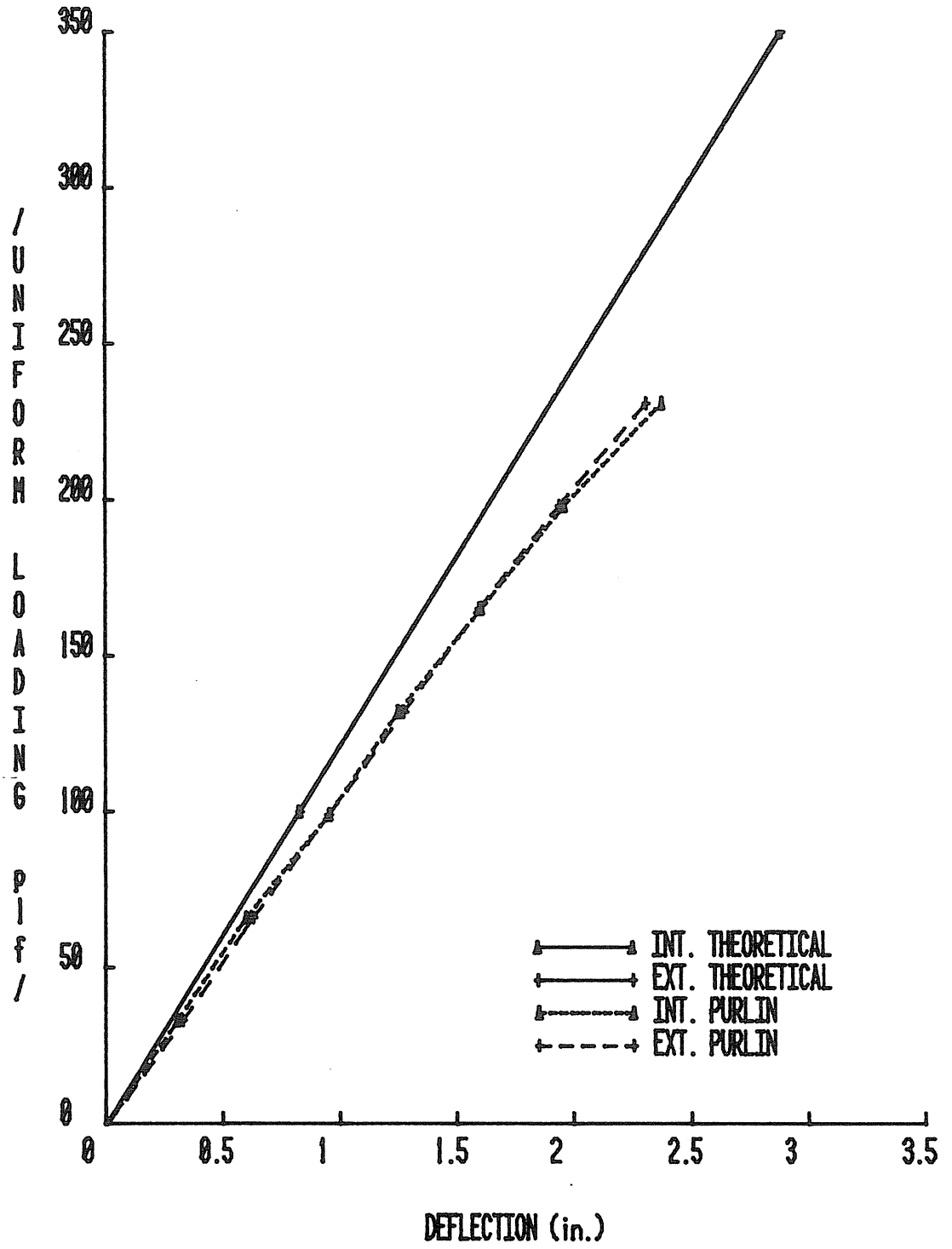


Figure G.5 Load vs. Vertical Deflection, Test VII

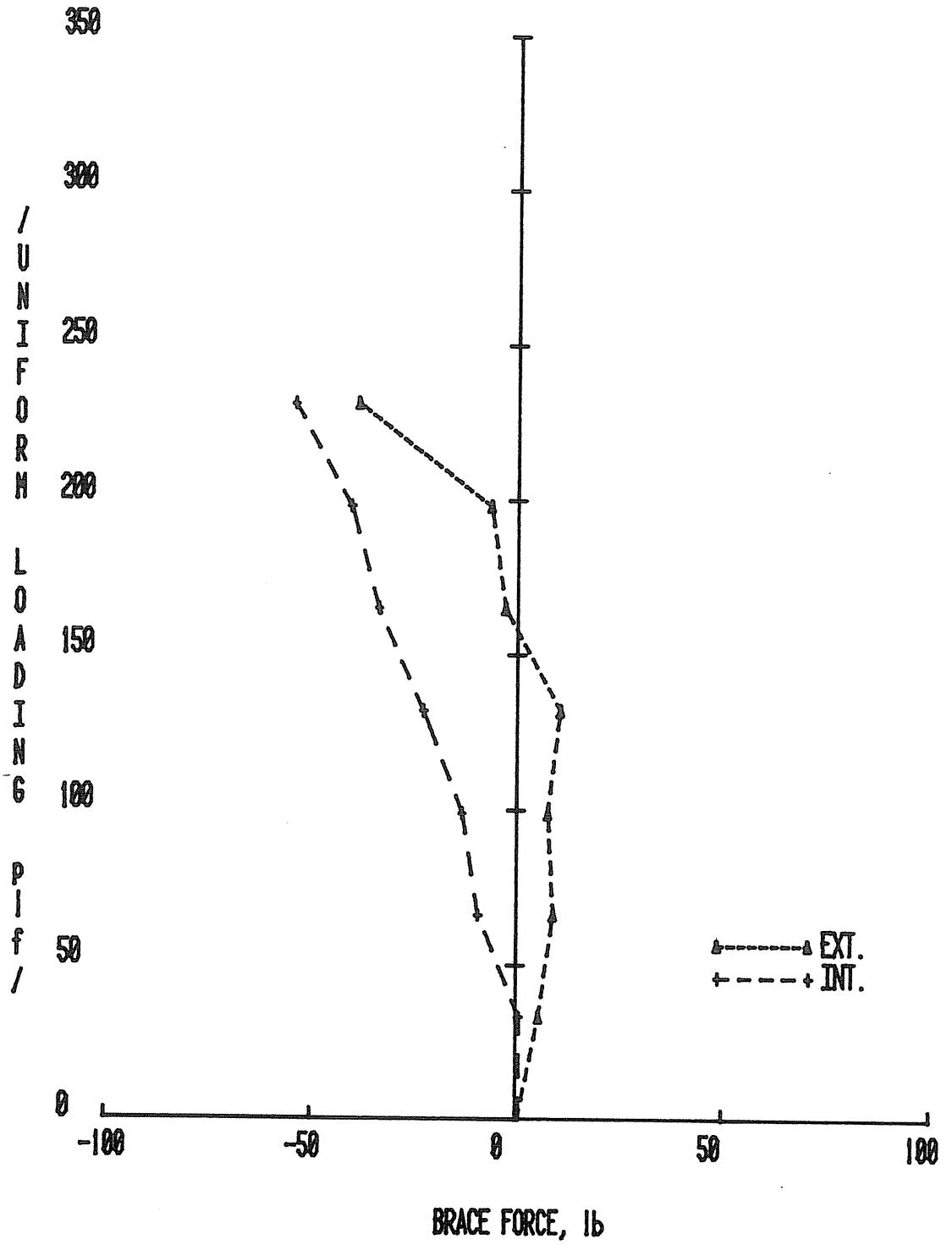


Figure G.6 Vertical Loading vs. Brace Force at North Rafter, Test VII

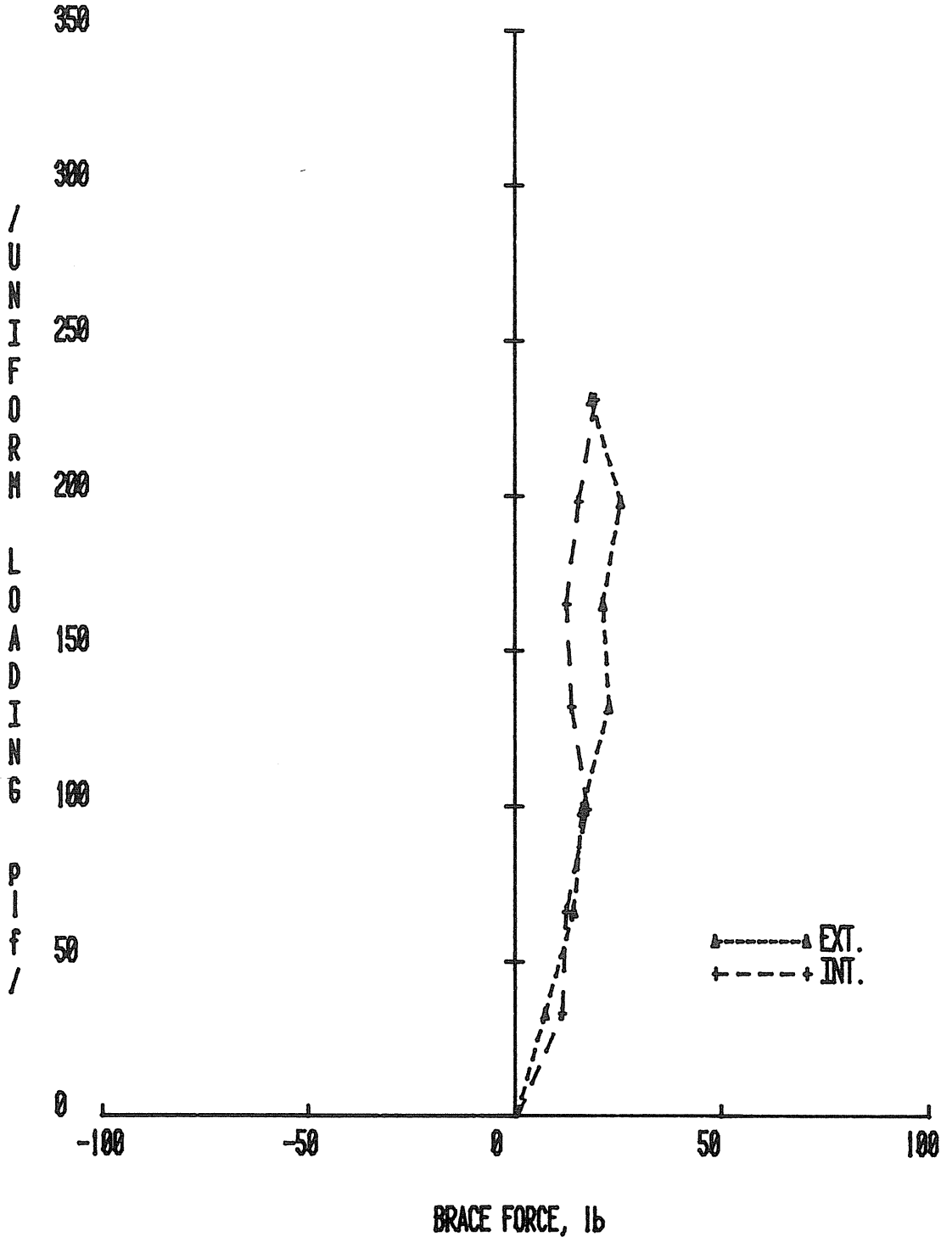


Figure G.7 Vertical Loading vs. Brace Force at South Rafter, Test VII

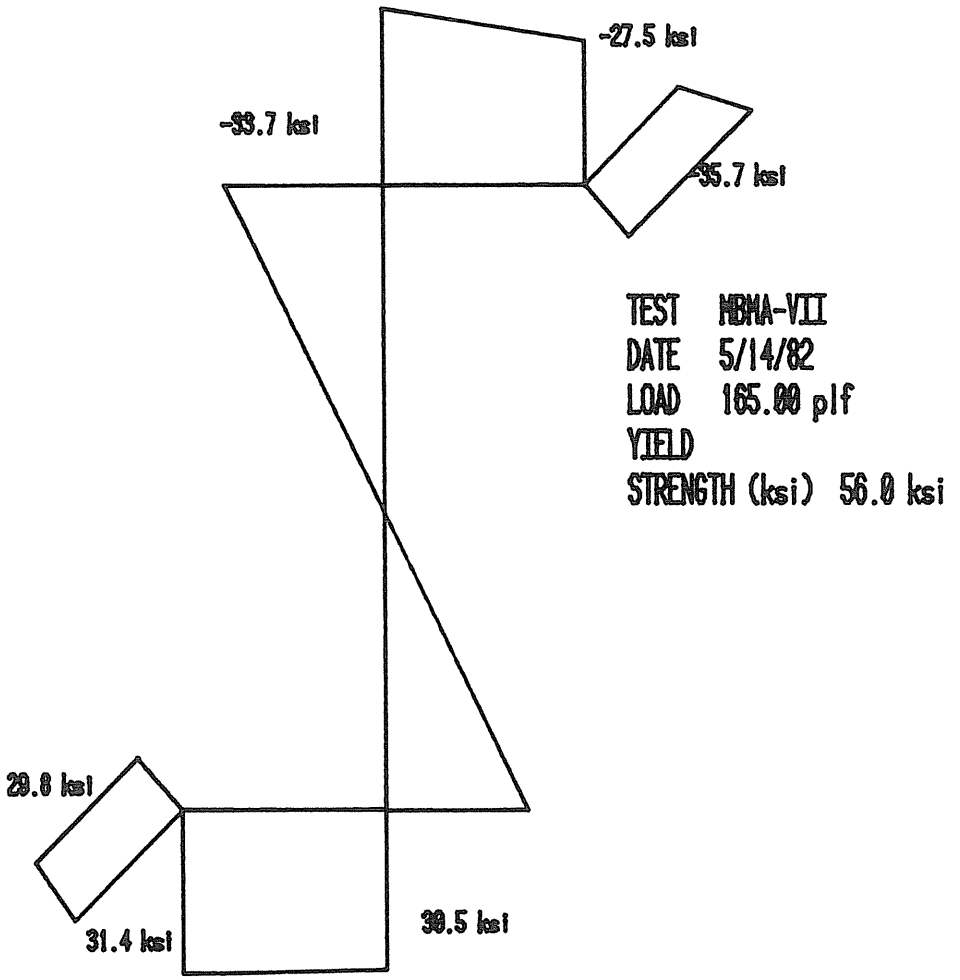


Figure G.8 Stress Distribution at 165 plf, Test VII

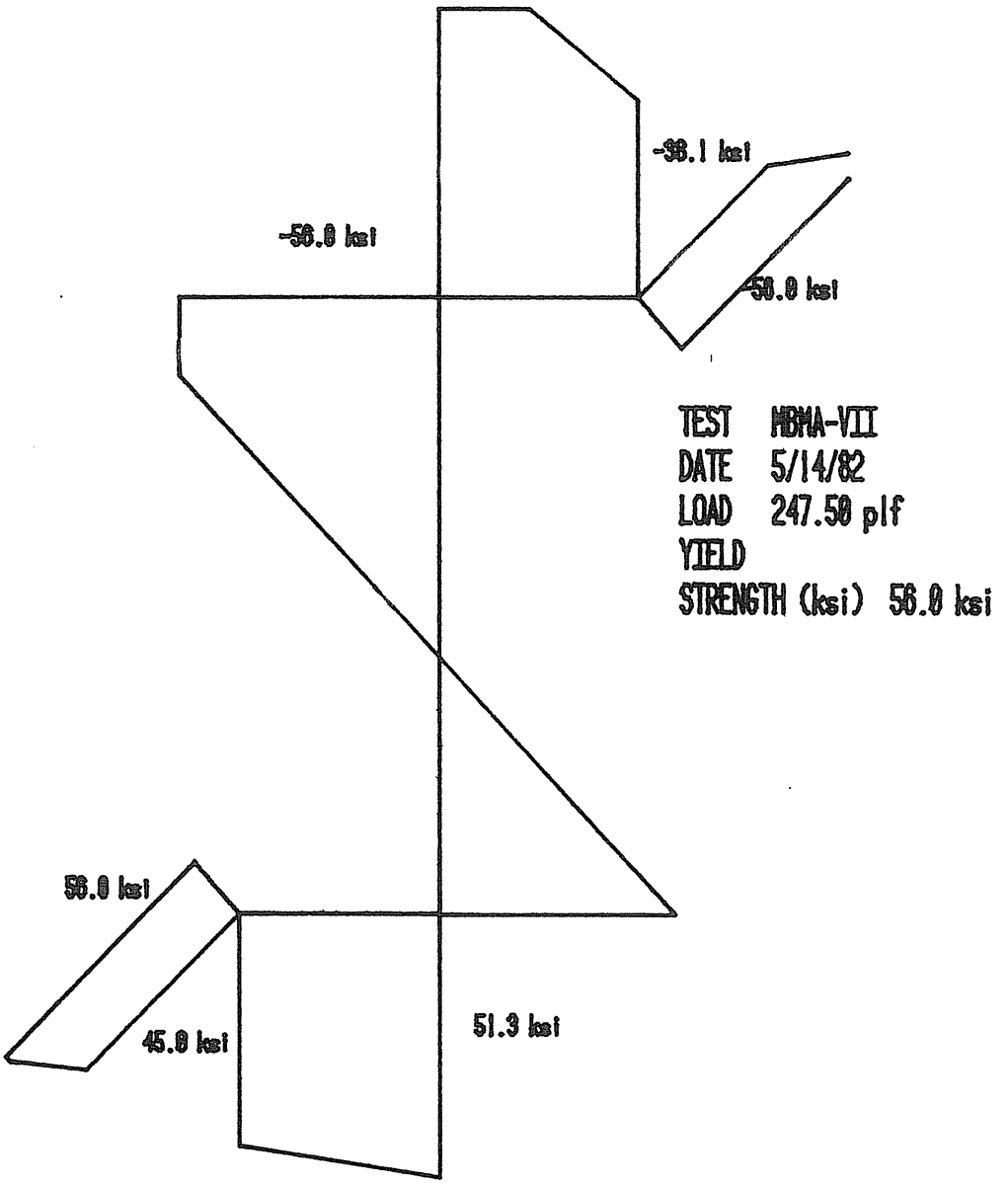


