FEARS STRUCTURAL ENGINEERING LABORATORY

PURLIN STUDIES
Progress Report

VACUUM AND GRAVITY LOADING
COMPARISON TESTS

by

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Sponsored by

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Oklahoma City, Oklahoma

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CHAPTER I

INTRODUCTION

1.1 Background

This progress report documents a portion of an extensive research program concerning the behavior of cold-formed Z-purlin supported roof systems sponsored by Star Manufacturing Company, Oklahoma City, Oklahoma. The program includes tests of both details and complete systems. System testing has included both conventional and standing seam metal building roof systems. The test procedure for all conventional systems has been to load two lines of purlins to failure using concrete blocks to simulate live load (referred to henceforth as "gravity" loading). The test procedure for the standing seam systems has been to load a portion of a complete system (4 or 5 lines of purlins with a simulated eave) to failure using a speciality constructed vacuum chamber ("vacuum" loading). Results for both types of tests are reported in References 1 to 4.

The purpose of the phase of the research reported here is twofold:

1. To compare results from similar conventional roof systems tests using different loading methods, e.g. gravity loading and vacuum loading.

2. To compare results from tests of conventional and standing seam systems with similar purlin sizes and configuration.

To accomplish the objectives two tests of conventional roof systems were conducted using vacuum loading. The first test was of a three span system which was similar to a previously tested standing seam system. The second test was of a two span system which was similar to a previously tested conventional system tested using gravity loading.

The following sections detail the testing procedure and test results. Comparisons are made with the previously conducted tests in Chapter III.

1.2 Test Configuration and Set-up

The purpose and the configuration of each test are as follows:

<u>Test C-1</u> Three 20 ft. spans; three eave purlins, three ridge purlins, two intermediate rows of three purlins, continuous system, loading by vacuum.

Purpose:

To compare the behavior of a three span conventional panel roof system with that of a standing seam roof system.

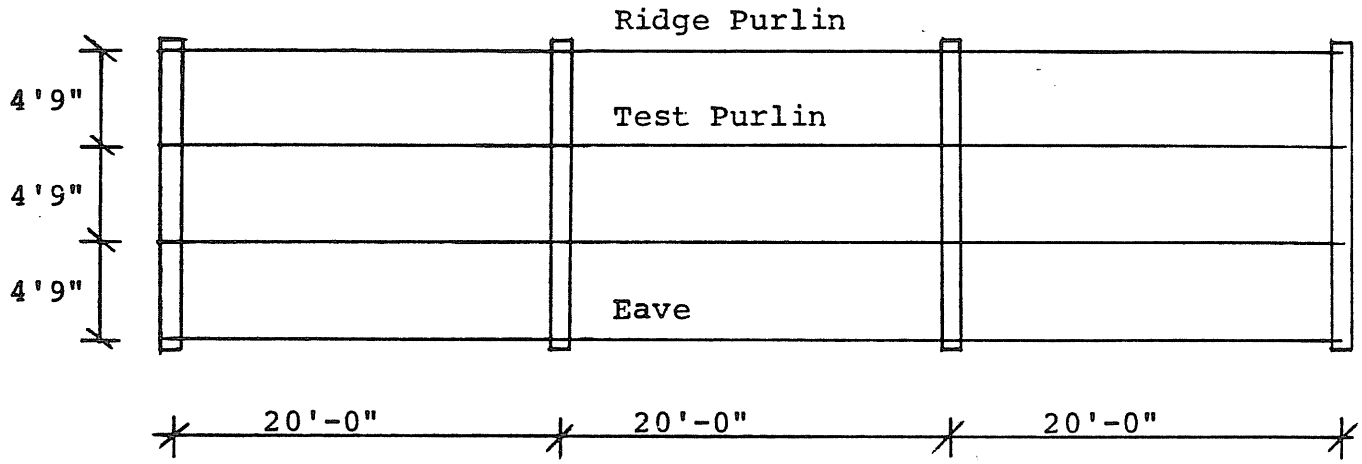
<u>Test C-2</u> Two 25 ft. spans; two eave purlins, two ridge purlins, and two intermediate rows of two purlins, continuous systems, loading done by vacuum.

Purpose:

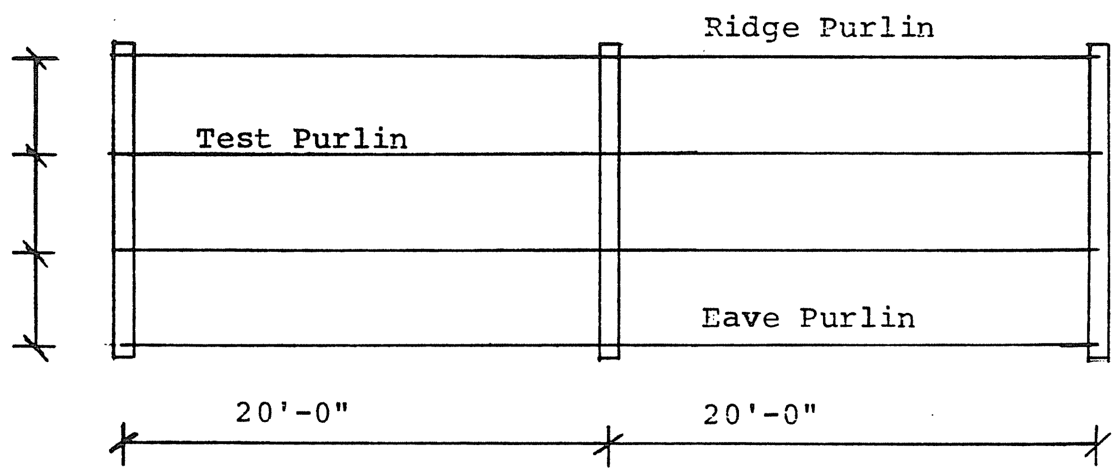
To compare the behavior of a two span conventional panel roof system loaded by vacuum to that of a two span conventional panel roof system under gravity loading.

Details of the test set-up are shown in Figure 1. Short sections of typical building rafters support the purlins. The purlins were oriented with the top flanges facing in the same direction. No intermediate bracing was used in either test.

The test purlins were all cold-formed under the same specification in a continuous operation. Laboratory personnel constructed the test set-ups using standard industry procedures. A complete description of the testing procedures and results are given in Chapters II and III.



(a) Plan View - Test C-1



(b) Plan View - Test C-2

Figure 1. Test Set-ups

CHAPTER II

CONVENTIONAL PANEL AND VACUUM LOADING DETAILS

2.1 Test Components

Z-Purlins. The Z-purlins used for the tests were supplied by Star Manufacturing Company. In both tests, the purlin that was expected to fail first and the purlin it was lapped with, were carefully measured. The dimensions of each purlin are shown in Table 1. Table 2 and Table 3 show cross-sectional properties and load and deflection data for the three-span and the two-span tests, respectively. This data was calculated using AISI criteria with an assumed yield stress of 56 ksi. Measured yield stress was approximately 62 ksi for the 3 span test and 58 ksi for the 2 span test. Results of tensile coupon tests are given in Table 4.

Panels and Fasteners. In both tests, conventional panels were used having a profile as shown in Figure 3. Sheet size was 3 ft. by 15 ft. and nominally 26 ga. Self-drilling fasteners, No. 12 by 1 in. were used for both sheet-to-purlin and sheet-to-sheet connections. Sheet-to-purlin fasteners were uniformly spaced at 12 inches on center for the intermediate rows of the purlins and the ridge purlin while the panels were fastened to the eave purlin at 6 inches on center. Sheet-to-sheet fasteners were spaced at 2 ft. on center beginning at 6 inches from the edge (seven per lap).

Table 1

Measured Z-Purlin Dimensions

Test No.		Total Depth (in)	Thickness (in)	TOP					BOTTOM				
				W_1^* (in)	T_1^* (in)	R_1^* (in)	R_2^* (in)	θ_1^* (deg)	W_2^* (in)	T_2^* (in)	R_3^* (in)	R_4^* (in)	θ_2^* (deg)
C-1	N	7.93	0.084	2.87	0.64	0.281	0.281	45	2.92	0.63	0.313	0.313	45
	S	8.02	0.066	2.92	0.60	0.281	0.281	44	2.80	0.64	0.313	0.313	44
C-2	N	7.88	0.066	2.91	0.59	0.281	0.281	45	2.90	0.58	0.281	0.281	42
	S	8.03	0.066	2.94	0.58	0.281	0.25	37	2.87	0.57	0.281	0.313	42

*See Figure 2

Note: N = North, S = South. The north purlin was the test purlin in both tests.

Table 2

Z-Purlin Properties (F_y = 62 ksi, Span = 3 @ 20)

Test No.		GROSS			STRENGTH										1.67xAllowable		Deflection	
		I (in⁴)	S_t (in³)	S_b (in³)	I (in⁴)	S_t (in³)	S_b (in³)	b_e (in)	F_e ksi	F_t ksi	F_{bw} ksi	M_c ft-k	M_t ft-k	M_w ft-k	M_u ft-k	W_u (lb/ft)	I (in⁴)	1/100 plf (in)
C-1	N	12.627	3.205	3.232	12.552	3.174	3.225	2.447	35.989	37.200	35.809	9.520	9.999	10.316	15.898	317.953	12.627	0.966
	S	10.182	2.568	2.553	9.763	2.399	2.514	2.719	33.427	37.200	33.109	6.683	7.792	7.173	11.160	223.203	10.182	1.202

Table 3

Z-Purlin Properties (F_y = 58 ksi, Span = 2 @ 25)

Test No.		GROSS			STRENGTH										1.67xAllowable		Deflection	
		I (in⁴)	S_t (in³)	S_b (in³)	I (in⁴)	S_t (in³)	S_b (in³)	b_e (in)	F_e ksi	F_t ksi	F_{bw} ksi	M_c ft-k	M_t ft-k	M_w ft-k	M_u ft-k	W_u (lb/ft)	I (in⁴)	1/100 plf (in)
C-2	N	9.809	2.508	2.513	9.436	2.356	2.478	2.202	32.285	34.800	31.530	6.337	7.186	6.716	10.583	135.469	9.809	3.037
	S	10.344	2.618	2.573	9.979	2.473	2.541	2.287	29.511	34.800	31.325	6.081	7.368	6.941	10.155	129.981	10.334	2.883

c = compression flange controls
t = tension flange controls
w = web controls
-- controlling moment

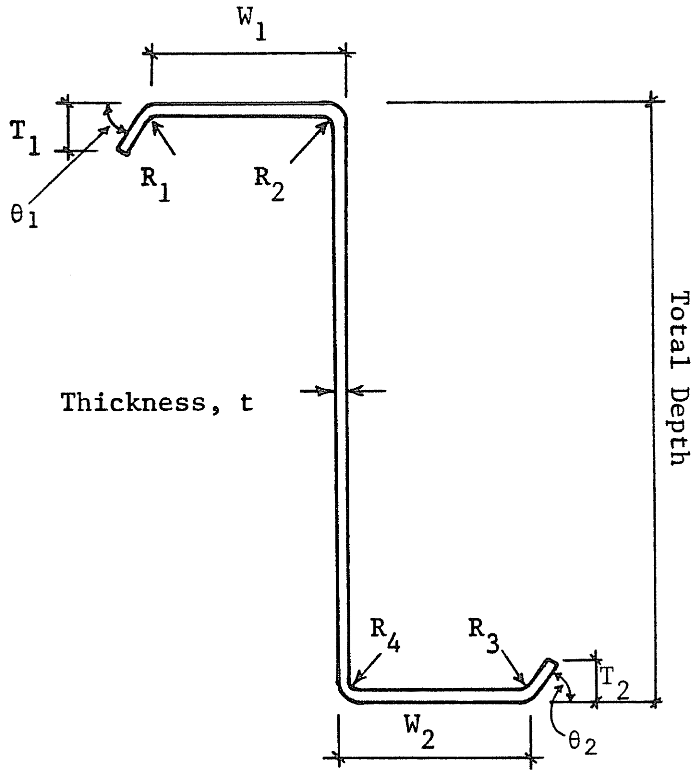
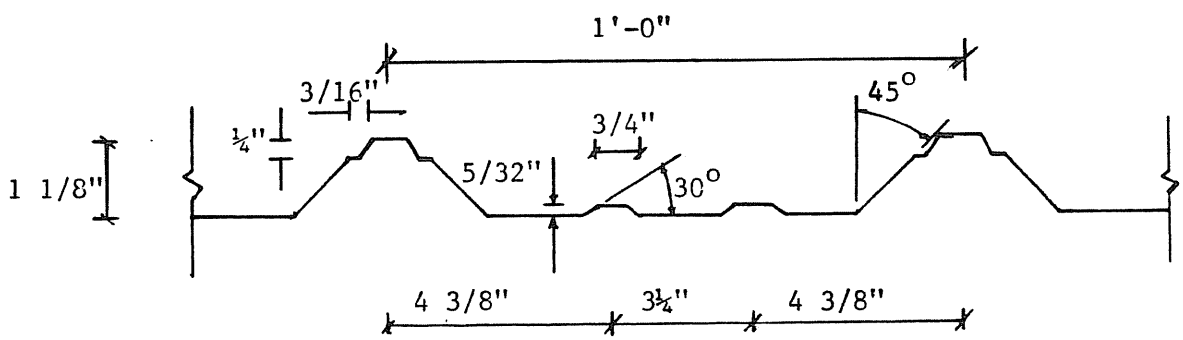


Figure 2. Cross-Section Measurements



Star Dura Rib Panel

Figure 3. Typical Panel Shape

2.2 Test Set-up

General details of test set-up are shown in Figure 1. The test chamber was constructed in such a way that the roof section simulates actual field conditions. Light weight metal panels, 42 inches in height and varying in length from 1 ft. to 8 ft., were used as walls. Each panel was braced laterally to the reinforced concrete floor by A-frame braces. Adjacent panels were bolted together with unfinished bolts. In both tests, the chamber was 15 ft. wide while the length was changed from 60 ft. to 50 ft. by rearranging the wall panels.

Inside the chamber, the ridge purlins, the intermediate purlins, and the eave strut were supported by short sections of rafters which in turn were supported by short column stands that rest on the laboratory floor. At one end of the set-up, knife-edge bearing plates were inserted between the column stands and the rafter to provide free rotation at the support. One-half inch diameter machine bolts through the bottom flange of the rafter kept the knife-edges in place. At the intermediate supports, and at the other end of the chamber, ½ inch diameter rollers were inserted between the rafter sections and the column to allow rafter section to rotate. The purlins were bolted to the top flange of the rafters and were lapped together over the intermediate supports. For the two span test, the lapped sections consisted of 1 ft. 2 in. on each side of the centerline of the rafter. The exterior lap for the three span test was also 1 ft. 2 in. while the interior lap 2 ft. 4 in. Two ½ in. diameter machine bolts were used to connect adjacent webs near each end of every lap.

In each test, the intermediate rows of purlins were standard cold-formed Z-purlins provided by Star Manufacturing Company. The ridge purlins were selected from purlins that were left over from previous tests done at the Fears Structural Engineering Laboratory. These were lapped together in such a way that the centerline deflection was less than the centerline deflection of the test purlin. The eave strut consisted of a Z-purlin and two channels. The channels were bolted together back to back and then bolted to the web of the purlin, making the system very rigid. (See Figure 4). Once the purlins were all in place, the conventional panels were connected to the purlins and the eave strut using self drilling fasteners through the panel and the top flange.

2.3 Instrumentation

Instrumentation consisted of strain gages, dial gages and linear displacement transducers. For both tests, the strain gages were located just outside the lap in the north bay. Strain was measured at ten locations on the cross-section. Figure 5 shows the location of the gages. One gage was installed on each lip, two gages on each flange, and four gages equally spaced along a vertical line on the web, one side only.

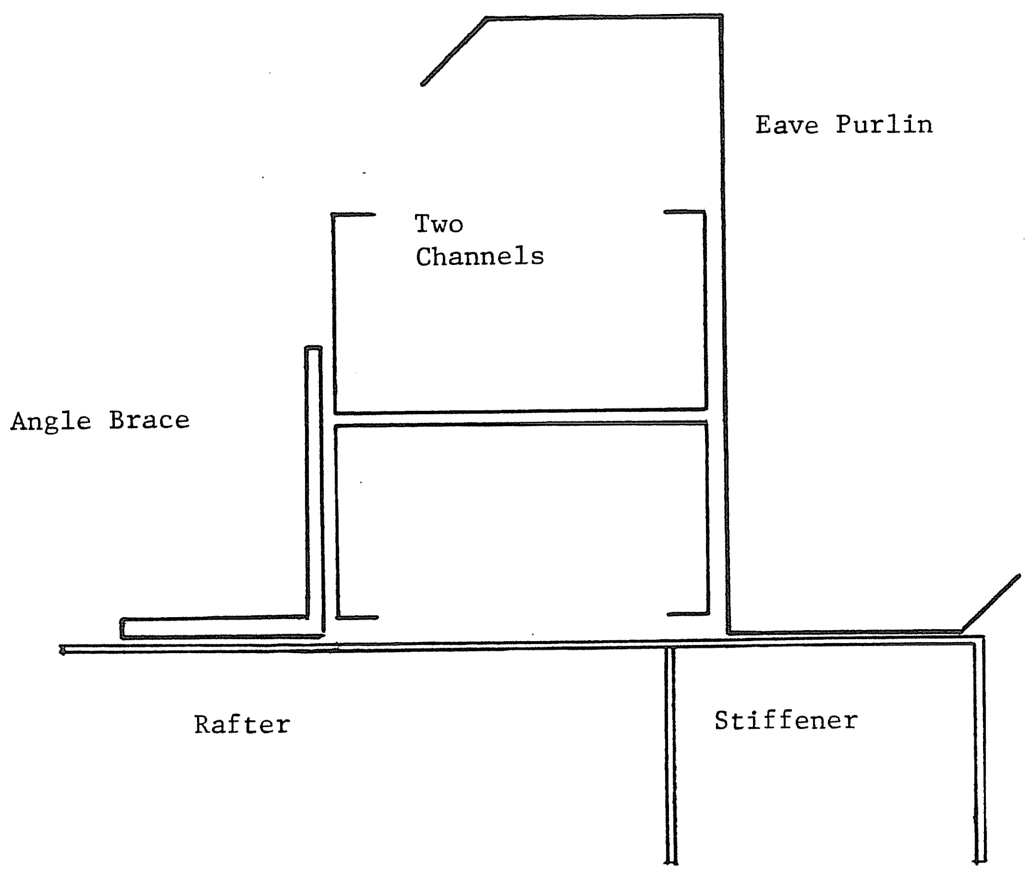


Figure 4. Detail of Eave Support

Four linear displacement transducers were used to measure vertical and lateral displacement of the test and ridge purlins. One transducer was used to measure the vertical deflection of the ridge purlin to insure that its deflection was less than that of the test purlin. The location of the transducer was at the midspan of the north-most bay. A transducer was also placed at the same location of the test purlin to measure its vertical deflection. Two transducers were used to measure the lateral displacement of the test purlin, also at the midspan. As shown in Figure 6, one transducer measured horizontal displacement of the bottom flange and one measured horizontal displacement of the top flange. Dial gages were placed directly underneath the rafter supports in the north bay to measure the vertical deflection of the rafters. Data from these gages permitted a correction for the test purlin deflection.

2.4 Testing Procedure

At the beginning of each test, the roof system was loaded to the approximate working load as given by Star Manufacturing Company. Vacuum loading was measured by a manometer outside the chamber that read equivalent inches of water, and also by a pressure transducer that read change in voltage which could be converted to amount of load per linear foot. Following this initial loading, zero readings were recorded for all strain gages, displacement transducers, and dial gages. The system was then loaded in 1 inch of water (5.2 psf)

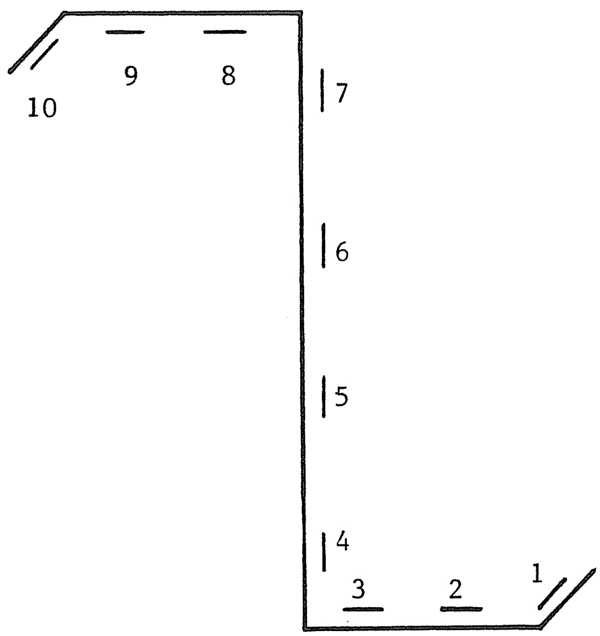


Figure 5. Location of Strain Gages

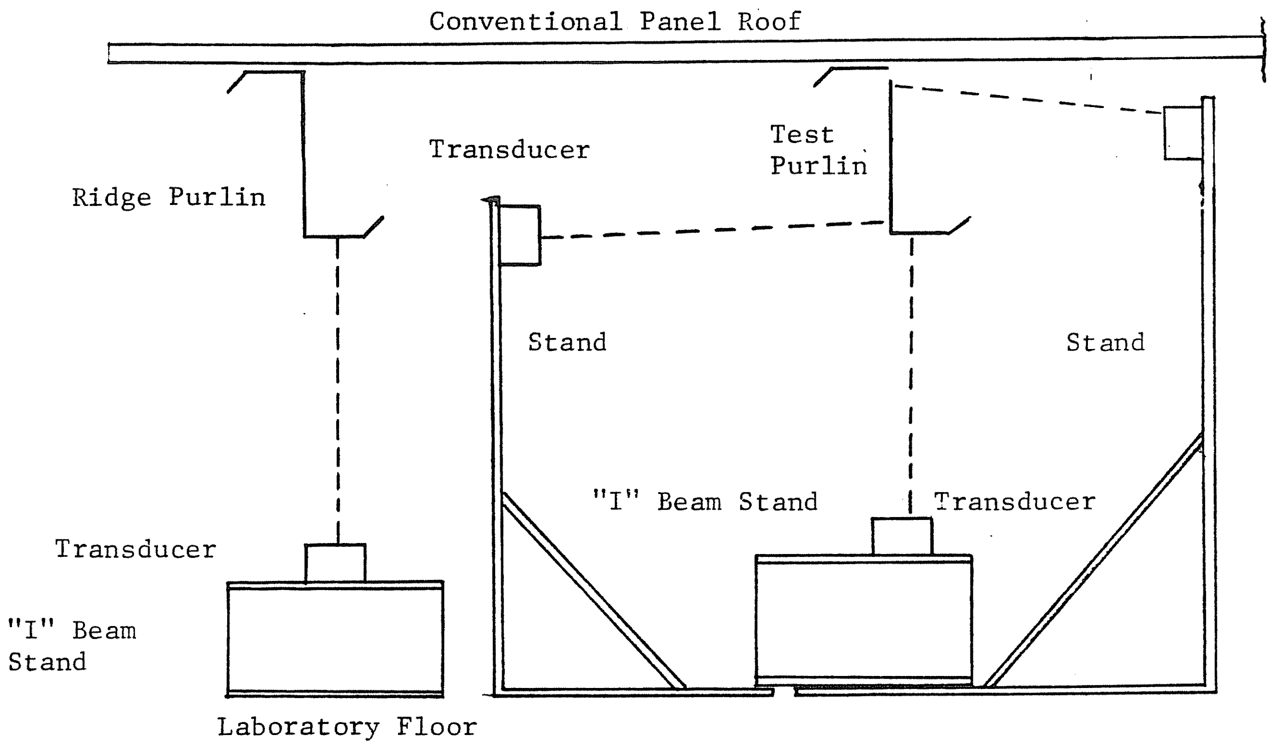


Figure 6. Location of Displacement Transducers

increments. The loading procedure was continued in the same increments until the load-deflection plot began showing non-linearity. The load increments were then reduced. After each increment, readings of all instrumentation were recorded. The system was loaded until failure occurred and the failure mode and other observations recorded for each test.

2.5 Supplementary Tests

Coupon Tests. Standard tensile coupon tests were made from samples cut from the test purlin. Results are given in Table 4. Results are also given for the test purlin from the three span standing system.

2.6 Test Results

Test results consist of load versus deflection data, load versus lateral displacement data, stress distribution data, and description of failure mode. Load versus deflection data includes plots of simulated live load vs. vertical deflection at the centerline of the test purlin. Load versus lateral displacement data includes plots of simulated live load vs. lateral displacement of the top and bottom flanges of the test purlin. The vertical deflection plot also includes a theoretical deflection as computed using a stiffness analysis program for plane frames. Stress distribution is plotted at both the working load and the failure load. Results for Tests C-1 and C-2 are found in Appendices A and B, respectively.

Table 4

Tensile Coupon Test Results

Test No.	Thickness (in)	Width (in)	Yield Stress (ksi)	Ultimate Stress (ksi)	Elongation %
C-1	0.0840	0.4858	61.765	80.39	25
C-2	0.0670	0.4853	57.846	79.385	24
6-B	0.082	0.5021	53.398	72.816	27.5

Note: Coupon tests were not available for test 2SPT-2.

CHAPTER III

COMPARISON TESTS DETAILS

3.1 Standing Seam Panel

The comparison test for Test C-1 is Test 6-B of Reference 4. The details of Test 6-B were nearly identical to that of Test C-1. The ridge purlins, intermediate rows of purlins, and eave strut were all supported by short sections of standard rafters which in turn were supported by short column stands, as in Test C-1. The loading procedure was also the same -- one inch increments of water (5.2 psf) until non-linearity and then reduced increments until failure. The only distinct difference between the tests was that lateral bracing was provided at the centerline of each bay in Test 6-B. The braces were 3/4 in. diameter steel electrical conduit which were anchored to the eave strut.

The dimensions of the north purlin and the center purlin from Test 6-B are given in Table 5. The cross-sectional properties and the load-deflection data calculated using AISI criteria are shown in Table 6. Appendix C lists all test results including load vs. deflection data, load vs. lateral displacement data, stress distributions, and description of failure mode. Standard tensile coupon tests were made from samples cut from the test purlin. Results are given in Table 4.

3.2 Conventional Panel System

The comparison test for Test C-2 is 2SPT-2 as reported in Reference 3. The testing program consisted of two lines of standard 8 x 3 Z-purlins as cold-formed by Star Manufacturing Company. The purlins were oriented with top flanges opposed and pointing outwards. The purlins were lapped 1 ft. 2 in. on each side of the centerline of intermediate rafters in Test C-2. Two ½ in. diameter machine bolts connected adjacent webs. The purlins were bolted to knife edge rockers which were supported by rafter sections. A roller was placed between the rafter section and the support beam. Conventional roof sheeting 3 ft. wide by 6 ft. long was attached to the top flanges of the purlins using self-drilling fasteners at approximately 1 ft. centers. Load was applied to the system using 3 in. by 8 in. by 16 in. solid concrete blocks weighing 33.0±0.1 lbs. each. The blocks were set directly in the troughs of the roof deck at approximately 1 ft. on center. Load increments were initially 33 psf and were decreased to 4.25 psf near failure.

Appendix D lists the available test results from the 2SPT-2 test. Table 5 gives the dimensions of the test purlin and Table 7 lists the cross-sectional properties and the load-deflection data. Results of standard coupon tests were not available.

Table 5

Measured Z-Purlin Dimensions

Test No.		Total Depth (in)	Thickness (in)	TOP					BOTTOM				
				W_1^* (in)	T_1^* (in)	R_1^* (in)	R_2^* (in)	θ_1^* (deg)	W_2^* (in)	T_2^* (in)	R_3^* (in)	R_4^* (in)	θ_2^* (deg)
6-B	N	8.03	0.082	3.01	0.57	0.46	0.406	41	2.94	0.68	0.406	0.500	42
	S	7.93	0.066	2.94	0.78	0.406	0.406	51	2.71	0.66	0.406	0.500	51
2SPT-2	N	8.00	0.066	3.00	0.45	0.313	0.313	40	3.00	0.45	0.313	0.313	40
	S	8.00	0.066	3.00	0.45	0.313	0.313	40	3.00	0.45	0.313	0.313	40

*See Figure 2

Note: N = North, S = South. The north purlin was the test purlin in both tests.

Table 6

Z-Purlin Properties (F_y = 53 ksi, Span = 3 @ 20)

Test No.		GROSS			STRENGTH										1.67xAllowable		Deflection	
		I (in^4)	S_t (in^3)	S_b (in^3)	I (in^4)	S_t (in^3)	S_b (in^3)	b_e (in)	F_e ksi	F_t ksi	F_{bw} ksi	M_c ft-k	M_t ft-k	M_w ft-k	M_u ft-k	W_u (lb/ft)	I (in^4)	1/100 plf (in)
6-B	N	12.595	3.149	3.188	12.524	3.12	3.182	2.468	32.040	32.040	30.937	8.331	8.495	9.050	13.912	278.244	12.595	0.969
	S	9.829	2.553	2.449	9.559	2.438	2.424	2.197	31.262	35.580	32.045	6.352	7.186	7.332	10.608	212.164	9.829	1.242

Table 7

Z-Purlin Properties (F_y = 55 ksi, Span = 2 @ 25)

Test No.		GROSS			STRENGTH										1.67xAllowable		Deflection	
		I (in^4)	S_t (in^3)	S_b (in^3)	I (in^4)	S_t (in^3)	S_b (in^3)	b_e (in)	F_e ksi	F_t ksi	F_{bw} ksi	M_c ft-k	M_t ft-k	M_w ft-k	M_u ft-k	W_u (lb/ft)	I (in^4)	1/100 plf (in)
2SPT-2	N	10.107	2.548	2.548	9.659	2.368	2.506	2.202	33.000	33.000	30.010	6.511	6.892	6.469	10.800	138.282	10.059	2.962
	S	10.107	2.548	2.548	9.659	2.368	2.506	2.202	33.000	33.000	30.010	6.511	6.892	6.469	10.800	138.282	10.059	2.962

t = top
b = bottom

CHAPTER IV

TEST RESULTS

4.1 Three Span Tests - Conventional and Standing Seam Systems

The purpose of these tests was to compare the behavior of a three span conventional panel roof system with that of a three span standing seam roof system. The test configurations consisted of three spans of 20 ft. 0 in. center-to-center of rafter webs. Vacuum loading was used for both tests. For the conventional system, the exterior bay purlins had a measured thickness of 0.084 in. and those in the intermediate bay measured 0.066 in. The measured purlin dimensions for the standing seam were nominally the same. The spacing between the rows of intermediate purlins was 4 ft. 9 inches for both tests. The test set-up was identical for both tests with the exception that intermediate braces were installed at the centerline of each bay in the standing seam test and no braces were used for the conventional test.

Failure of the conventional system occurred at 273.1 plf by web crippling above the exterior support in the north bay. The standing seam system failure load was 284.5 plf caused by local buckling of the compression flange and lip just outside the lap. Using the AISI criteria and the constrained bending assumption but not considering the interaction of shear and bending, the predicted failure loads were 479.0 and 436.0 plf for the conventional and standing seam systems, respectively. The failure loads predicted by Star Manufacturing Company were 309 plf and 290 plf for the conventional and standing seam tests, respectively. The Star Manufacturing Company analyses predicted failure by shear plus bending in the middle bay immediately outside the lapped portion of the purlin line. Continuous lateral support was assumed in the analysis of the conventional system; lateral support was assumed to exist only at the rafter and intermediate brace locations (midspan of each bay) for the standing seam analysis. A summary of the predicted and test results for both tests is given in Table 8.

4.2 Two Span Tests - Vacuum and Gravity Loading

The purpose of these tests was to compare the behavior of conventional panel roof systems under vacuum loading and gravity loading. The test configurations consisted of two spans of 25 ft. 0 in. center-to-center of rafter webs. The thickness of all purlins was 0.066 in. Spacing between purlin rows was 4 ft. 9 in. for the vacuum chamber tests and 5 ft-0 in. for the gravity loading tests. Lateral bracing was not provided in either test set-up. In the gravity test, the purlins were faced in opposite directions while for the vacuum tests they were faced in the same directions.