Figure G.9 Stress Distribution at 247.5 plf, Test VII

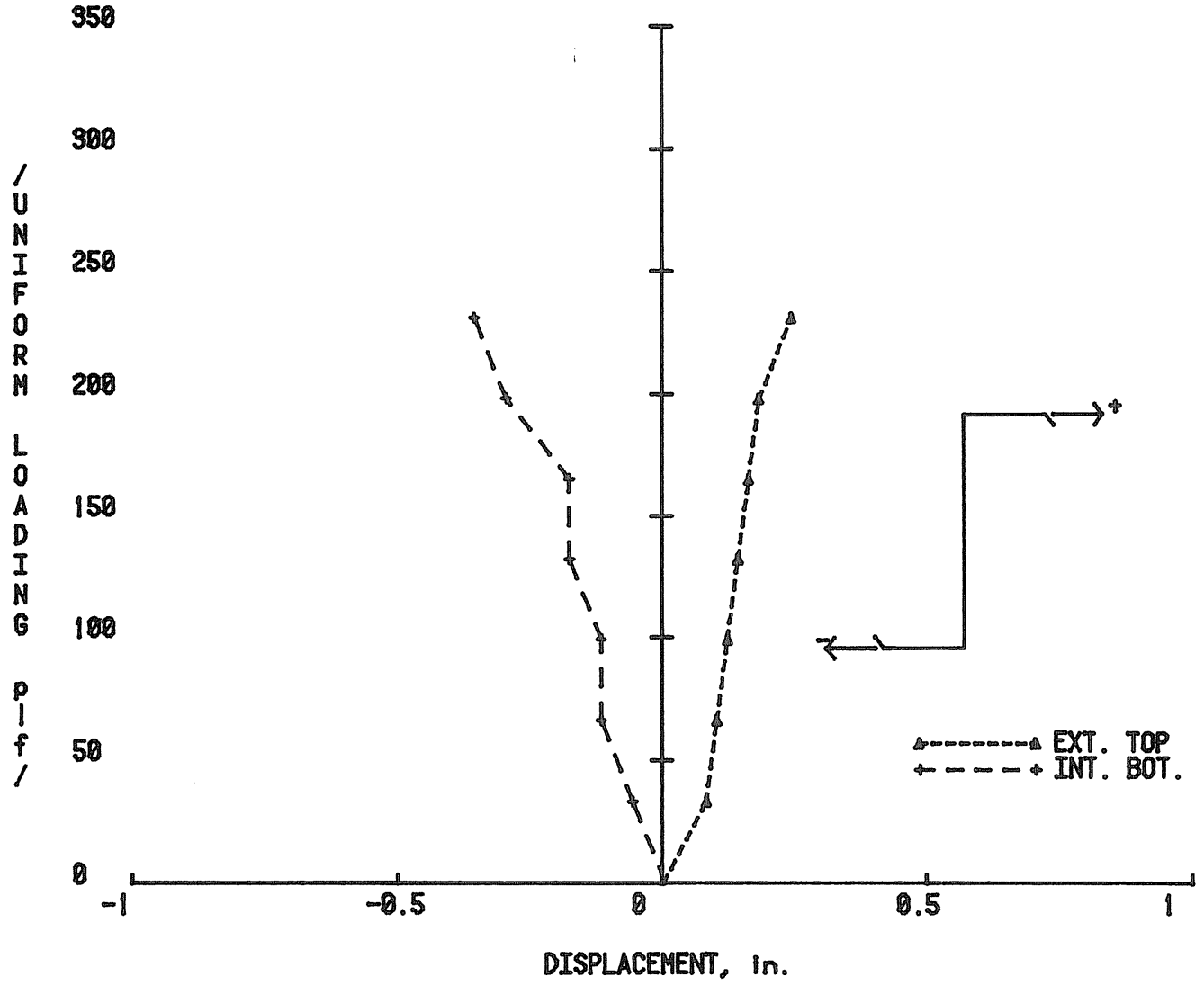


Figure G.10 Vertical Loading vs. Lateral Displacement, Test VII

APPENDIX H

CANTILEVER DIAPHRAGM TEST RESULTS

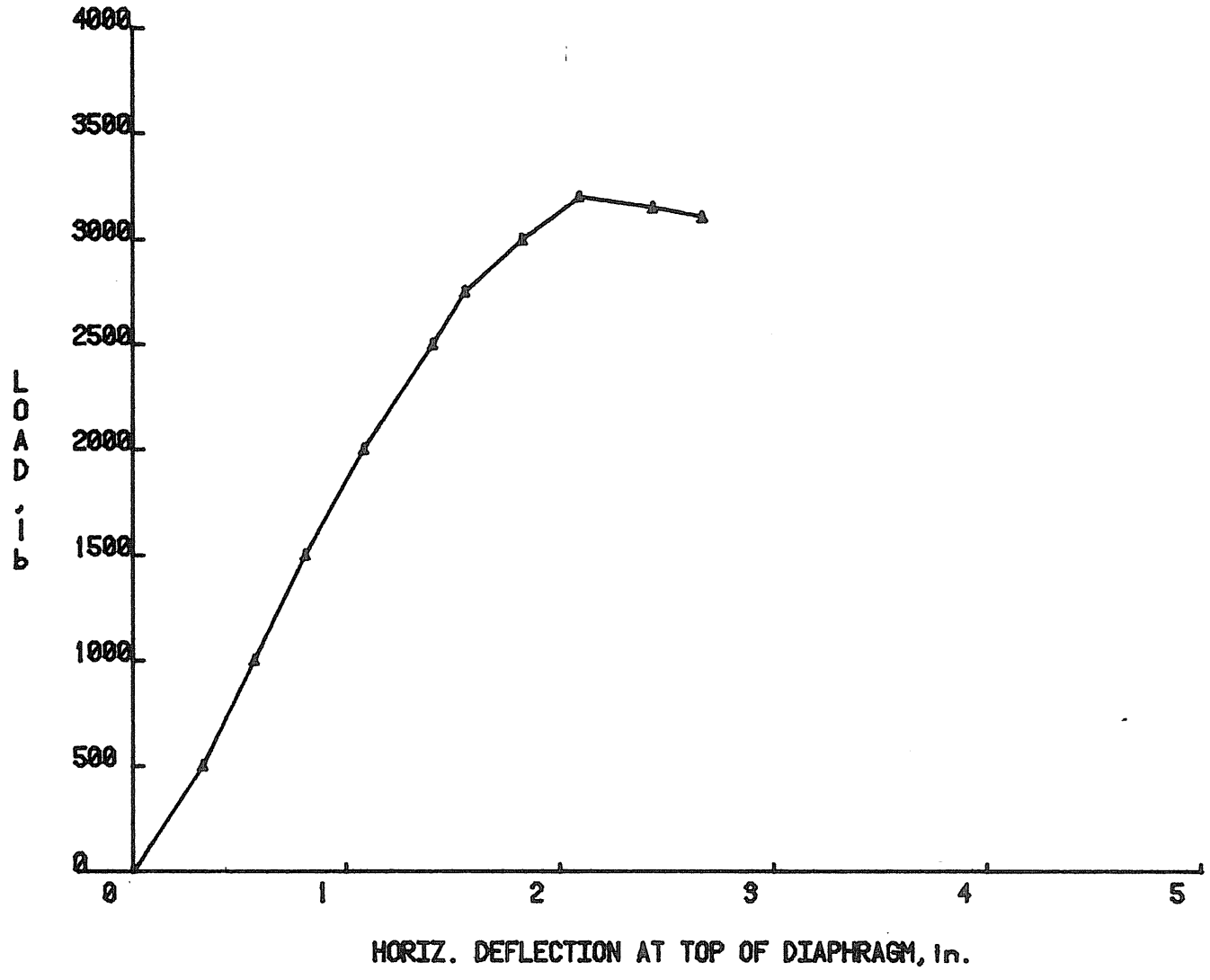


Figure H.1 Load vs. Deflection, Series A Test 1

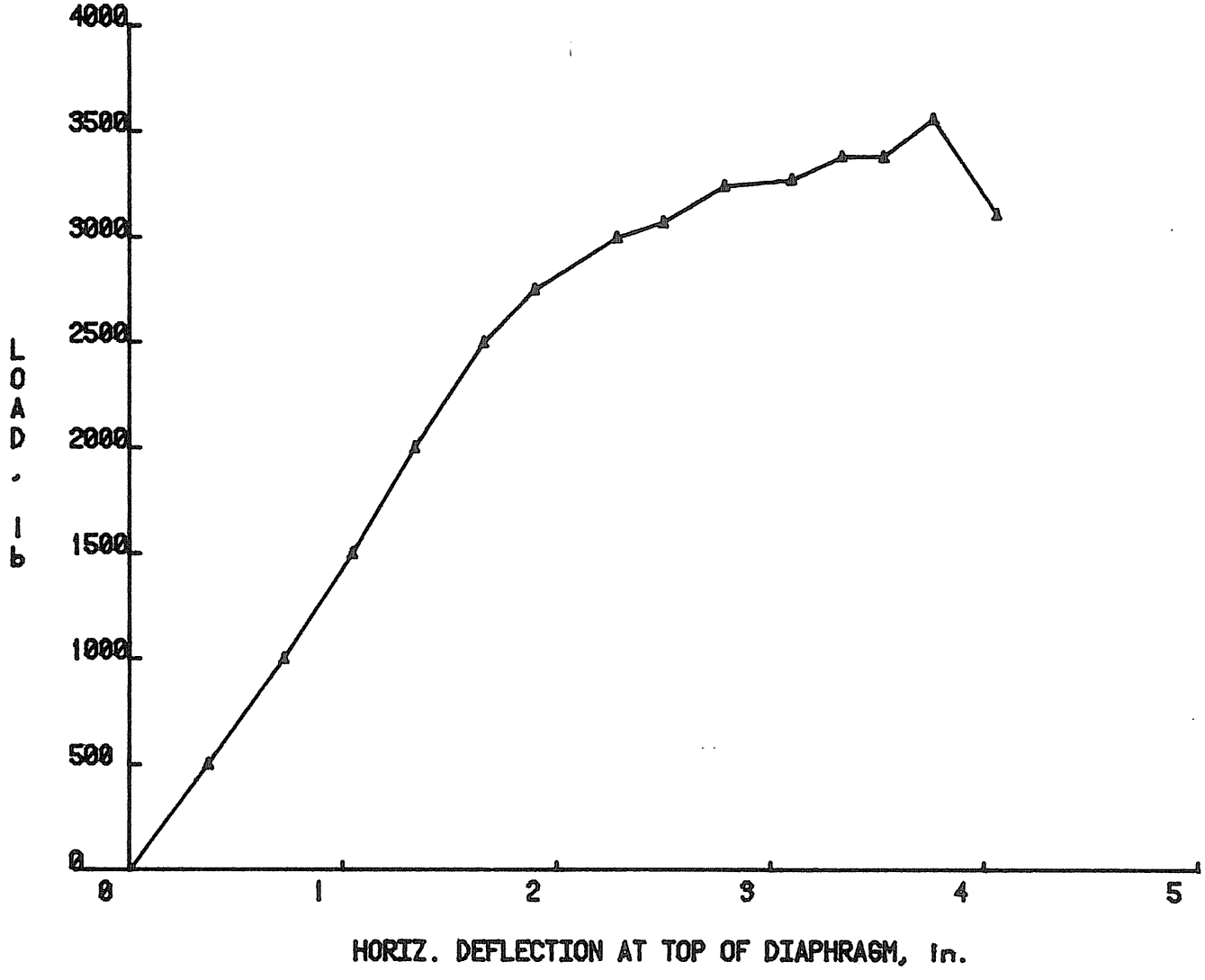


Figure H.2 Load vs. Deflection, Series A Test 2

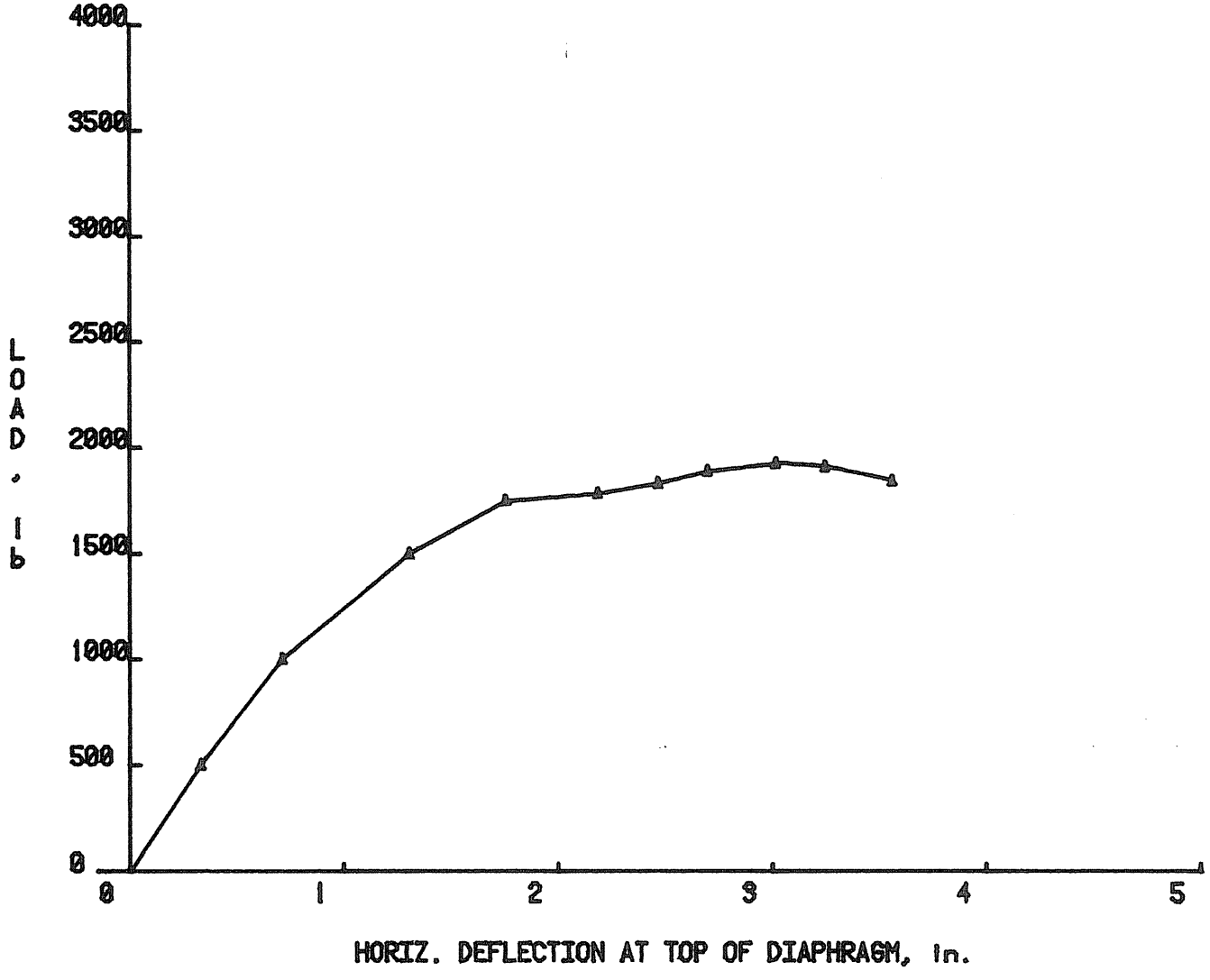


Figure H.3 Load vs. Deflection, Series B Test 2