The failure load for the vacuum chamber test was 168.0 plf. The failure mode was web crippling above the exterior supports. Failure occurred at 121.4 plf by web buckling in the gravity loading test. The predicted failure load using AISI criteria and assuming constrained bending, but not considering the interaction of shear and bending, was 153.2 plf and 162.9 plf for the vacuum and gravity loading tests, respectively. The Wallace model[3,5] predicted failure loads of 137.5 plf and 115.4 plf for the chamber and gravity tests, respectively. The predicted failure mode for both tests was web buckling just outside the lap. Star Manufacturing Company predicted failure loads of 119.5 plf for the vacuum chamber test and 114 plf for the gravity test. Continuous lateral support was assumed for both analyses. Predicted failure mode was shear plus bending immediately outside the lapped portion of the purlin line. A summary of predicted and test results for both tests is given in Table 9.

Table 8
Comparison of Predicted and Test Results
Conventional and Standing Seam Systems
Three Span Tests - 3 @ 20'-0"

Test Configuration	Failure Loads			Test Failure Mode
	Constrained[1] Bending plf	S.M.C.[2] plf	Test plf	
Test C-1 (conventional)	479.0	309.2	273.1	Web crippling
Test 6-B[(4)] Standing Seam Bracing @ ℄	436.0	290.2	284.5	Local buckling of compression flange and lip

[1]AISI design criteria with constrained bending assumption times 1.67 (shear plus bending not considered)

[2]Star Manufacturing Company analysis including effects of unbraced length Predicted failure mode was bearing failure at end supports.

Table 9
Comparison of Predicted and Test Results
Conventional Panel
Two Span Tests 2 @ 25'-0"

Test Configuration	Failure Loads				Test Failure Mode
	Constrained[1] Bending plf	Wallace[2] plf	S.M.C.[3] plf	Test plf	
Test C-2	153.2	137.5	119.5	168.0	Web crippling
Test 2SPT-2 Z-Purlin Gravity Loading	162.9	115.4	114.3	121.4	Web buckling just outside lap.

[1]AISI design criteria with constrained bending assumption times 1.67 (shear plus bending not considered)

[2]Wallace model, References 3 and 5

[3]Star Manufacturing Company analysis assuming constrained bending. Predicted failure mode shear plus bending just outside lap.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two new tests of conventional panel roof systems under vacuum loading are reported here. A three span test was preformed and the results were compared to a standing seam roof system tested with nearly identical configuration. A two span conventional system was also tested and the results were compared to a conventional system with essentially the same configuration but tested using gravity loading. A summary of both predicted and test results for each test is given in Tables 8 and 9.

The following observations are made:

Three Span Tests. For both tests the failure mode predicted by the Star Manufacturing Company analysis procedure was bearing failure at the end supports. Actual failure of the conventional system (Test C-1) was web crippling at the outside supports. Failure of the standing seam system was by local buckling of the compression flange and lip just outside the lap in the north bay. The last reading prior to failure in the conventional panel system was 88.4% of the Star Manufacturing Company predicted failure load. In the standing seam system the last reading was 98% of the Star Manufacturing Company predicted failure load.

Comparison of load versus deflection curves for the two tests (Figures A.5 and C.5) show substantial agreement. For both tests the measured vertical deflections were greater than the predicted. Comparison of measured stress distributions for the two tests (Figures A.6, A.7 and C.6, C.7) shows somewhat similar patterns. The major difference is at the top lip. A stress reversal occurred in the standing seam test; the entire lip remained in tension in the conventional test. Comparison of the load versus lateral displacement curves (Figures A.8 and C.8) shows more movement in the standing seam test than in the conventional test. This is expected, since movement is permitted by the panel to purlin clip used in the standing seam system.

From the results, it is concluded that little difference exists in the behavior of similar standing seam and conventional roof systems.

Two Span Tests. For both tests, the failure mode predicted by Star Manufacturing Company analysis procedure was bearing at the end supports. Actual failure of the vacuum loaded system, Test C-2, was web crippling at the outside supports. Failure of the gravity loaded system, Test 2SPT-2, was by web buckling just outside the lap in the north bay. The last reading prior to failure in Test C-2 was 40.5% greater than the predicted failure load of Star Manufacturing Company. In the 2SPT-2 test, the last reading was 6.2% greater than the predicted failure load of Star Manufacturing Company.

Comparison of load versus deflection curves for the two tests (Figures B.5 and D.5) show good agreement. Again, measured vertical deflections were less than predicted deflections for both tests. (The somewhat erratic load-deflection curve shown in Figure B.5 was caused by instrument malfunction). Strain (hence stress) and lateral displacement data were not available for Test 2SPT-2.

From the results, it is concluded that no difference exists between the gravity loading and vacuum loading test methods described herein. However, the difference in failure load and failure mode cannot be explained with the limited test data available.

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APPENDIX A

TEST C-1 RESULTS

TEST SUMMARY

Project: Star Purlin Study

Test No.: C-1 (conventional

Test Date: May 25, 1982

Purpose: To compare roof systems: conventional panel vs. standing seam.

Span(s): 3 @ 20 ft. 0 in.

Thickness: 0.084, 0.066, 0.084 Moment of Inertia: 12.627 in^4, 10.182 in^4, 12.627 in^4

Parameters: Conventional Roof System
No intermediate braces
No insulation
Spacing 4 ft. 9 in.

Failure Load: 273.1 plf

Failure Mode: Web crippling at the north support.

Predicted Failure Loads:

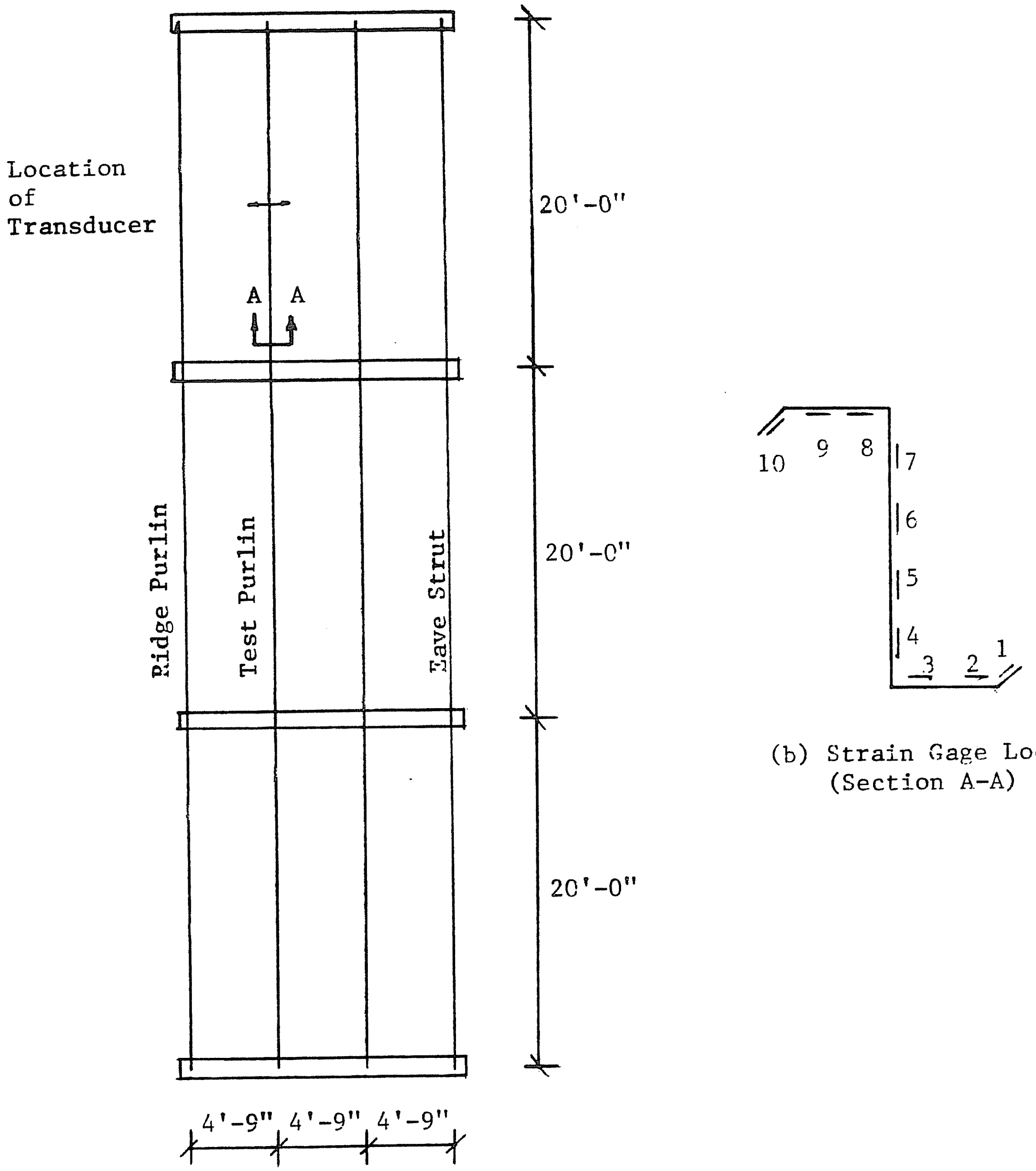
Method Star Manufacturing Co. Load 317 plf

Method AISI Constr. Bending Load 479 plf

Method Load

Discussion:

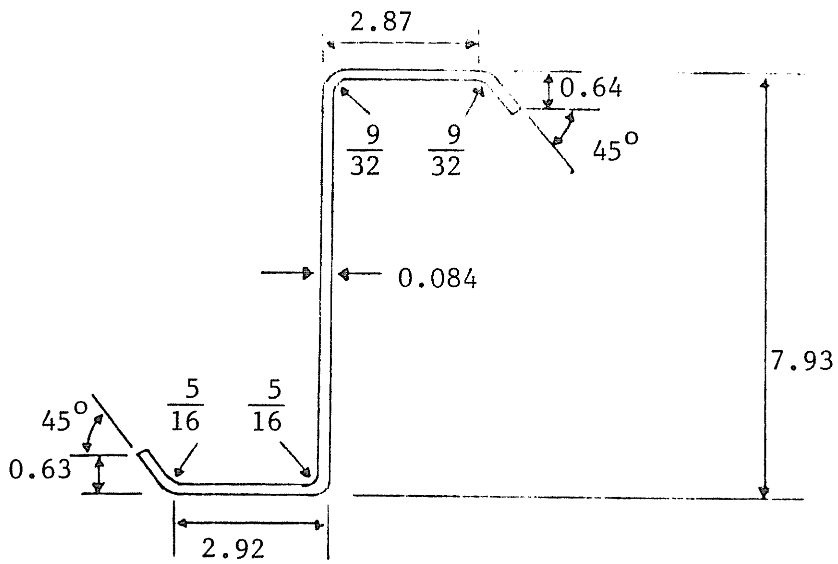
- -Web crippling or bearing failure occurred first at the north bay at the exterior support at 273.1 plf.
- -Web crippling occurred in the south bay at the exterior support at 281.2 plf.
- -Loading was continued to 346 plf. Between 281 plf and 346 plf web crippling occurred at the intermediate support.
- -Measured vertical deflections were greater than the theoretical for the test purlin. The ridge purlin deflections were less than the theoretical.
- -Bottom flange of test purlin showed considerably move lateral movement than the top flange.
- -Strains were measured at a cross-section immediately outside the lap on the exterior side of the north bay.
- -Yielding did not occur before failure.



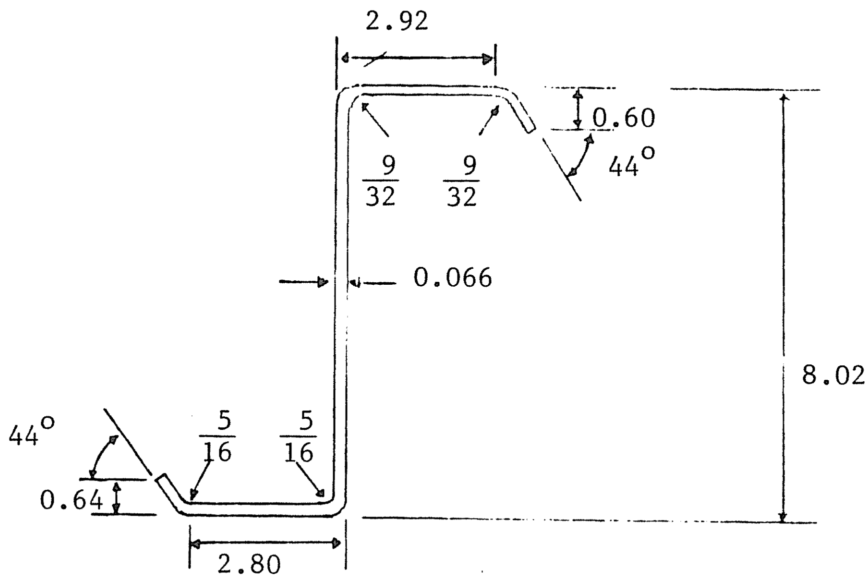
(a) Plan View

(b) Strain Gage Locations (Section A-A)

Figure A.1 Instrumentation Location, Test C-1



(a) Test Purlin - North Bay



(b) Center Bay

Figure A.2 Measured Purlin Dimensions, Test C-1

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

IDENTIFICATION: STAR TEST C-1 TEST PURL[illegible]

	TOP	BOTTOM
FLANGE(in)	2.870	2.920
LIP(in)	0.640	0.630
LIP ANGLE(deg)	45.000	45.000
RADIUS L/F(in)	0.281	0.313
RADIUS F/W(in)	0.281	0.313

TOTAL DEPTH(in)	7.93
THICKNESS(in)	0.084
YIELD STRENGTH(ksi)	62

	MOMENTS OF INERTIA(in^4)	SECTION MODULII(in^3) TOP	SECTION MODULII(in^3) BOTTOM
GROSS=	12.627	3.205	3.23[illegible]
STRENGTH=	12.552	3.174	3.22[illegible]
DEFLECTION=	12.627		

BE=	2.447	in
FC=	35.989	ksi
FT=	37.200	ksi
FBW=	35.809	ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC=	9.520	ft-k
MT=	9.999	ft-k
MW=	10.316	ft-k
MU=	15.898	ft-k (1.67*allowable)
SPAN =	20.000	ft.
UNIFORM LOAD=	317.953	plf (1.67*allowable)
DEFLECTION =	0.966	in./100plf

Figure A.3 AISI Purlin Analysis, Test C-1 North Purlin

```
-------------------------------------------------------------------------------
A I S I   P U R L I N   A N A L Y S I S
IDENTIFICATION: STAR TEST C-1 (MIDDLE BAY)
-------------------------------------------------------------------------------
                             TOP                BOTTOM
FLANGE(in)                 2.920                 2.800
LIP(in)                    0.600                 0.640
LIP ANGLE(deg)            44.000                44.000
RADIUS L/F(in)             0.281                 0.313
RADIUS F/W(in)             0.281                 0.313

TOTAL DEPTH(in)                      8.02
THICKNESS(in)                        0.064
YIELD STRENGTH(ksi)                  62
                                                SECTION MODULII(in^3)
     MOMENTS OF INERTIA(in^4)                   TOP                BOTTOM
GROSS=          10.182                      2.568              2.557
STRENGTH=        9.763                      2.399              2.514
DEFLECTION=     10.152
BE=     2.179    in
FC=     33.427   ksi
FT=     37.200   ksi
FBW=    33.109   ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
          MC=        6.683    ft-k
          MT=        7.792    ft-k
          MW=        7.173    ft-k
          MU=       11.160    ft-k (1.67*allowable)
SPAN        =       20.000    ft.
UNIFORM LOAD=      223.203    plf (1.67*allowable)
DEFLECTION  =        1.202    in./100plf
```

Figure A.4 AISI Purlin Analysis, Test C-1 Center Purlin

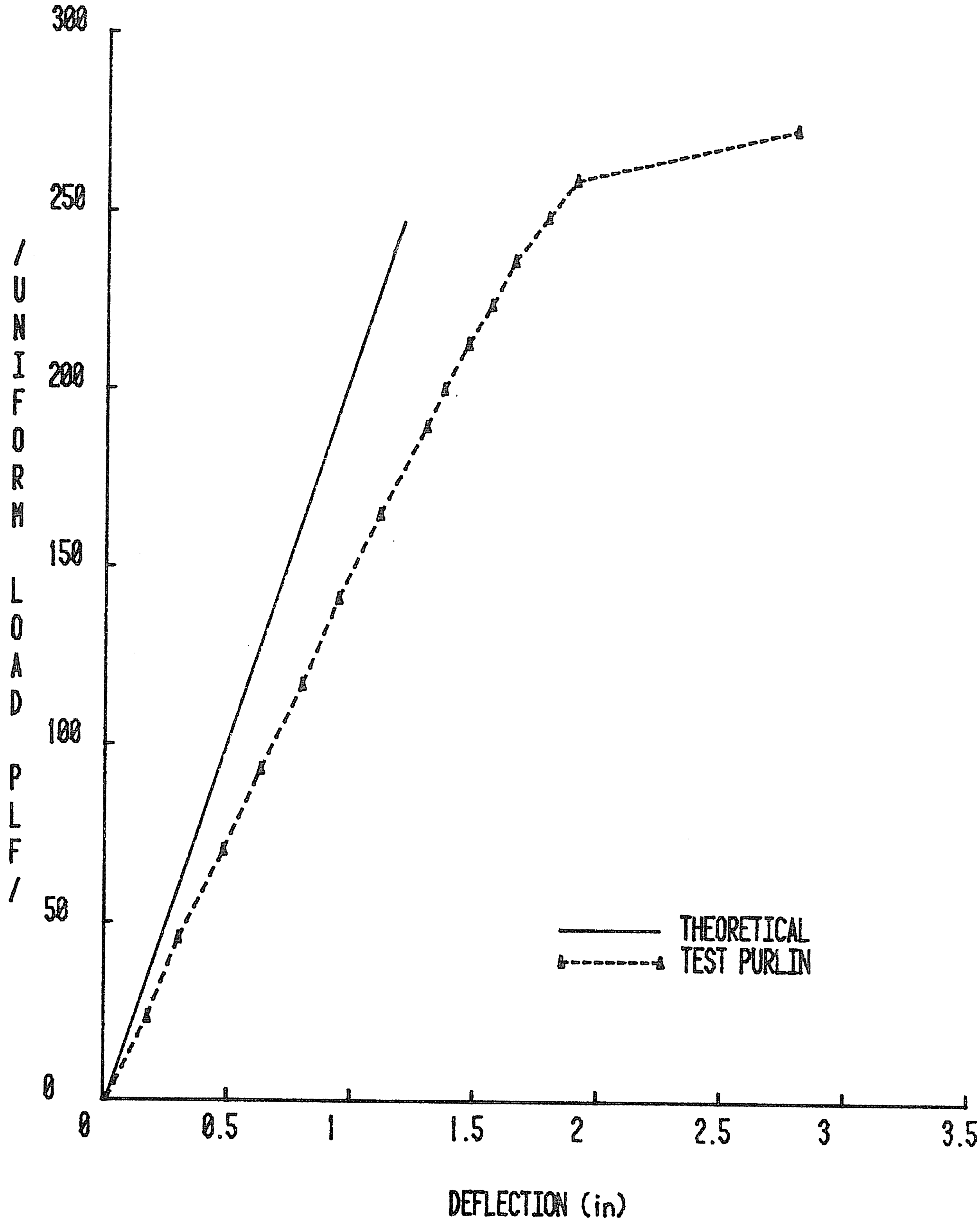


Figure A.5 Load vs. Vertical Deflection, Test C-1

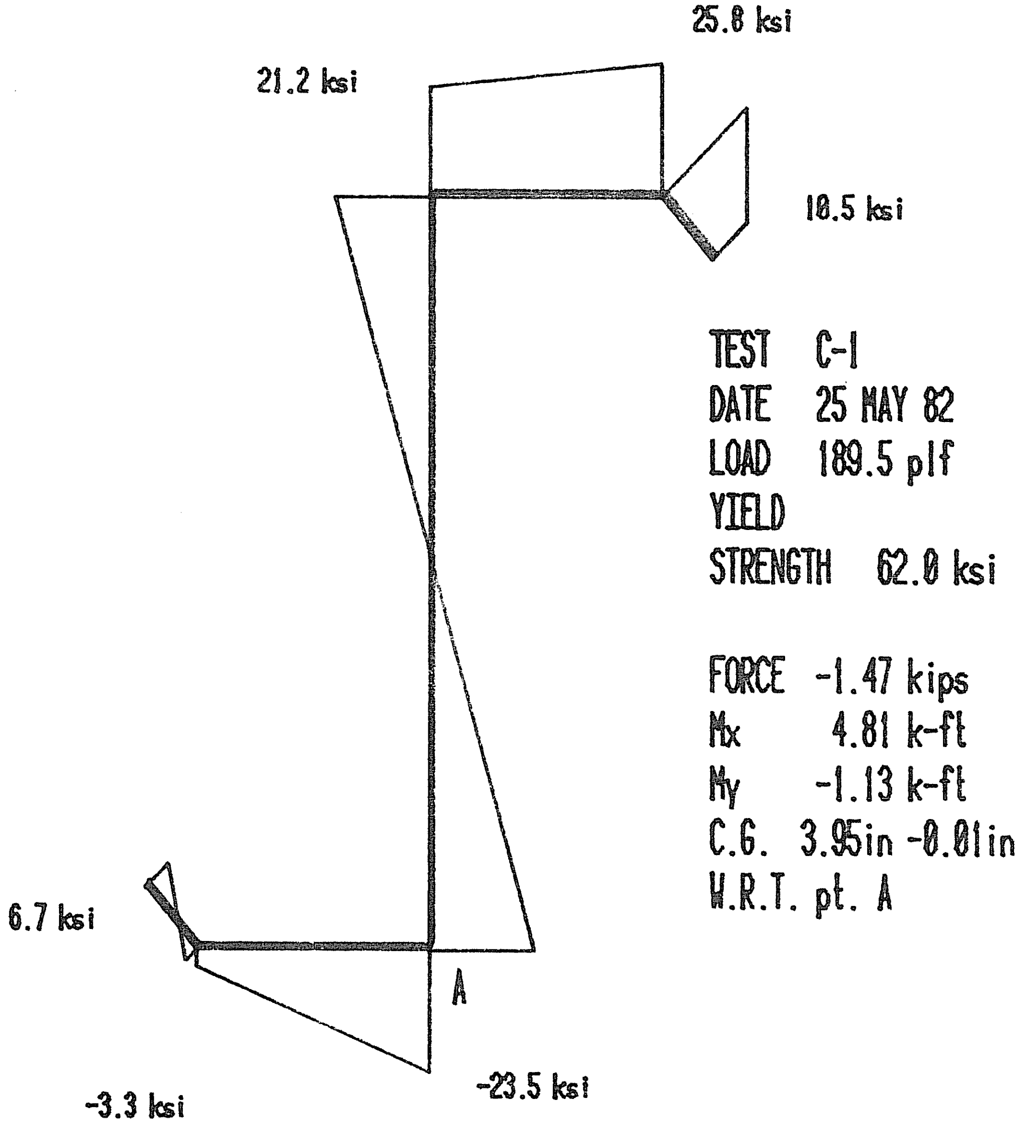


Figure A.6 Stress Distribution at 189.5 plf, Test C-1

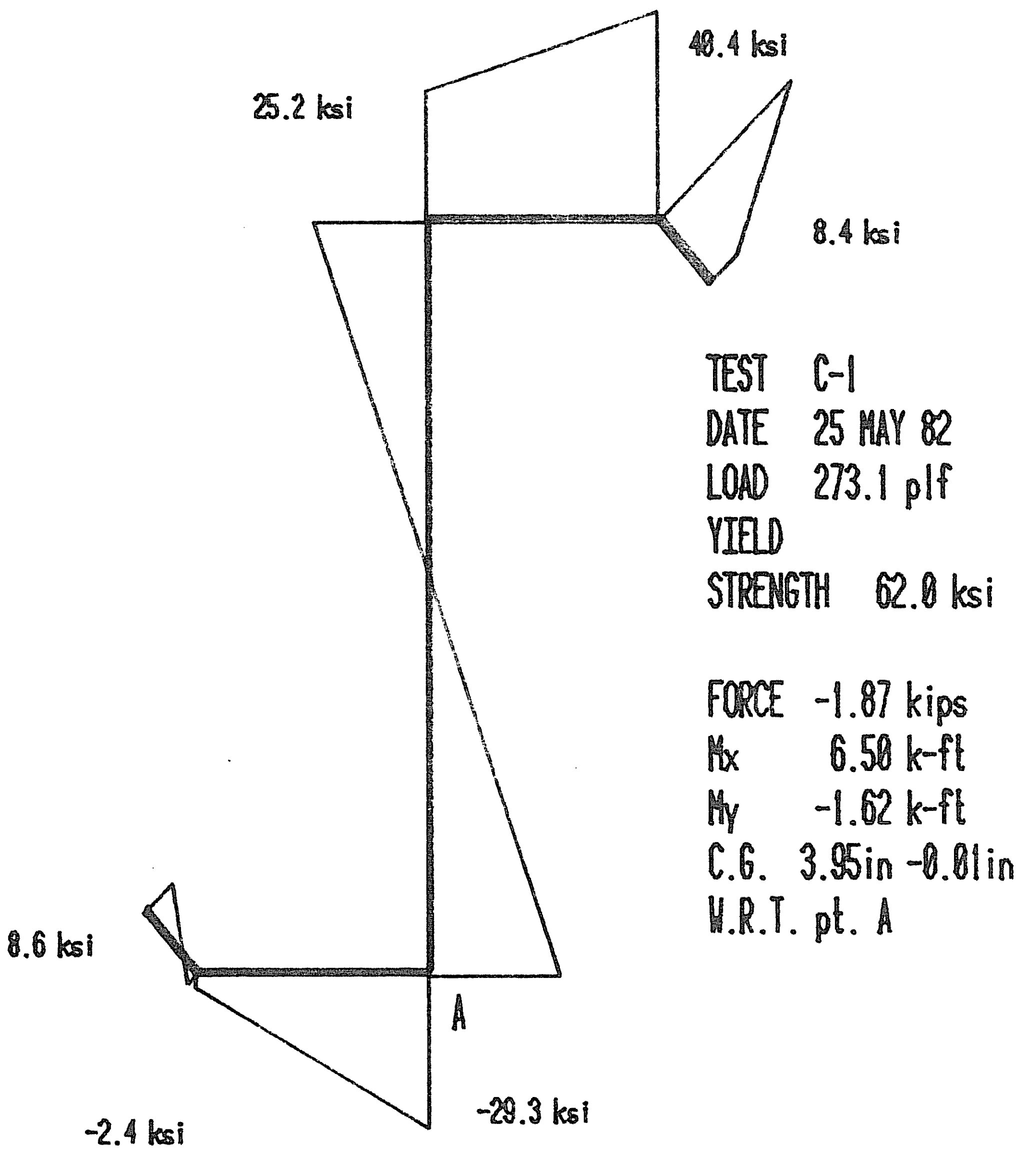


Figure A.7 Stress Distribution at 273.1 plf, Test C-1

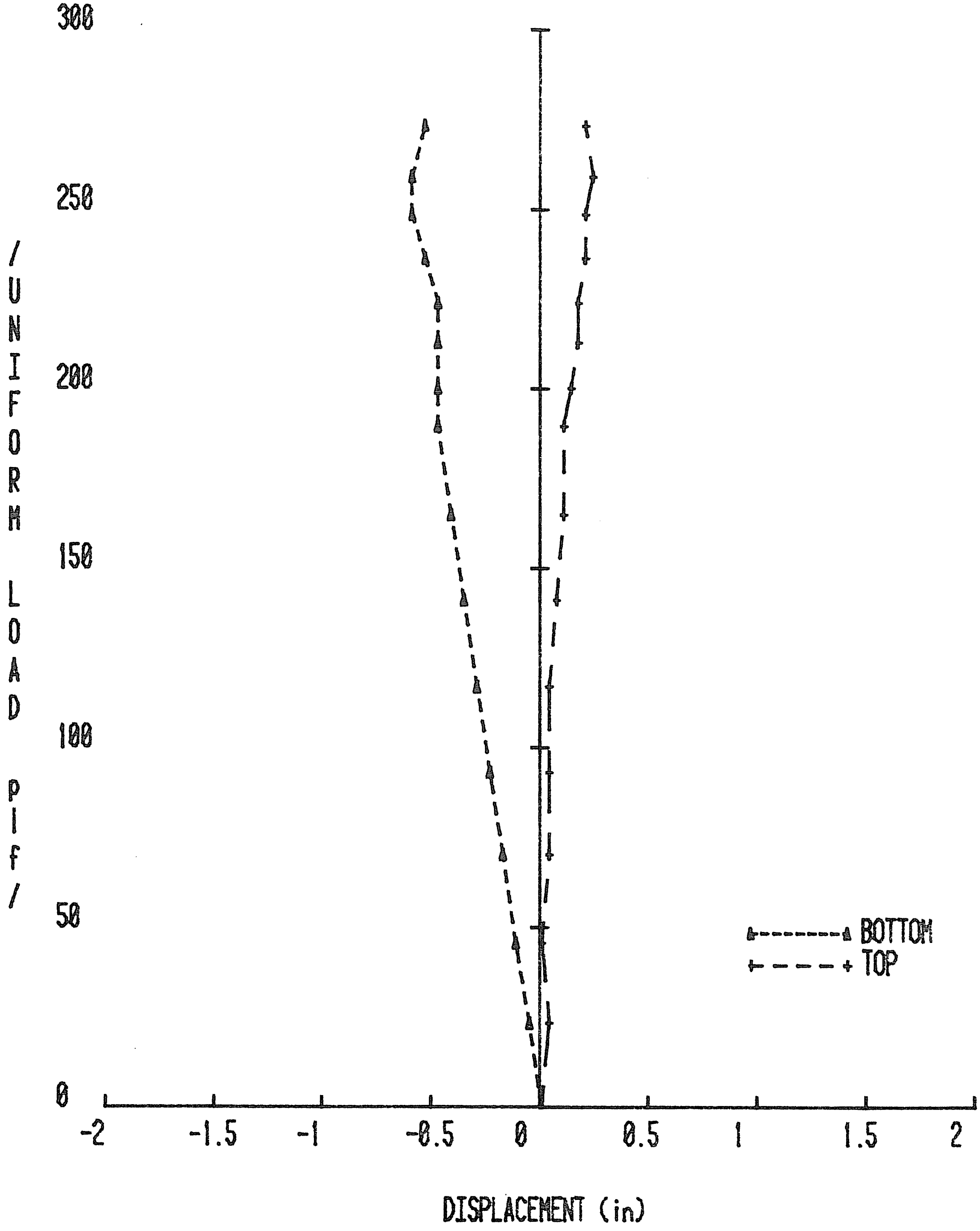


Figure A.8 Vertical Loading vs. Lateral Displacement, Test C-1

APPENDIX B

TEST C-2 RESULTS

TEST SUMMARY

Project: Star Purlin Study

Test No.: C-2 (conventional)

Test Date: June 2, 1982

Purpose: To compare test results: vacuum loading vs. gravity loading

Span(s): 2 @ 25'

Thickness: 0.066 in., 0.066 in. Moment of Inertia: 9.809 in^4, 10.334 in^4

Parameters: Conventional Roof System

Intermediate braces

No insulation

Spacing 4 ft 9 in.

Failure Load: 168 plf

Failure Mode: Web crippling above supports @ both ends

Predicted Failure Loads:

Method Star Manufacturing Co. Load 115 plf

Method AISI Load 153.2 plf

Method Load

Discussion:

- Web crippling occurred at supports at each end of chamber at 168 plf.
- Web crippling also occurred at the interior supports but not as severely as at the end supports.
- Vertical deflections of the test purlin were greater than theoretical. Vertical deflection of the ridge purlin was less than theoretical
- Vertical deflections of the test purlin were somewhat erratic.
- Stress distribution at the strain gaged cross-section did not confirm constrained bending assumption.
- Top flange lateral displacements exceeded bottom flange displacements.
- Maximum lateral displacement was less than 0.85 inches.