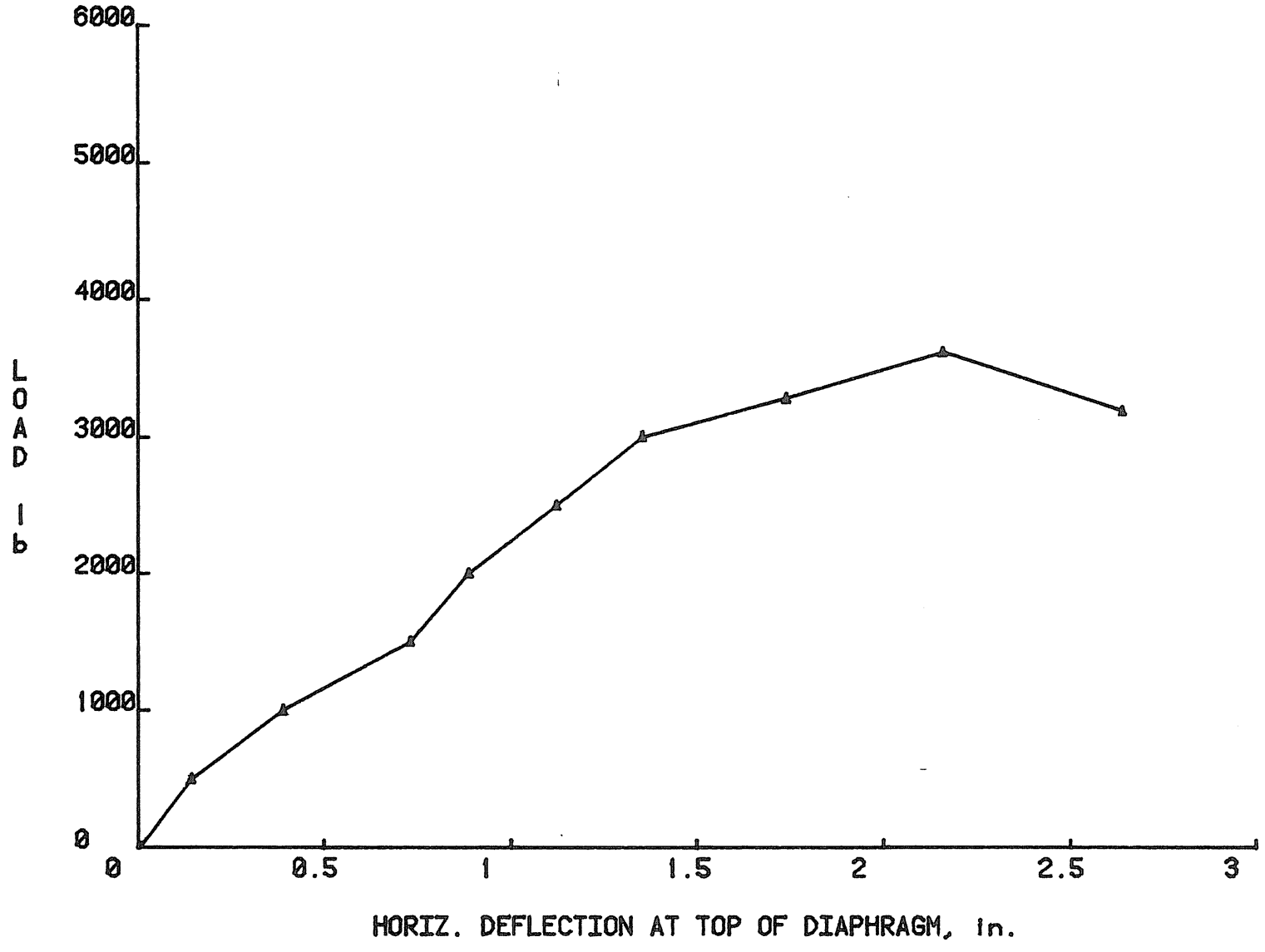


Figure H.4 Load vs. Deflection, Series C Test 1

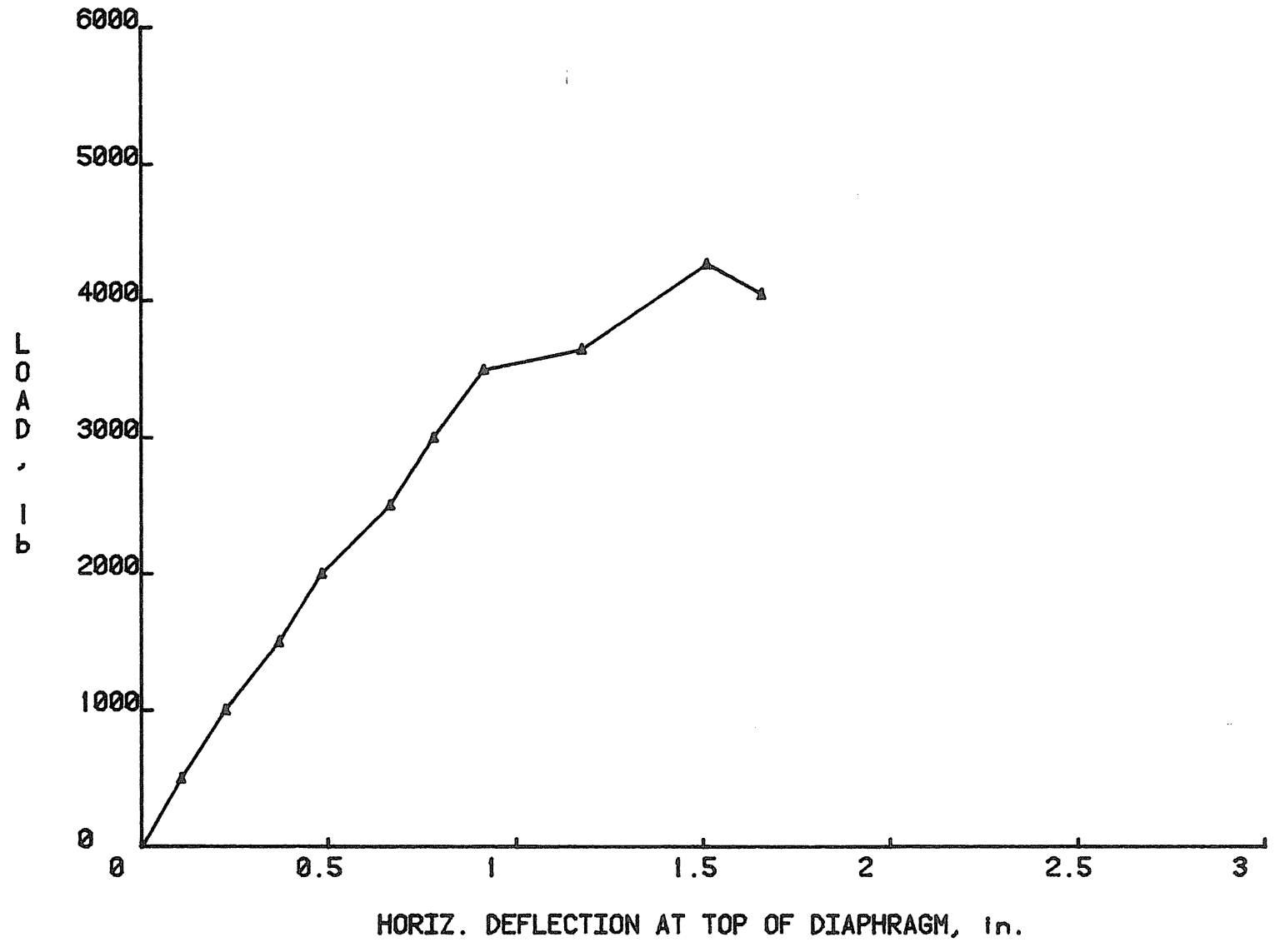


Figure H.5 Load vs. Deflection, Series C Test 2

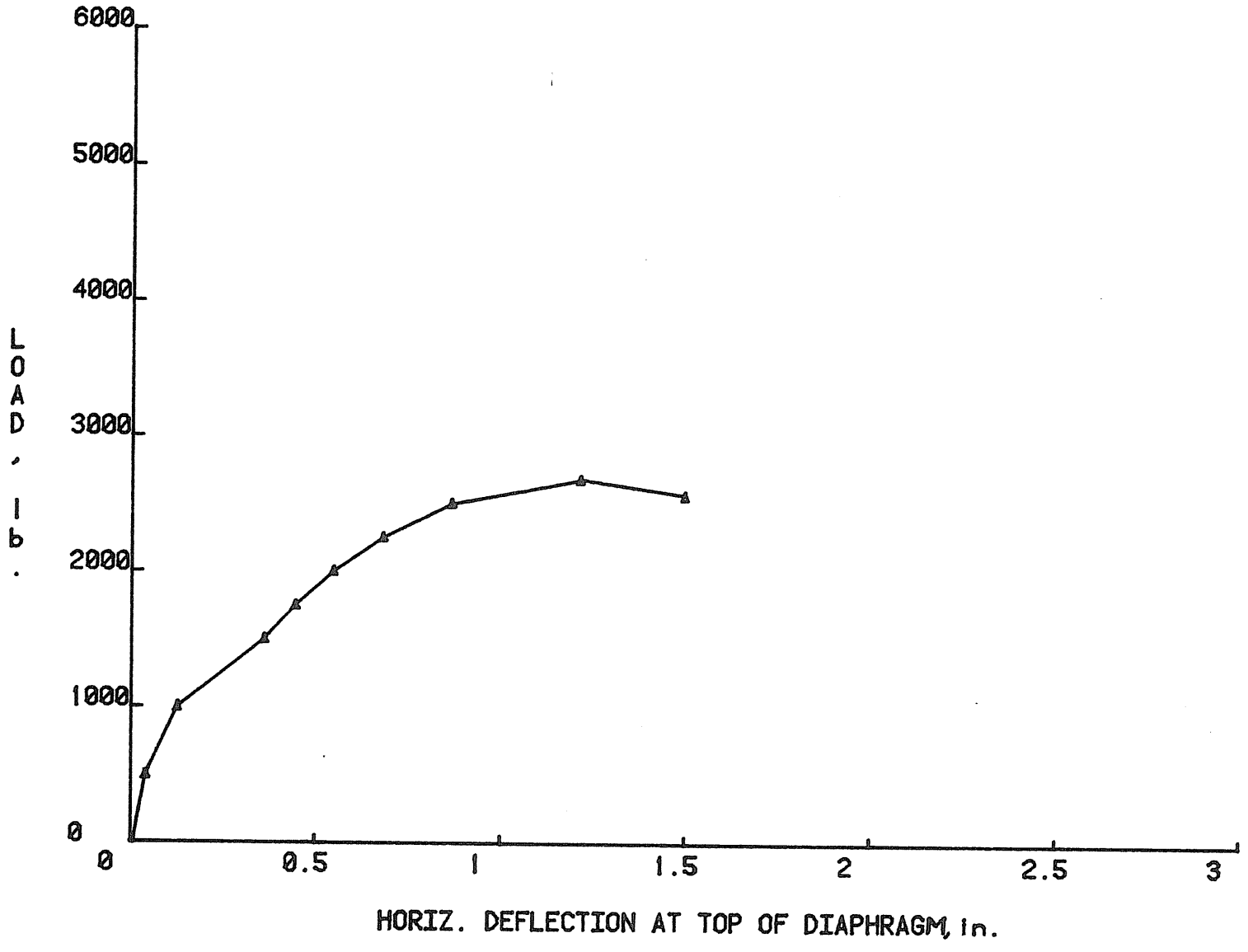


Figure H.6 Load vs. Deflection, Series D Test 1

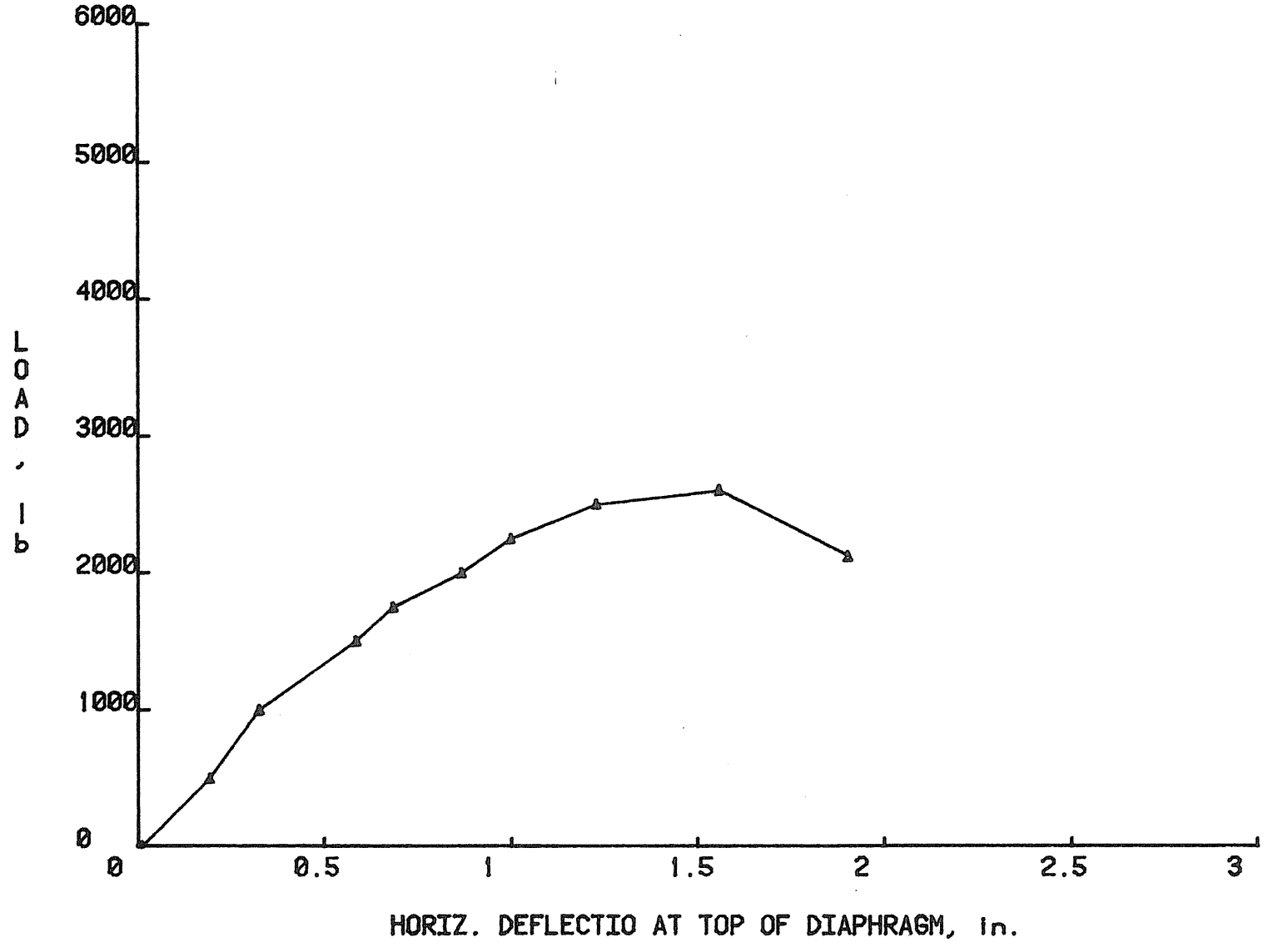


Figure H.7 Load vs. Deflection, Series D Test 2

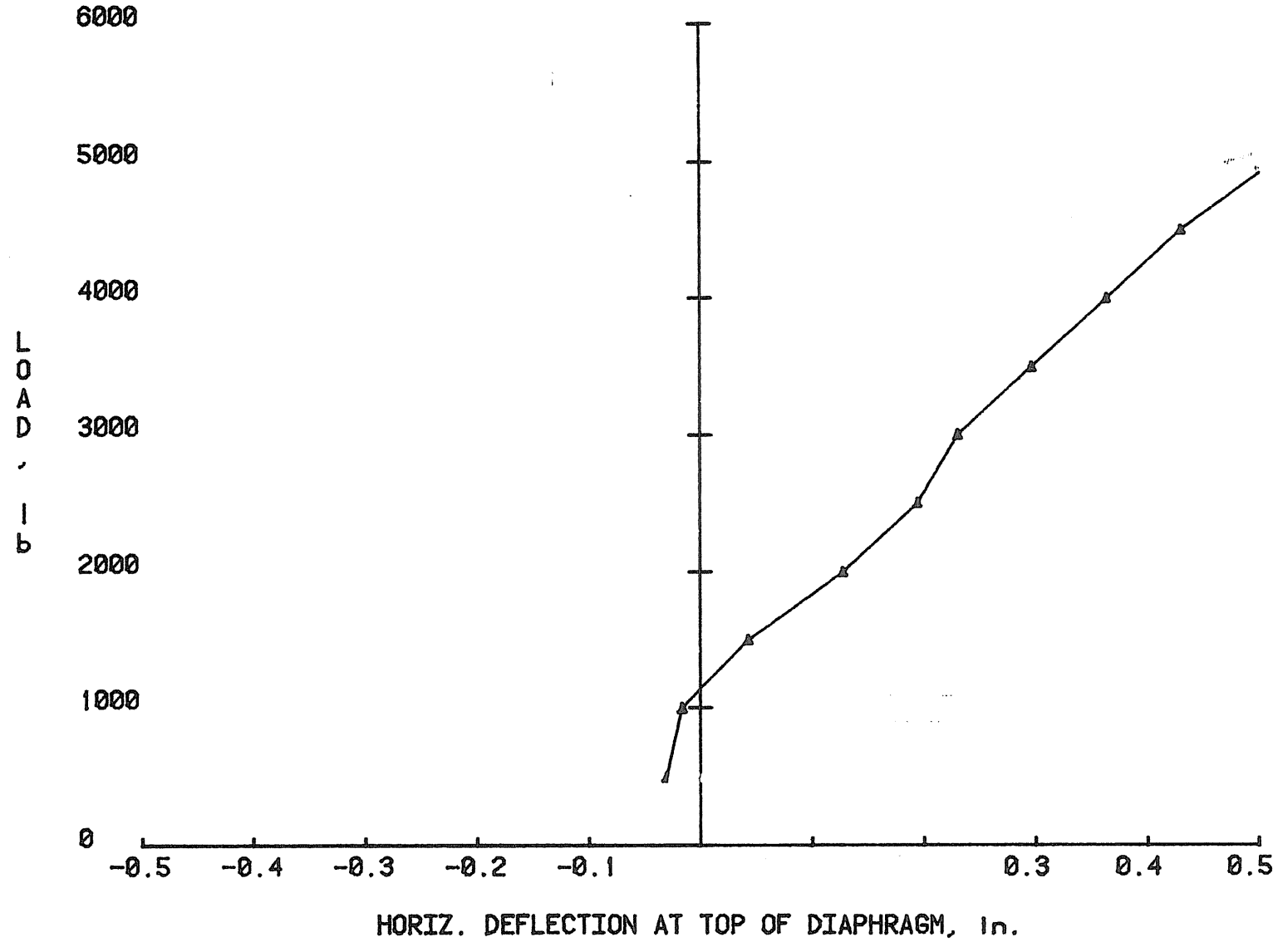


Figure H.8 Load vs. Deflection, Series E Test 1

APPENDIX I