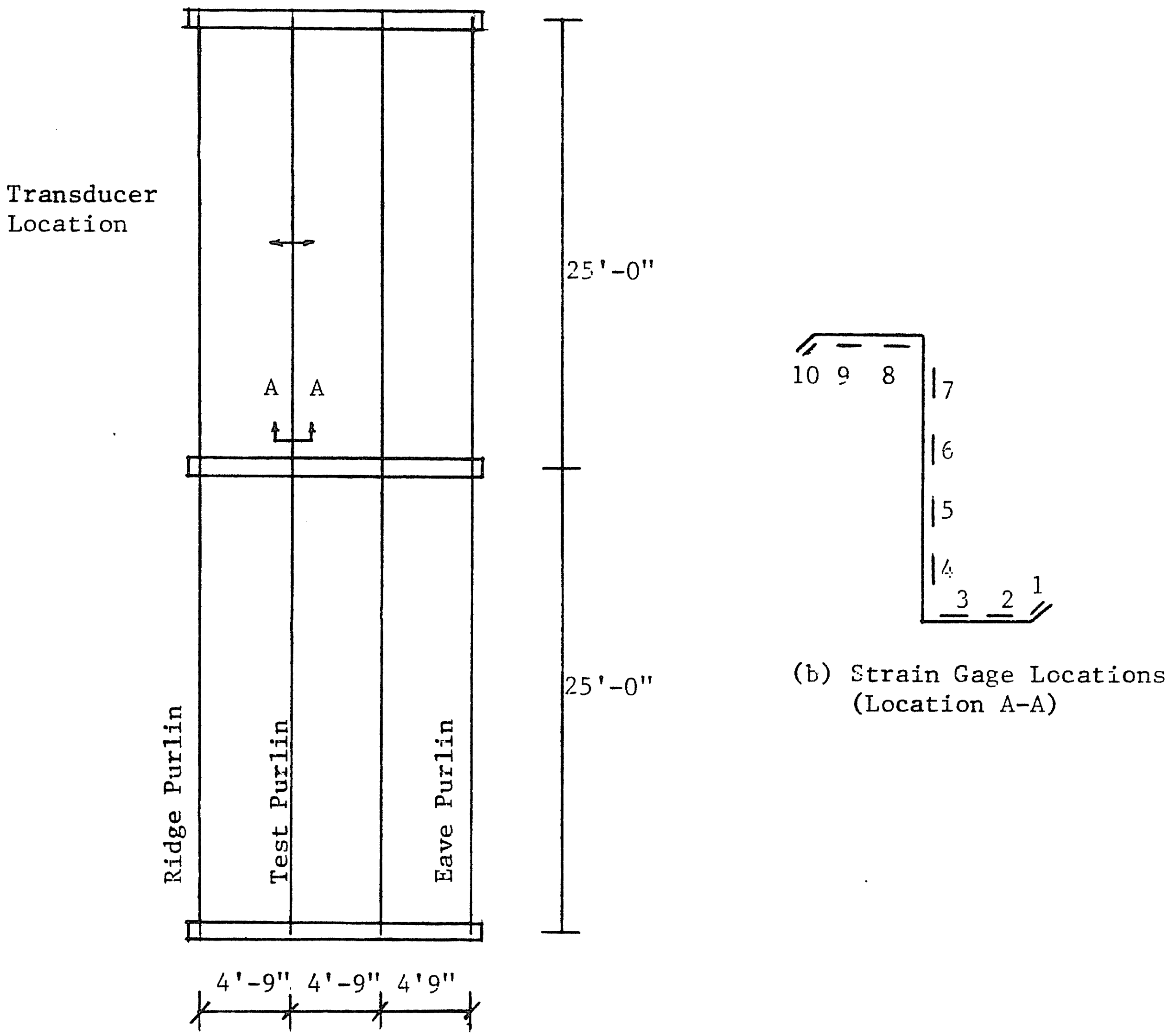
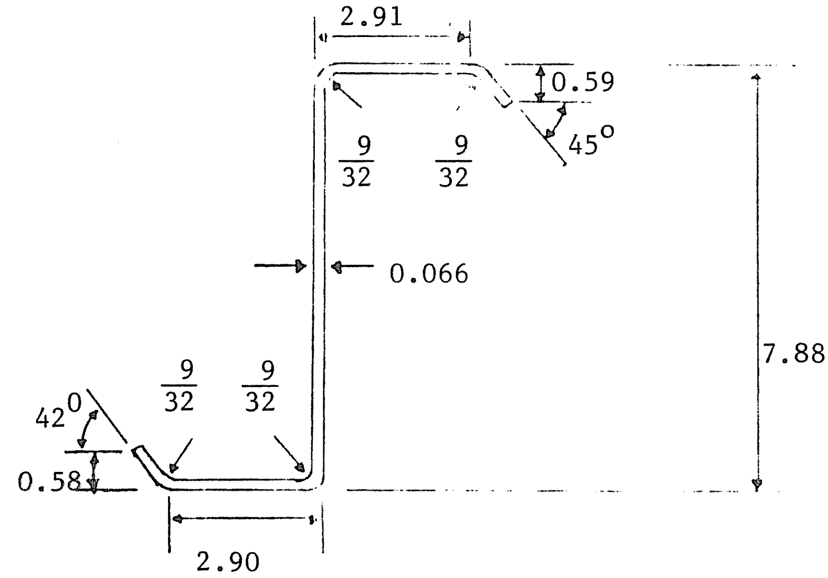


Figure B.1 Instrumentation Location, Test C-2



Test Purlin - North Bay

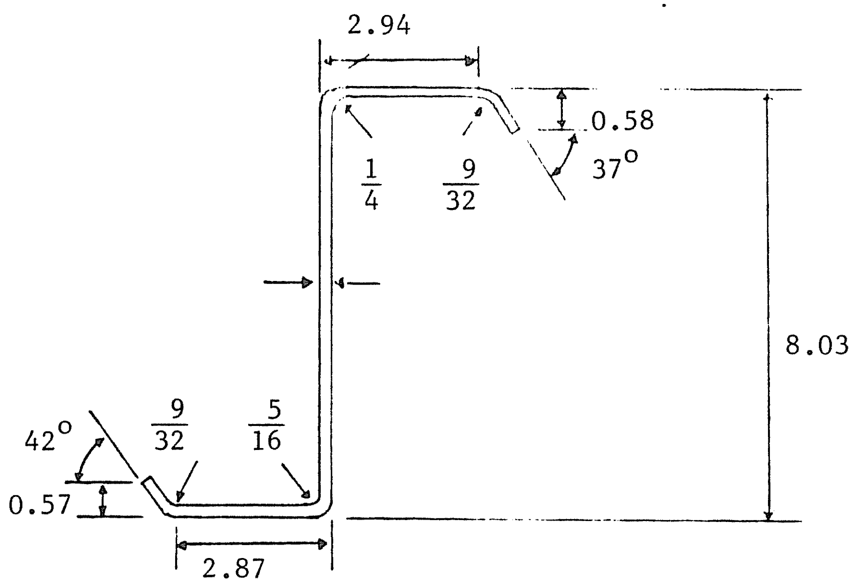


Figure B.2 Measured Purlin Dimensions, Test C-2

```
A I S I   P U R L I N   A N A L Y S I S
IDENTIFICATION: STAR TEST C-2 TEST PURLIN

                          TOP              BOTTOM
FLANGE(in)               2.910              2.900
LIP(in)                  0.590              0.580
LIP ANGLE(deg)          45.000             42.000
RADIUS L/F(in)           0.281              0.281
RADIUS F/W(in)           0.281              0.281

TOTAL DEPTH(in)                7.88
THICKNESS(in)                  0.066
YIELD STRENGTH(ksi)            58
                                         SECTION MODULII(in^3)
     MOMENTS OF INERTIA(in^4)           TOP               BOTTOM
GROSS=           9.809                  2.508              2.513
STRENGTH=        9.436                  2.356              2.478
DEFLECTION=      9.809
BE=     2.202   in
FC=     32.285   ksi
FT=     34.800   ksi
FBW=    31.530   ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
          MC=       6.337   ft-k
          MT=       7.186   ft-k
          MW=       6.716   ft-k
          MU=      10.583   ft-k  (1.67*allowable)
SPAN        =      25.000   ft.
UNIFORM LOAD=     135.469   plf (1.67*allowable)
DEFLECTION  =       3.037   in./100plf
```

Figure B.3 AISI Purlin Analysis, Test C-2, North Purlin

```
A I S I   P U R L I N   A N A L Y S I S
IDENTIFICATION: STAR TEST C-2 (SOUTH BAY)
-------------------------------------------------------------
                          TOP            BOTTOM
FLANGE(in)               2.940            2.870
LIP(in)                  0.580            0.570
LIP ANGLE(deg)          37.000           42.000
RADIUS L/F(in)           0.281            0.281
RADIUS F/W(in)           0.250            0.313

TOTAL DEPTH(in)                8.03
THICKNESS(in)                  0.066
YIELD STRENGTH(ksi)            58
                                          SECTION MODULII(in^3)
     MOMENTS OF INERTIA(in^4)        TOP              BOTTOM
GROSS=          10.334              2.618              2.573
STRENGTH=        9.979              2.473              2.541
DEFLECTION=     10.334
BE=     2.287   in
FC=     29.511   ksi
FT=     34.800   ksi
FBW=    31.325   ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)
          MC=        6.081   ft-k
          MT=        7.368   ft-k
          MW=        6.941   ft-k
          MU=       10.155   ft-k  (1.67*allowable)
SPAN          =     25.000   ft.
UNIFORM LOAD=      129.981   plf  (1.67*allowable)
DEFLECTION    =      2.883   in./100plf
```

Figure B.4 AISI Purlin Analysis, Test C-2, Center Purlin

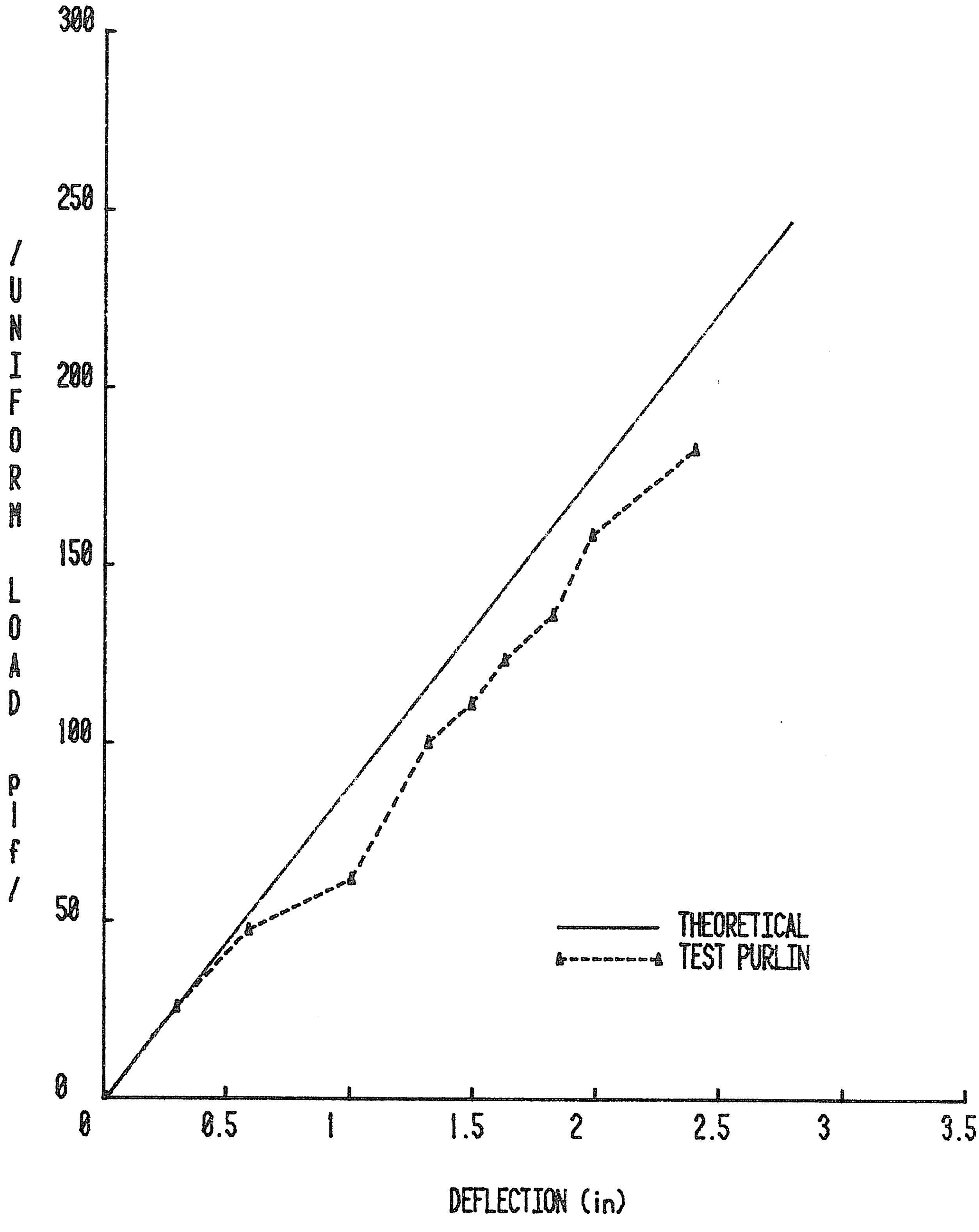


Figure B.5 Load vs. Vertical Deflection, Test C-2

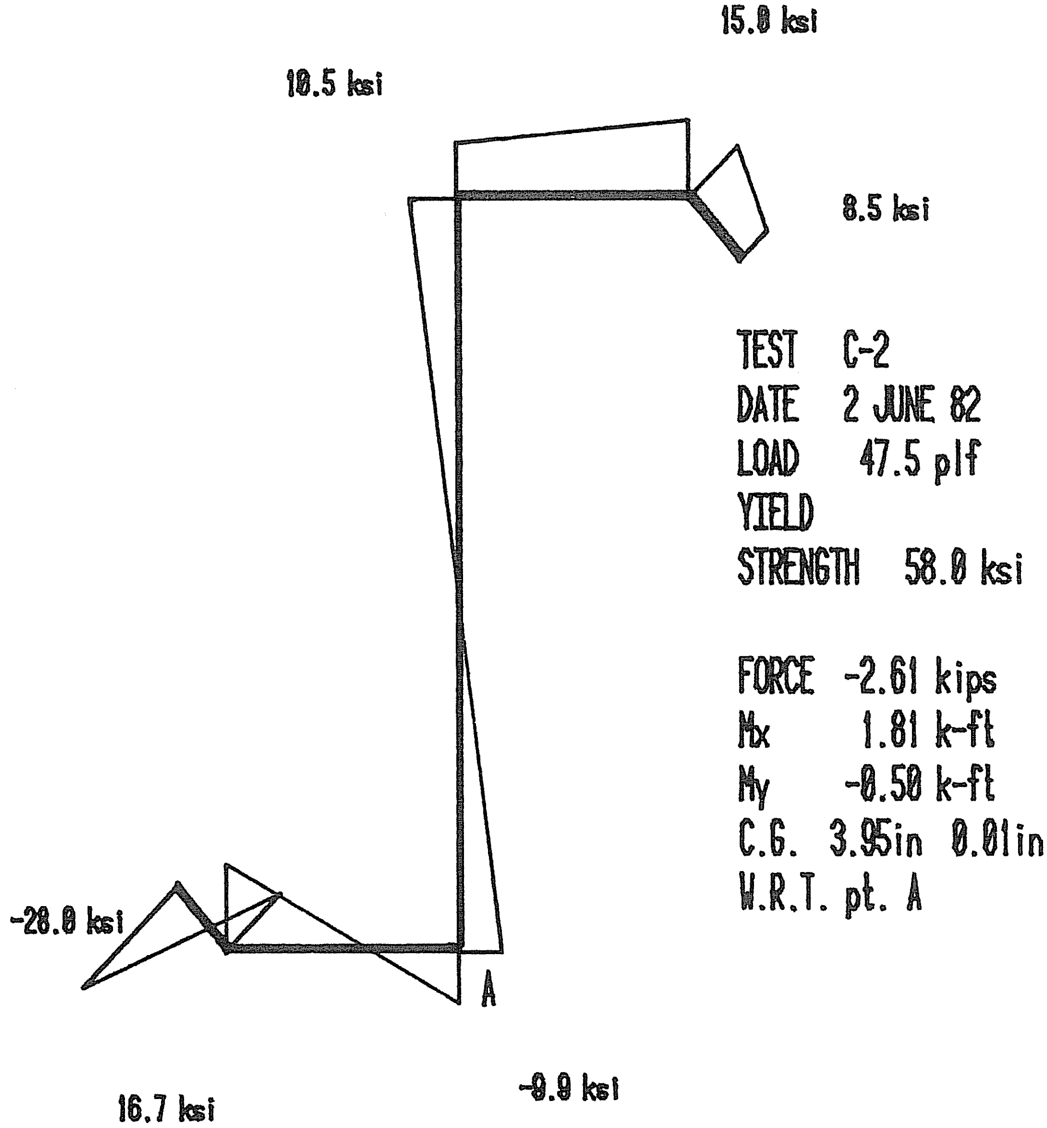


Figure B.6 Stress Distribution at 47.5 plf, Test C-2

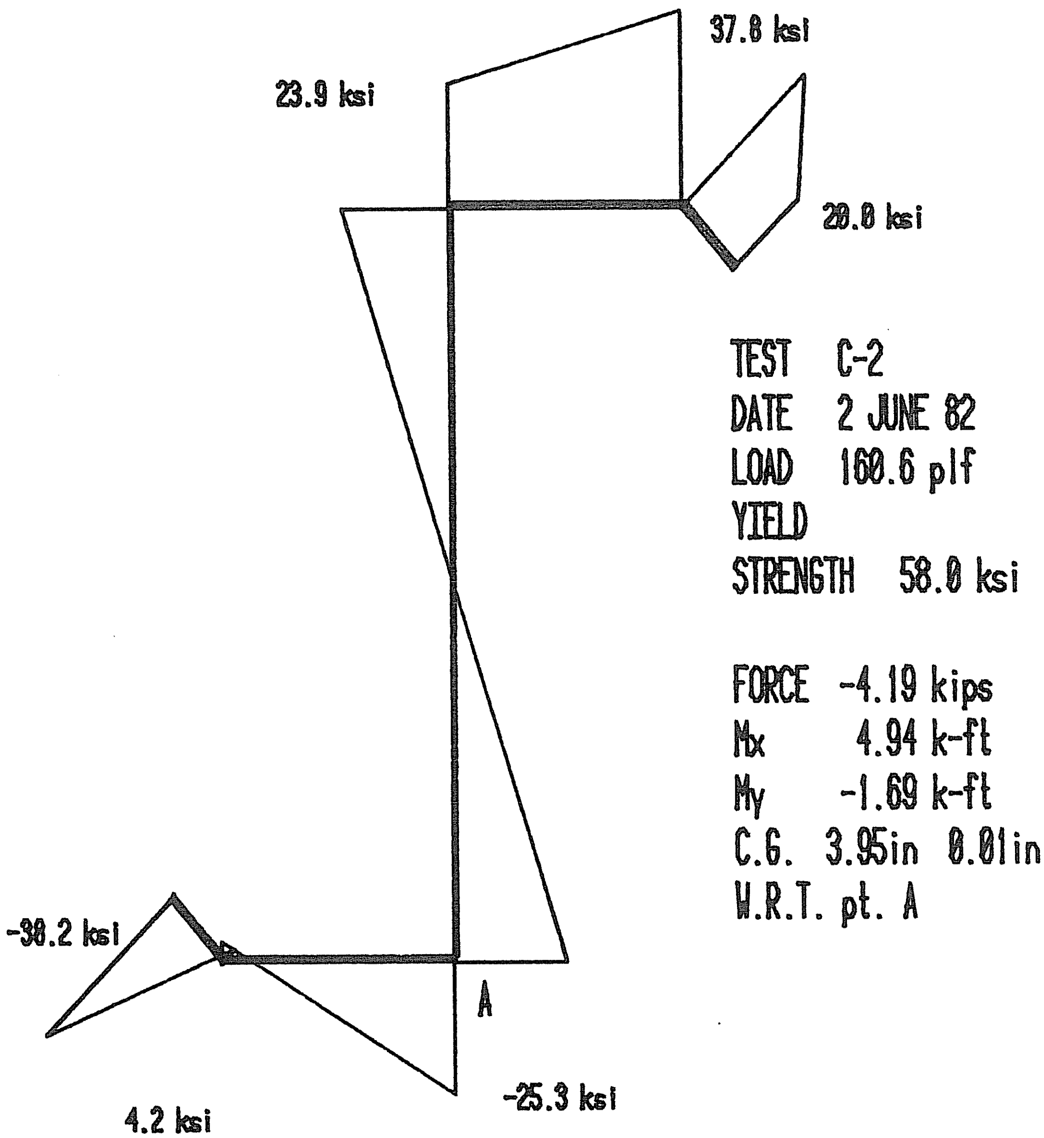


Figure B.7 Stress Distribution at 160.6 plf, Test C-2

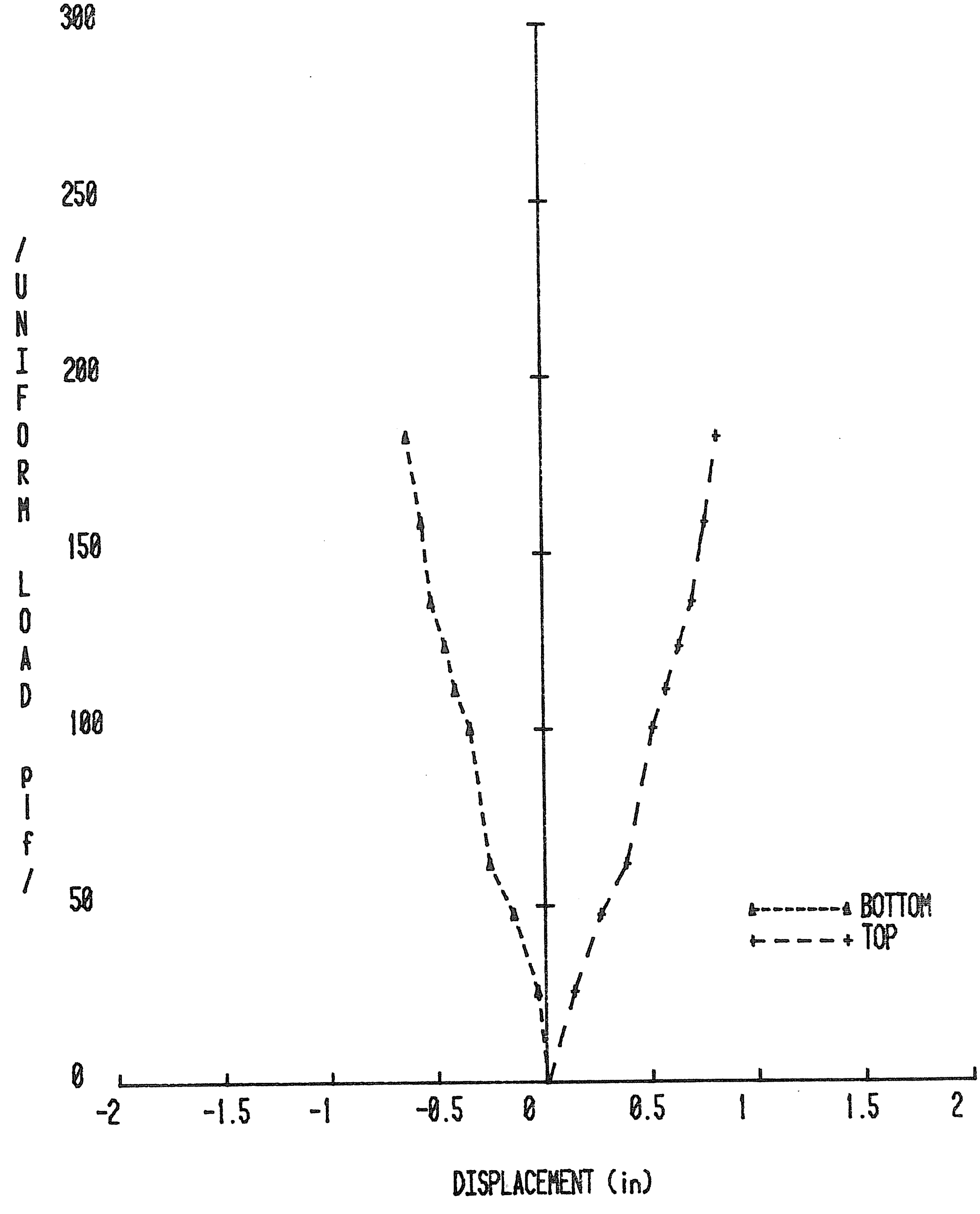


Figure B.8 Vertical Loading vs. Lateral Displacement, Test C-2

APPENDIX C

THREE SPAN STANDING SEAM TEST 6-B RESULTS
(From Reference 4)

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 6B

Test Date: March 8, 1982

Purpose: Adequacy of single brace at midspan

Span(s): 3 @ 20'

Thickness: .080 & .066 Moment of Inertia: $I_x = 12.595''^4$, $I_x = 9.829''^4$

Parameters: Intermediate braces at ℄

Clips installed

No insulation

Spacing 4' 9"

Failure Load: 284.5 plf

Failure Mode: Local buckling

Predicted Failure Loads:

Method	Load
Star Manufacturing	290 plf
AISI (Cont. Bracing)	436.0 plf

Discussion:

- Failure occurred by local buckling of the bottom (compression flange) in the interior span immediately outside the lap. Buckling of the compression flange in the outside bay at midspan followed.
- Measured vertical deflections were greater than theoretical predictions.
- The moment of inertia of the eave purlin was 79.6% of that of the test purlin. It was not possible to determine if the eave purlin failed first.
- The strain gages, which were mounted 3" from the end of the lap on the north outside purlin, did not indicate yield strain near failure.
- Stress plots indicate unconstrained bending.
- At 37 psf, the brace forces in the interior spans as a percentage of stabilized vertical load were 9.1%, 5.6%, and 5.1% in the direction of ridge to eave and at 60 psf they were 11.7%, 5.9% and 4.3%.
- At 37 psf the brace forces in the exterior span as a percentage of stabilized vertical load were 14.2%, 9.1%, 9.2% and at 60 psf they were 14.3%, 8.3% and 7.7% in the direction of ridge to eave.
- For the intermediate brace location in the exterior span at 37 psf, the ratio of brace forces was 1.0:1.92:3.24 and at 60 psf the ratio was 1.0:1.73:3.34. The ratio of tributary areas was 1:3:5.
- At 37 psf, the ratio of brace forces at the intermediate brace location in the interior span was 1.0:1.84:2.81 and at 60 psf the ratio was 1.0:1.53:2.24. The ratio of the tributary areas was 1:3:5.

-Lateral displacement of the lower flange of the test purlin at midspan of the exterior span was 1.70 in. near failure. The top flange lateral displacement was less than .5 in.

-The top and bottom moved laterally in the same direction.

-At 240 plf, slippage of the horizontal displacement transducer at the top flange may have occurred.

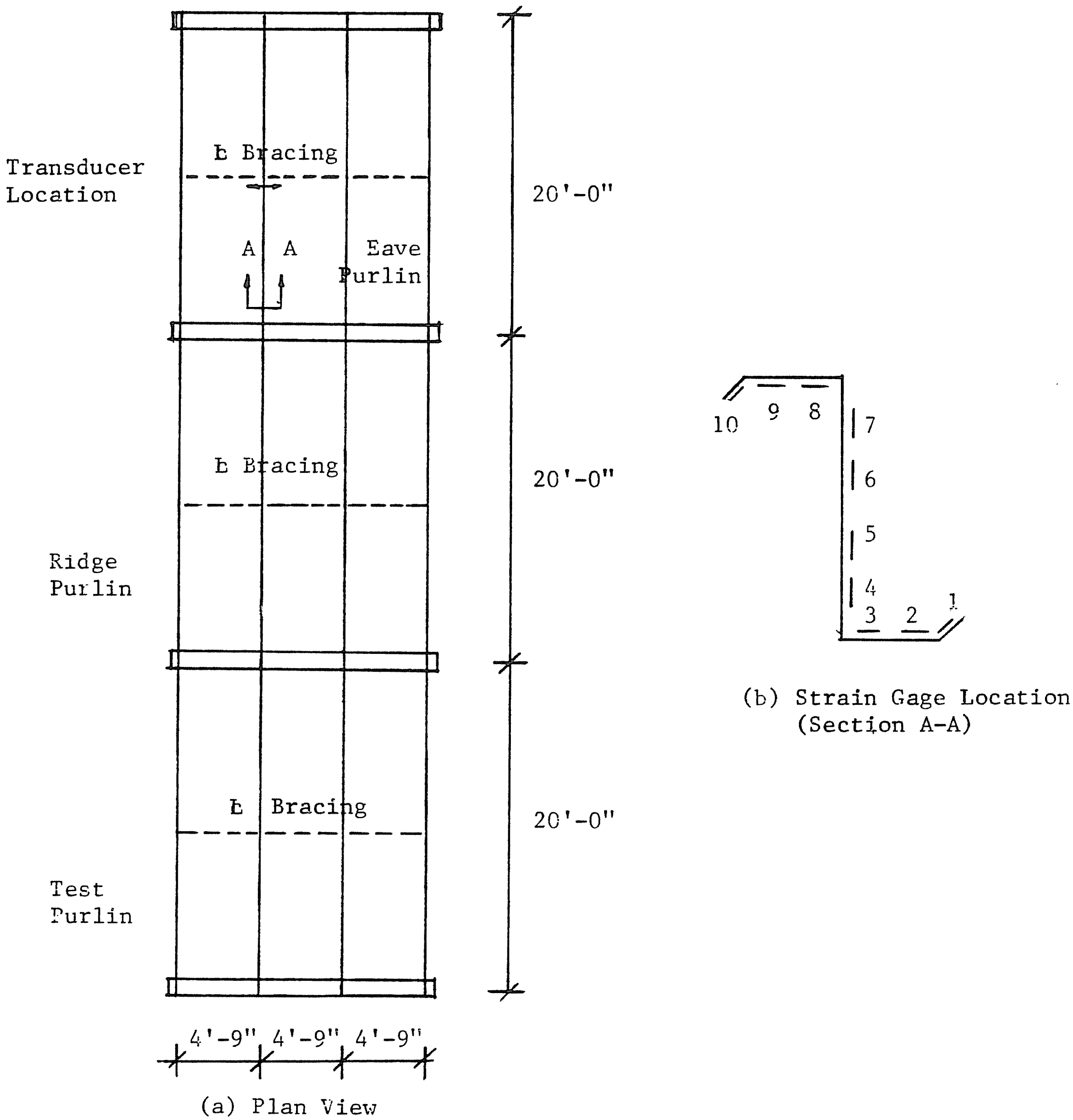
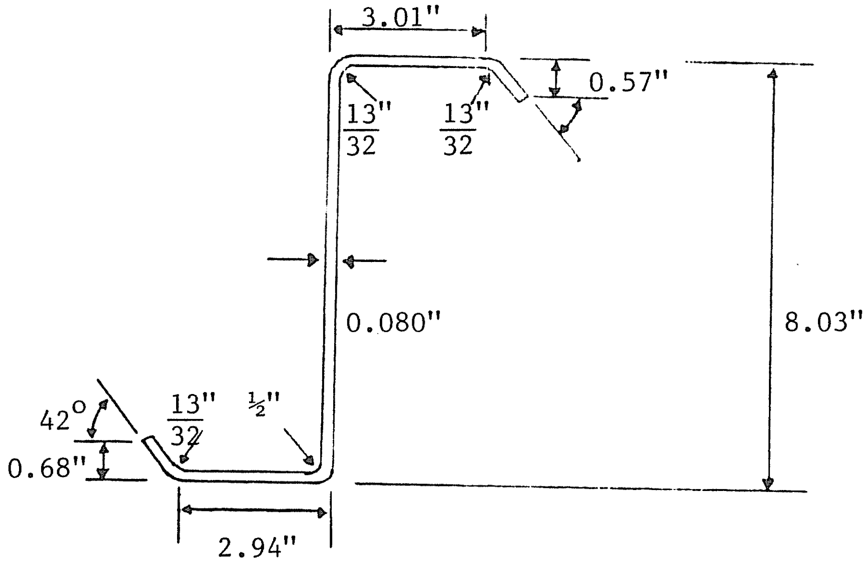
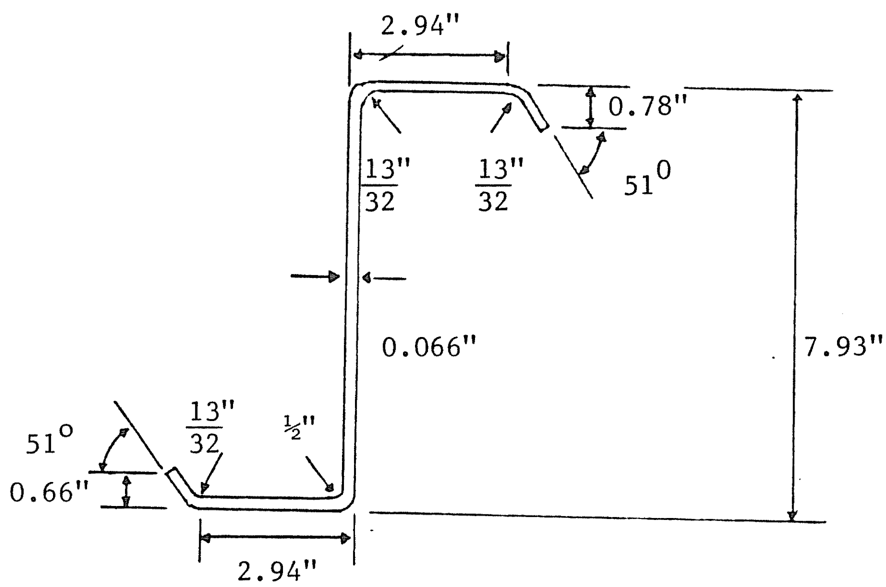