AISI CONSTRAINED BENDING ANALYSES
(Measured Yield Stresses)

```
A I S I  P U R L I N  A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-I-W (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.500	2.560
LIP(in)	0.500	0.500
LIP ANGLE(deg)	44.000	44.000
RADIUS L/F(in)	0.468	0.468
RADIUS F/W(in)	0.281	0.281

TOTAL DEPTH(in)	8.12
THICKNESS(in)	0.093
YIELD STRENGTH(ksi)	57.9

	MOMENTS OF INERTIA(in^4)	SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	13.426	3.331	3.359
STRENGTH=	13.426	3.331	3.359
DEFLECTION=	13.426		

BE=	2.126	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	34.368	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	9.644	ft-k
MT=	9.725	ft-k
MW=	10.385	ft-k
MU=	16.106	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	334.554	plf (1.67*allowable)
DEFLECTION =	0.843	in./100plf

Figure I.1 AISI Purlin Analysis for Measured Yield Stress, Test I, West Purlin

```
A I S I   P U R L I N   A N A L Y S I S
                Z-SECTION
IDENTIFICATION: MBMA-I-A-W (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.400	2.420
LIP(in)	0.520	0.600
LIP ANGLE(deg)	41.000	38.000
RADIUS L/F(in)	0.440	0.500
RADIUS F/W(in)	0.250	0.250

TOTAL DEPTH(in)	8.04
THICKNESS(in)	0.09
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.739	3.163	3.247
STRENGTH=	12.739	3.163	3.247
DEFLECTION=	12.739		

BE=	2.060	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	34.186	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	9.158	ft-k
MT=	9.401	ft-k
MW=	9.725	ft-k
MU=	15.294	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	317.686	plf (1.67*allowable)
DEFLECTION =	0.888	in./100plf

Figure I.2 AISI Purlin Analysis for Measured Yield Stress, Test IA, West Purlin

A I S I P U R L I N A N A L Y S I S

Z-SECTION

IDENTIFICATION: MBMA-II-W (11/22/82)

	TOP	BOTTOM
FLANGE(in)	2.400	2.500
LIP(in)	0.500	0.460
LIP ANGLE(deg)	43.000	43.000
RADIUS L/F(in)	0.500	0.500
RADIUS F/W(in)	0.219	0.219