Figure C.1 Instrumentation Location, Test 6-B



North Span



Center Span

Figure C.2 Measured Purlin Dimensions, Test 6-B

```
A I S I   P U R L I N   A [illegible]
IDENTIFICATION: STA[illegible]
--------------------------------------------------------
                         TOP            BOTTOM
FLANGE(in)              3.010           [illegible]
LIP(in)                 0.570           0.580
LIP ANGLE(deg)         41.000           [illegible].000
RADIUS L/F(in)          0.406           [illegible]
RADIUS F/W(in)          0.406           [illegible]

TOTAL DEPTH(in)                 8.03
THICKNESS(in)                   0.08
YIELD STRENGTH(ksi)             5[illegible].4
                                      SECTION MODULII(in^3)
     MOMENTS OF INERTIA(in^4)         TOP           BOTTOM
GROSS=          12.595               3.149          3.18[illegible]
STRENGTH=       12.524               3.1[illegible]          3.1[illegible]
DEFLECTION=     12.595
BD=     2.468   in
FC=    32.040   ksi
FT=    32.040   ksi
FBW=   30.937   ksi

MOMENT CARRYING CAPACITY ([illegible]ISI CRITERIA)
             MC=        8.[illegible]  [illegible]
             MT=        8.4[illegible]  [illegible]
             MW=        9.050  [illegible]
             MU=       13.912  [illegible]
SPAN            =      20.000  ft.
UNIFORM LOAD=         278.244  [illegible]
DEFLECTION      =       0.969  in./100[illegible]
```

Figure C.3 AISI Purlin Analysis, Test 6-B North Purlin

A I S I   P U R L I N [illegible]

IDENTIFICATION: STAR PURLIN [illegible]

	TOP	BOTTOM
FLANGE(in)	2.[illegible]	[illegible]
LIP(in)	0.[illegible]	[illegible]
LIP ANGLE(deg)	51.[illegible]	[illegible]
RADIUS L/F(in)	0.[illegible]	[illegible]
RADIUS F/W(in)	0.[illegible]	[illegible]

TOTAL DEPTH(in) [illegible]

THICKNESS(in) 0.066

YIELD STRENGTH(ksi) 59.3

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	9.829	2.55[illegible]	[illegible].449
STRENGTH=	9.559	[illegible].4[illegible]8	[illegible].424
DEFLECTION=	9.829		

BE= 2.197 in

FC= 31.262 ksi

FT= 35.580 ksi

FBW= 32.045 ksi

MOMENT CARRYING CAPACITY (AISI CRITERIA)

MC= 6.352 ft-k

MT= [illegible].[illegible] ft-k

MW= [illegible] ft-k

MU= 10.[illegible] ft-k [illegible]

SPAN = 20.[illegible] ft.

UNIFORM LOAD= 21[illegible] plf [illegible]

DEFLECTION = [illegible] in. [illegible]

Figure C.4 AISI Purlin Analysis, Test 6-B Center Purlin

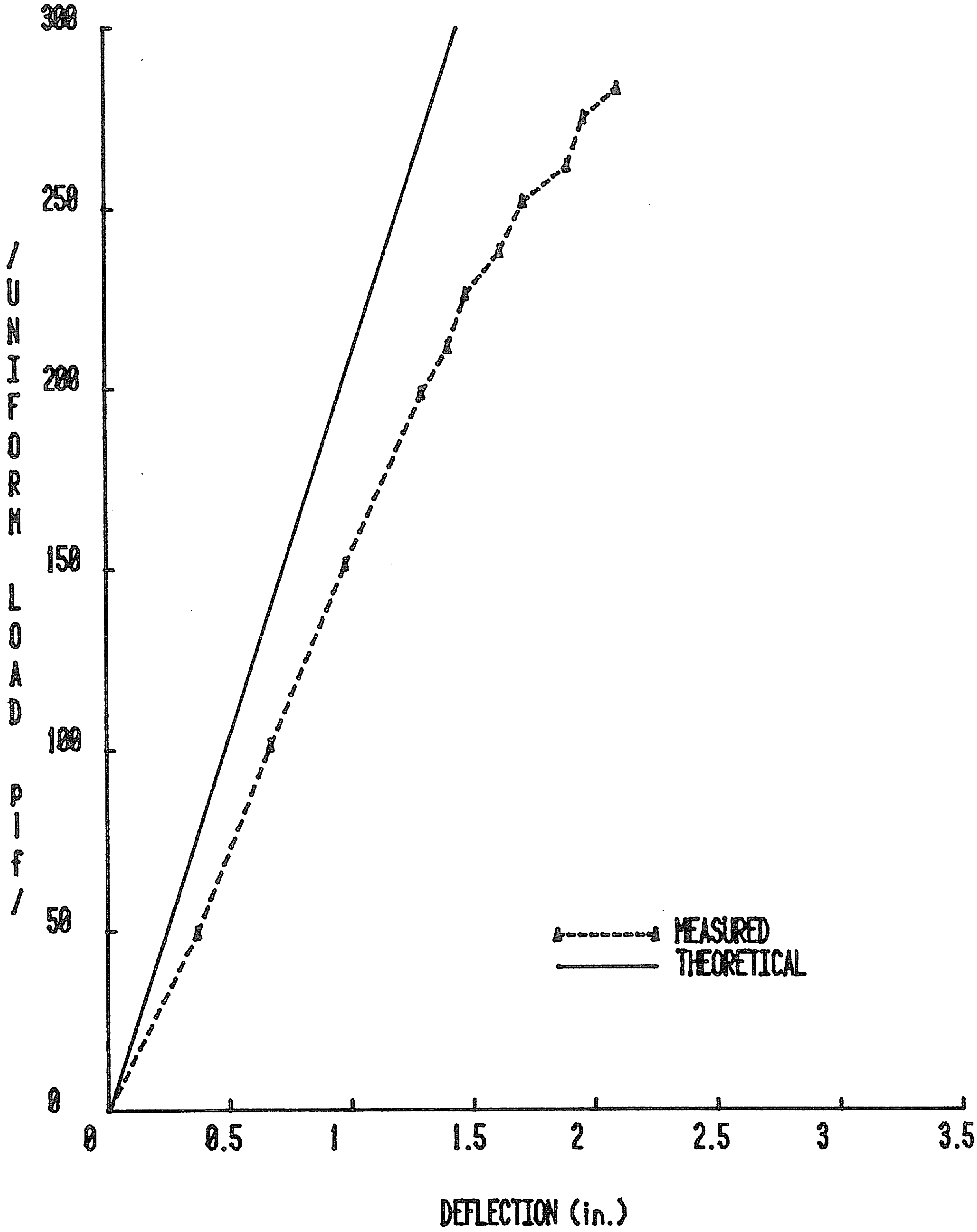


Figure C.5 Load vs. Vertical Deflection, Test 6-B

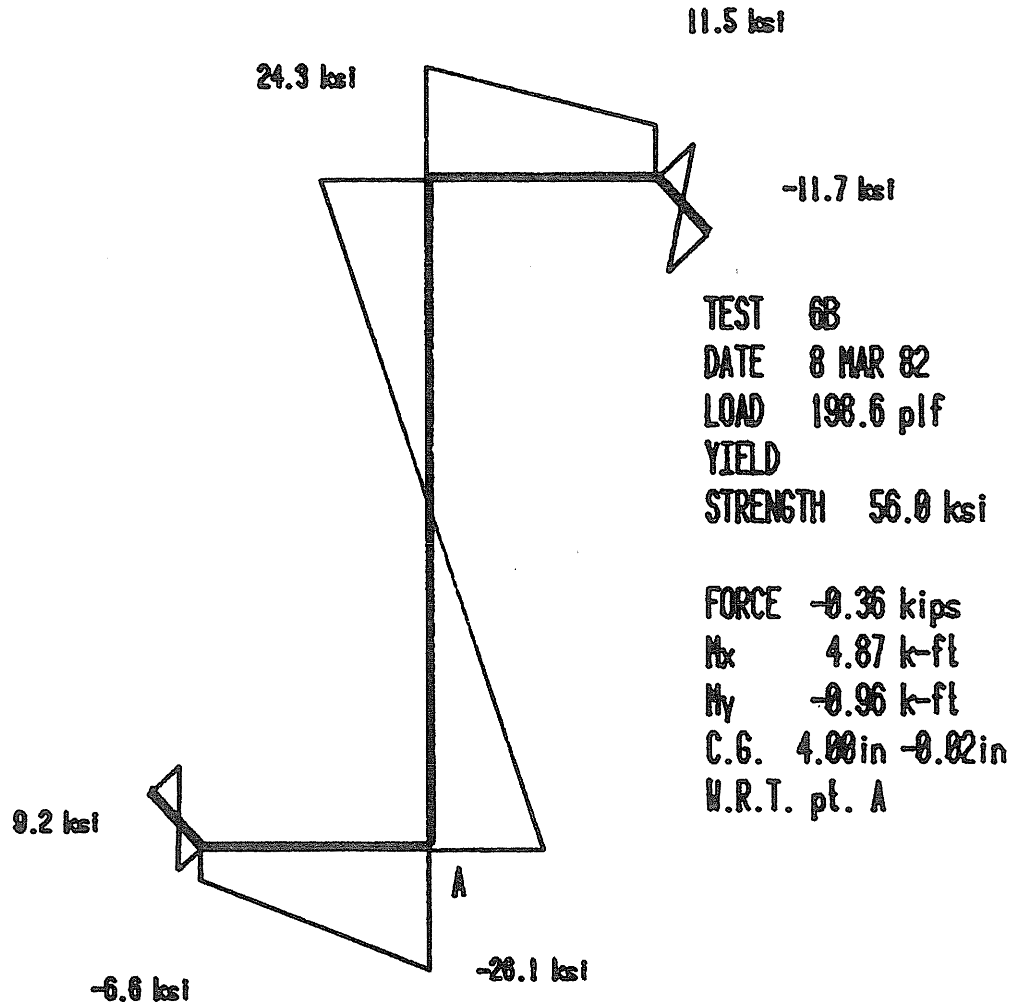


Figure C.6 Stress Distribution at 198.6 plf, Test 6-B

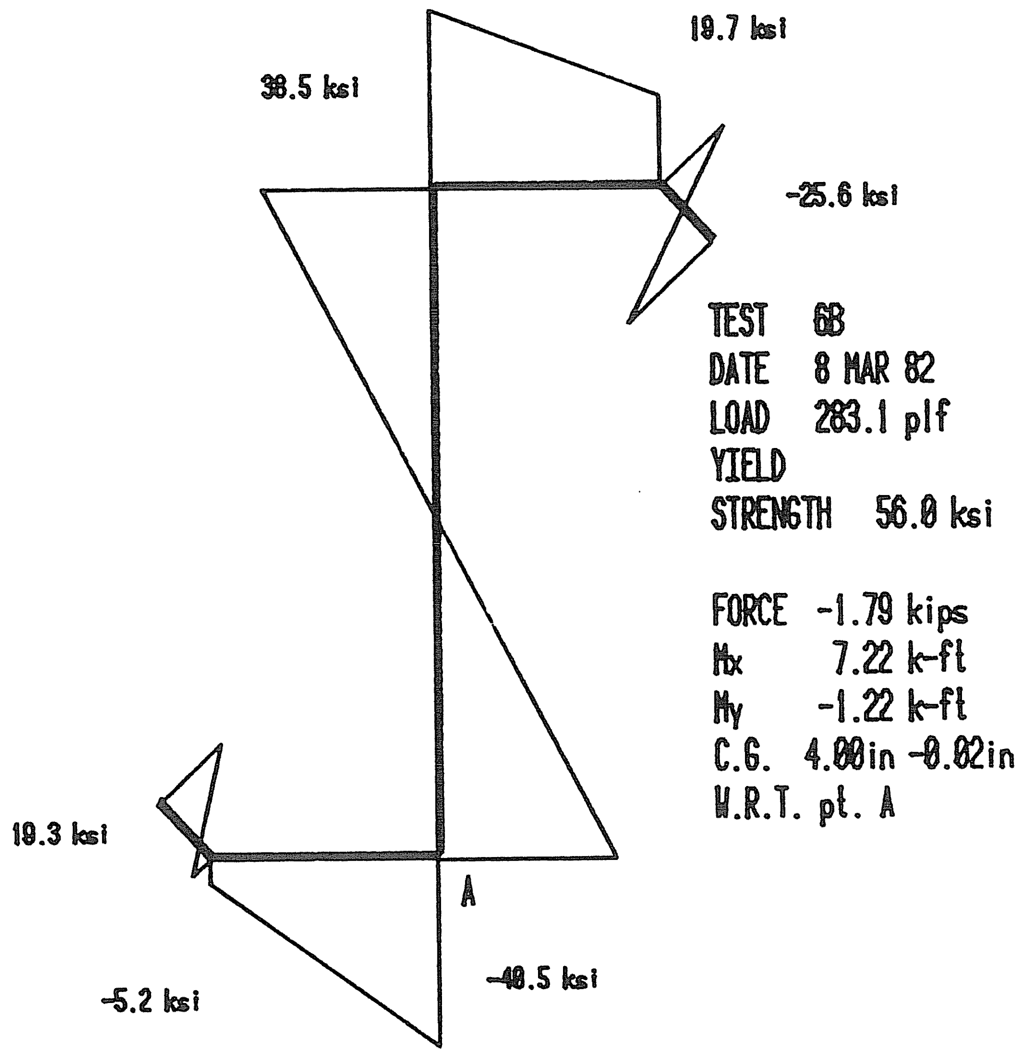


Figure C.7 Stress Distribution at 283.1 plf, Test 6-B

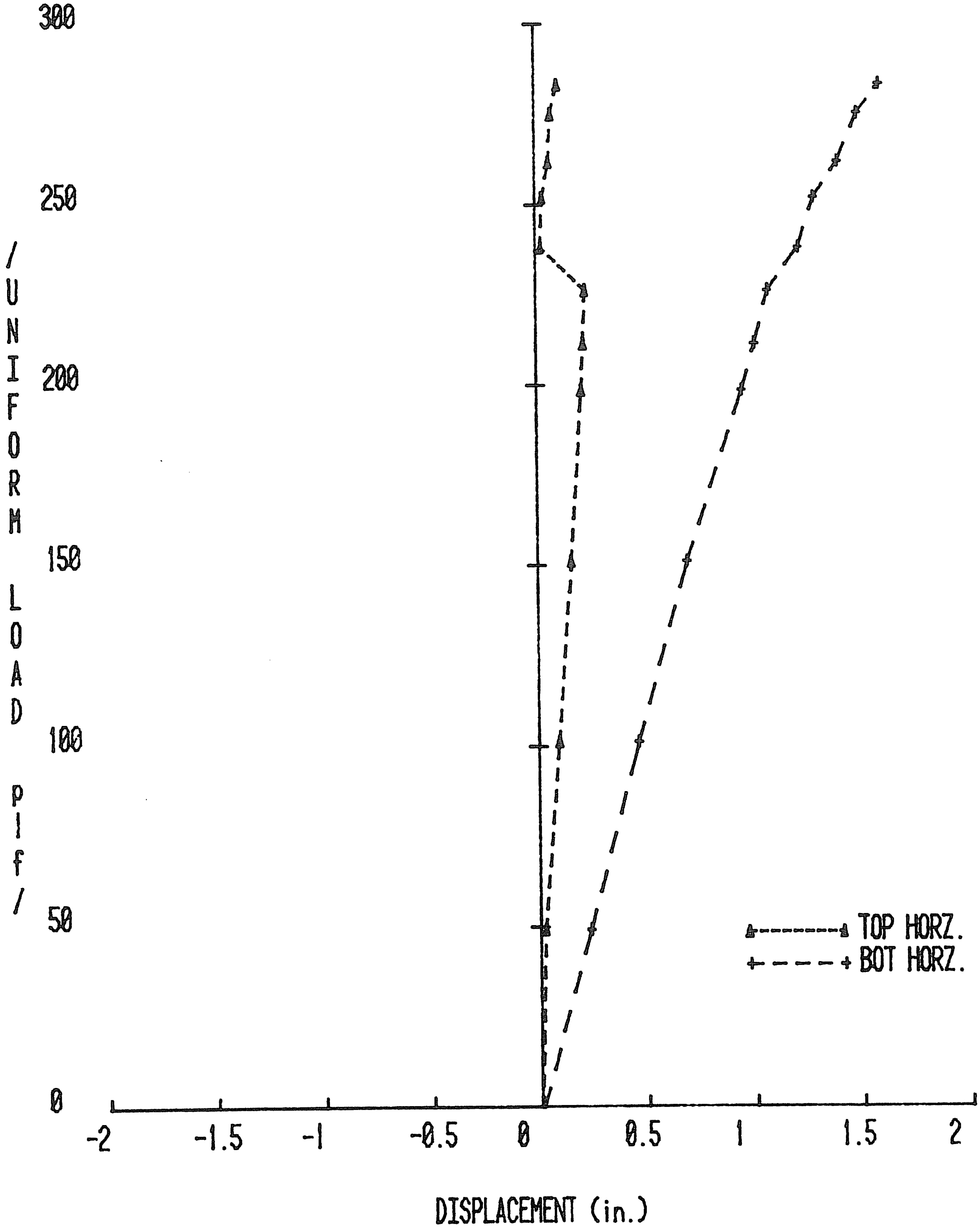


Figure C.8 Vertical Load vs. Lateral Displacements, Test 6-B

APPENDIX D

CONVENTIONAL PANEL TEST BY WALLACE
(From Reference 3)

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: Wallace Test

Test Date: March 27, 1979

Purpose: To observe behavior of conventional panel roof system under gravity loading.