TOTAL DEPTH(in)	7.96
THICKNESS(in)	0.09
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.264	3.106	3.127
STRENGTH=	12.264	3.106	3.127
DEFLECTION=	12.264		

BE=	2.091	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	34.266	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	8.992	ft-k
MT=	9.054	ft-k
MW=	9.505	ft-k
MU=	15.017	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	311.928	plf (1.67*allowable)
DEFLECTION =	0.922	in./100plf

Figure I.3 AISI Purlin Analysis for Measured Yield Stress, Test II, West Purlin

```
A I S I  P U R L I N  A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-II-A-E (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.500	2.460
LIP(in)	0.470	0.470
LIP ANGLE(deg)	45.000	42.000
RADIUS L/F(in)	0.500	0.500
RADIUS F/W(in)	0.219	0.219

TOTAL DEPTH(in)	7.96
THICKNESS(in)	0.086
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	11.782	2.996	2.989
STRENGTH=	11.782	2.996	2.989
DEFLECTION=	11.782		

BE=	2.195	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	33.896	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	8.673	ft-k
MT=	8.654	ft-k
MW=	9.066	ft-k
MU=	14.453	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	300.207	plf (1.67*allowable)
DEFLECTION =	0.960	in./100plf

Figure I.4 AISI Purlin Analysis for Measured Yield Stress, Test IIA, East Purlin

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-II-B-W (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.340	2.430
LIP(in)	0.450	0.480
LIP ANGLE(deg)	43.000	44.000
RADIUS L/F(in)	0.500	0.438
RADIUS F/W(in)	0.250	0.250

TOTAL DEPTH(in)	7.9
THICKNESS(in)	0.087
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	11.368	2.890	2.931
STRENGTH=	11.368	2.890	2.931
DEFLECTION=	11.368		

BE=	2.003	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	34.054	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	8.365	ft-k
MT=	8.484	ft-k
MW=	8.861	ft-k
MU=	13.970	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	290.187	plf (1.67*allowable)
DEFLECTION =	0.995	in./100plf

Figure I.5 AISI Purlin Analysis for Measured Yield Stress, Test IIB, West Purlin

```
A I S I  P U R L I N  A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-III-W (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.450	2.550
LIP(in)	0.480	0.500
LIP ANGLE(deg)	42.000	45.000
RADIUS L/F(in)	0.500	0.500
RADIUS F/W(in)	0.281	0.281

TOTAL DEPTH(in)	8
THICKNESS(in)	0.092
YIELD STRENGTH(ksi)	57.9

	MOMENTS OF INERTIA(in^4)	SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.758	3.204	3.249
STRENGTH=	12.758	3.204	3.249
DEFLECTION=	12.758		

```
BE=    2.077  in
FC=   34.740  ksi
FT=   34.740  ksi
FBW=  34.400  ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
           MC=     9.277  ft-k
           MT=     9.406  ft-k
           MW=    10.008  ft-k
           MU=    15.492  ft-k (1.67*allowable)
SPAN         =    19.625  ft.
UNIFORM LOAD=   321.802  plf (1.67*allowable)
DEFLECTION   =     0.887  in./100plf
```

Figure I.6 AISI Purlin Analysis for Measured Yield Stress, Test III, West Purlin

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-IV-E (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.380	2.380
LIP(in)	0.550	0.550
LIP ANGLE(deg)	42.000	42.000
RADIUS L/F(in)	0.500	0.500
RADIUS F/W(in)	0.250	0.250

TOTAL DEPTH(in)	8.1
THICKNESS(in)	0.086
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.243	3.055	3.055
STRENGTH=	12.243	3.055	3.055
DEFLECTION=	12.243		

BE=	2.044	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	33.750	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	8.845	ft-k
MT=	8.845	ft-k
MW=	9.271	ft-k
MU=	14.772	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	306.829	plf (1.67*allowable)
DEFLECTION =	0.924	in./100plf

Figure I.7 AISI Purlin Analysis for Measured Yield Stress, Test IV, East Purlin

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-V-E (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.480	2.400
LIP(in)	0.450	0.490
LIP ANGLE(deg)	44.000	44.000
RADIUS L/F(in)	0.470	0.470
RADIUS F/W(in)	0.250	0.250

TOTAL DEPTH(in)	7.98
THICKNESS(in)	0.09
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.186	3.095	3.083
STRENGTH=	12.186	3.095	3.083
DEFLECTION=	12.186		

```
BE=    2.140   in
FC=   34.740   ksi
FT=   34.740   ksi
FBW=  34.246   ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
            MC=      8.961   ft-k
            MT=      8.924   ft-k
            MW=      9.549   ft-k
            MU=     14.904   ft-k (1.67*allowable)
SPAN          =     19.625   ft.
UNIFORM LOAD=     309.576   plf (1.67*allowable)
DEFLECTION    =       0.928   in./100plf
```

Figure I.8 AISI Purlin Analysis for Measured Yield Stress, Test V, East Purlin

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-VI-E (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.340	2.800
LIP(in)	0.480	0.470
LIP ANGLE(deg)	44.000	44.000
RADIUS L/F(in)	0.438	0.500
RADIUS F/W(in)	0.219	0.219

TOTAL DEPTH(in)	8.13
THICKNESS(in)	0.086
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	12.582	3.031	3.239
STRENGTH=	12.582	3.031	3.232
DEFLECTION=	12.582		

BE=	2.035	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	33.719	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	8.773	ft-k
MT=	9.357	ft-k
MW=	9.089	ft-k
MU=	14.652	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	304.340	plf (1.67*allowable)
DEFLECTION =	0.899	in./100plf

Figure I.9 AISI Purlin Analysis for Measured Yield Stress, Test VI, East Purlin

```
A I S I   P U R L I N   A N A L Y S I S
              Z-SECTION
IDENTIFICATION: MBMA-VII-E (11/22/82)
```

	TOP	BOTTOM
FLANGE(in)	2.460	2.460
LIP(in)	0.570	0.510
LIP ANGLE(deg)	45.000	41.000
RADIUS L/F(in)	0.440	0.440
RADIUS F/W(in)	0.280	0.280

TOTAL DEPTH(in)	8.12
THICKNESS(in)	0.096
YIELD STRENGTH(ksi)	57.9

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	13.760	3.438	3.422
STRENGTH=	13.760	3.438	3.422
DEFLECTION=	13.760		

BE=	2.084	in
FC=	34.740	ksi
FT=	34.740	ksi
FBW=	34.613	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	9.952	ft-k
MT=	9.906	ft-k
MW=	10.801	ft-k
MU=	16.543	ft-k (1.67*allowable)
SPAN =	19.625	ft.
UNIFORM LOAD=	343.617	plf (1.67*allowable)
DEFLECTION =	0.822	in./100plf

Figure I.10 AISI Purlin Analysis for Measured Yield Stress, Test VII, East Purlin

APPENDIX J

ERRATA

Errata

ROOF SYSTEMS BEHAVIOR

Progress Report

SIMPLE SPAN Z-PURLIN TESTS
WITH VARIOUS RESTRAINT SYSTEMS

FSEL/MBMA 82-01

Second Printing

The following corrections should be made to the original report:

Page 13. The bottom of the page should read "56 ksi" instead of "57 ksi".

Page 13. Units for S_t and S_b should read "$(in.^3)$" instead of "(in.)".

Page 13. The top of column 9 should read "F_c" instead of "F_e".

Page 24. Column 2, line 3 should read "301.7" instead of "310.7".

Page 30. 6th line from the bottom should read "table 3" instead of "table 5".

Page 37. 8th line from the top should read "29.0" instead of "17.5".

Page 37. 12th line from the top should read "39.0" instead of "19.2".

Page B.3 External and internal purlin web thicknesses should read "0.090" instead of "0.90".

Page C.4 External purlin web thickness should read "0.090" instead of "0.90".

Page E.3 External purlin web thickness should read "0.090" instead of "0.40".

Page E.3 Internal purlin web thickness should read "0.091" instead of "0.91".