Span(s): 2 @ 25

Thickness: 0.066 Moment of Inertia: 10.175 in^4

Parameters: Conventional roof system

No intermediate braces

No insulation

Spacing 5 ft. 0 in.

Failure Load: 121 plf

Failure Mode: Web buckling immediately outside the lap

Predicted Failure Loads:

Method Star Manufacturing Co.	Load 120 plf
Method AISI	Load 138.2 plf
Method	Load

Discussion:

-Failure was caused by web buckling outside of the lap in one purlin.

-Measured vertical deflections were significantly less than theoretical.

-Load-stress relationship was linear until failure.

-The predicted and actual failure loads were in good agreement.

The load-deflection curve was linear until failure.

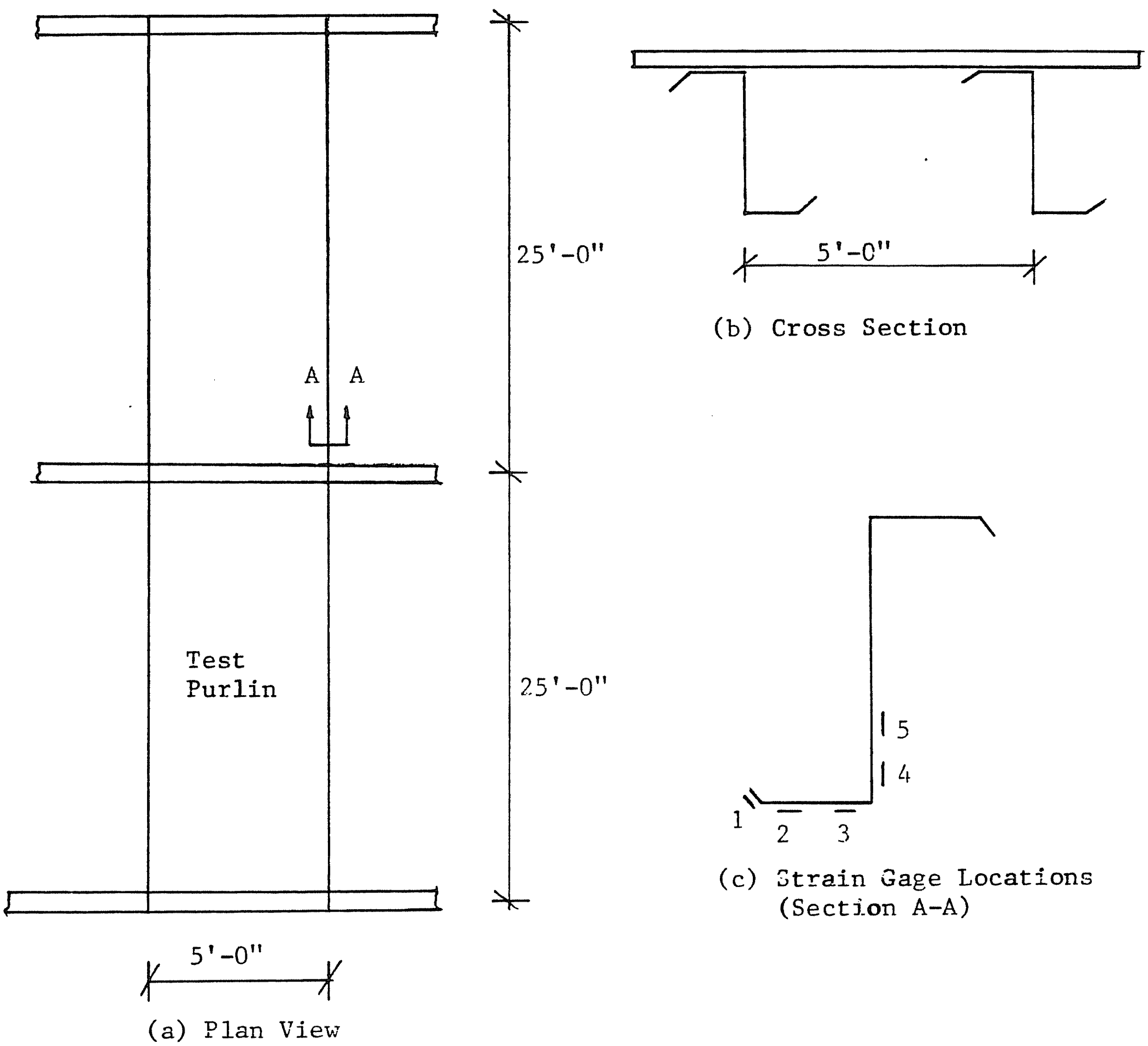
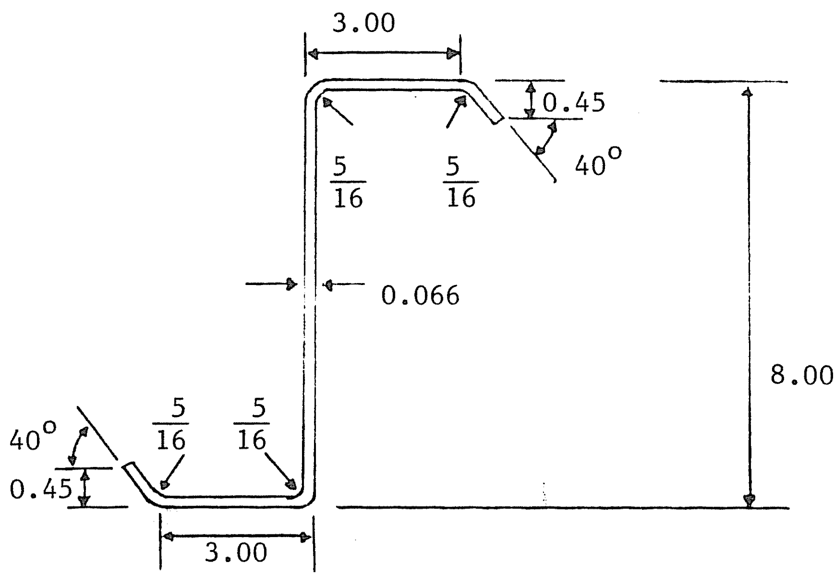
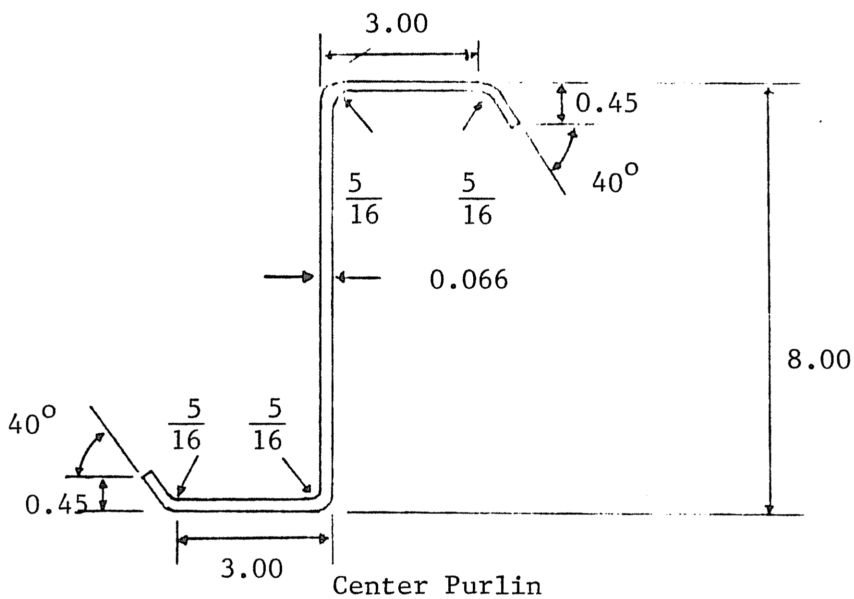


Figure D.1 Instrumentation Location, Test 2SPT-2



North Purlin



Center Purlin

Figure D.2 Measured Purlin Dimensions - Wallace Test

```
A I S I   P U R L I N   [illegible]
IDENTIFICATION: STAR [illegible] (WALLACE [illegible] NORTH
------------------------------------------------------------
                        [illegible]           BOTTOM
FLANGE(in)              3.[illegible]         3.000
LIP(in)                 [illegible]           0.4[illegible]
LIP ANGLE(deg)          40.[illegible]        [illegible].000
RADIUS L/F(in)          [illegible]           0.[illegible]
RADIUS F/W(in)          [illegible]           0.[illegible]

TOTAL DEPTH(in)
THICKNESS(in)                   [illegible].06[illegible]
YIELD STRENGTH(ksi)             [illegible]
                                        SECTION MODULII(in^3)
     MOMENTS OF INERTIA [illegible]4)   TOP              BOTTOM
GROSS=          10.107          [illegible]548           2.548
STRENGTH=        9.659          [illegible]              2.506
DEFLECTION=     10.059
BE=     2.202   in
FC=     33.000  ksi
FT=     33.000  ksi
FBW=    30.010  ksi

MOMENT CARRYING CAPAC[illegible] [illegible]ISI CRITERIA)
              MC=      6.[illegible]
              MT=      6.[illegible]
              MW=      6.[illegible]
              MU=      10.[illegible] (1.[illegible]
SPAN                   [illegible]
UNIFORM LOAD=      138.[illegible]  lf  1.[illegible]*allo[illegible]
DEFLECTION   =         [illegible] in./100[illegible]
```

Figure D.3 AISI Purlin Analysis, Test 2SPT-2, North Purlin

A I S I P[illegible]

IDENTIFICATION [illegible] (WALL[illegible]) CENTER

	TOP	BOTTOM
FLANGE(in)	3.000	3.000
LIP(in)	0.450	0.450
LIP ANGLE(deg)	40.000	[illegible].000
RADIUS L/F(in)	0.[illegible]	0.[illegible]
RADIUS F/W(in)	0.[illegible]	0.[illegible]

TOTAL DEPTH(in)	8
THICKNESS(in)	0.066
YIELD STRENGTH(ksi)	55

MOMENTS OF INERTIA(in^4)		SECTION MODULII(in^3) TOP	BOTTOM
GROSS=	10.107	2.548	2.5[illegible]
STRENGTH=	9.659	2.368	[illegible]
DEFLECTION=	10.059		

BE= 2.202 in

FC= 33.000 ksi

FT= 33.000 ksi

FBW= 30.010 ksi

MOMENT CARRYING CAPACITY (AIST CRITERIA)

MC	[illegible]	[illegible]
MT=	[illegible]	[illegible]
MW	[illegible]	[illegible]
MU=	10.80[illegible]	[illegible]
SPAN	[illegible]	[illegible]
UNIFORM LOAD=	[illegible]	[illegible]
DEFLECTION	[illegible]	[illegible]

Figure D.4 AIST Purlin Analysis, Test 2SPT-2, South Purlin

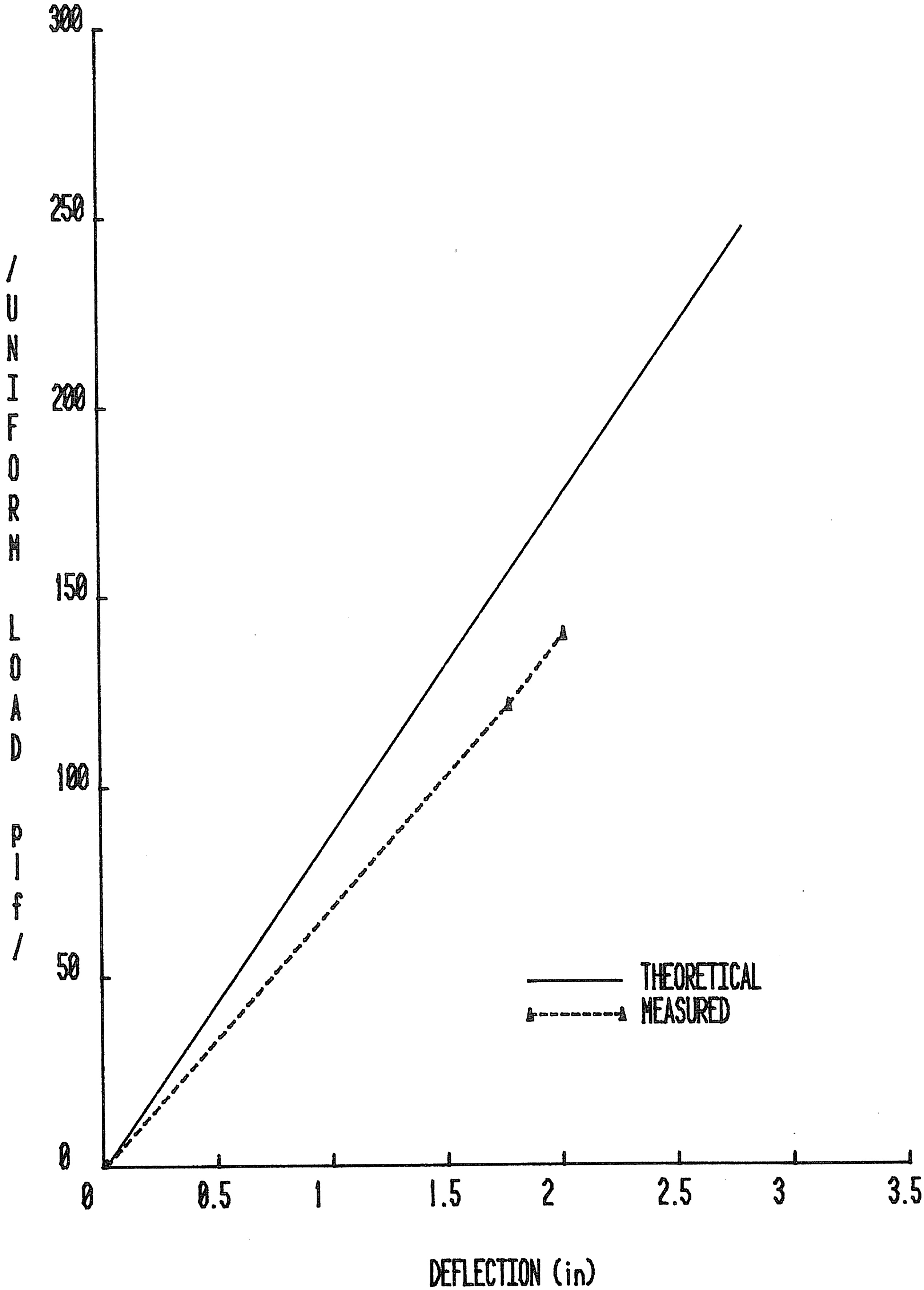


Figure D.5 Load vs. Vertical Deflection, Test 2SPT-2