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Evaluation of the base test method for predicting the flexural strength of standing seam roof systems under gravity loading

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EVALUATION OF THE BASE TEST METHOD FOR PREDICTING THE FLEXURAL STRENGTH OF STANDING SEAM ROOF SYSTEMS UNDER GRAVITY LOADING

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Submitted to
Metal Building Manufacturers Association
1230 Keith Building
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MBMA Project 403

Report No. CE/VPI-ST89/07

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Revised November 1990

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Research Report

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EVALUATION OF THE BASE TEST METHOD FOR PREDICTING THE CAPACITY OF STANDING SEAM ROOF SYSTEMS UNDER GRAVITY LOADS

CHAPTER I

INTRODUCTION

1.1 Background

Because of the complex structural behavior of Z- and C-purlin supported standing seam roof systems, an experimental procedure to determine system strength under gravity loading has been proposed [1]. The procedure is referred to as the "base test method" and uses the results of single span tests to predict the capacity of continuous multi-span systems. The primary objective of the study reported here was to validate the method through full scale testing of sets of two purlin line, simple span systems (the base tests) and three purlin line, three continuous span systems (the confirming tests).

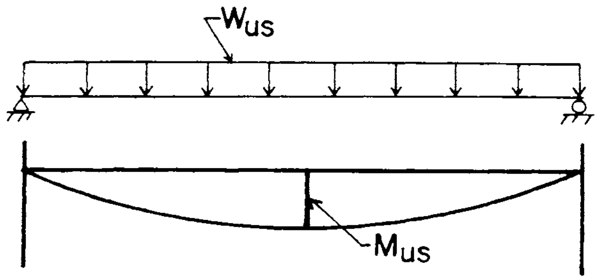
The testing program consisted of two sequences of tests categorized by the bracing of the system. The first sequence used purlins braced at the rafters only and included six sets of tests, one with opposed Z-purlins, four with Z-purlins facing the same direction, and one with C-purlins facing the same direction. The second sequence of tests used purlins braced at the third points and included three sets of tests with Z-purlins facing the same direction. Each set of tests consisted of a single span test and a three span test. In addition, two sets of similar test results, as reported in Reference 1, were used in the valuation phase. Test details, test results, and conclusions are found in later sections.

1.2 The Base Test Method

The basic concept of the base test method is to predict the flexural failure load of a multi-span, multi-purlin line standing seam roof system from the experimental failure load of a single span. The basic component of the method is the failure load of the single span test called the "base test". From this failure load, the corresponding moment capacity of the standing seam roof system braced purlin is calculated for the single span. This phase of the method must be completed in the laboratory by loading a full scale single span test to failure.

A stiffness analysis with a nominal uniform load (say 100 plf) on a multi-span system is then performed. The stiffness analysis results in maximum positive and maximum negative moments. For gravity loading, a positive moment is defined as a moment which causes compression in the purlin flange which is attached to the roof panel. A negative moment is a moment which causes tension in the same purlin flange.

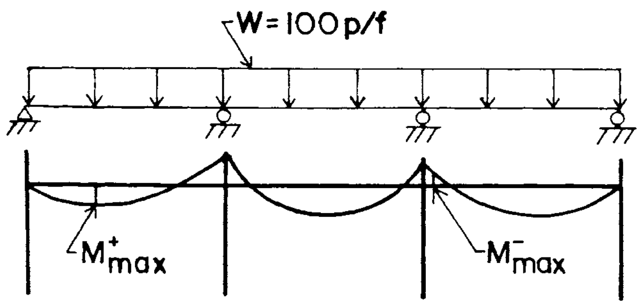
Two failure loads are then calculated using the data thus obtained and two assumptions: (1) the positive moment capacity of standing seam roof system braced purlins is limited to that determined from the base test, and (2) the negative moment capacity is limited to that of a fully-braced purlin. The first failure load is the nominal uniform load used in the stiffness analysis multiplied by the ratio of the single span failure moment to the maximum positive moment from the stiffness analysis. The second failure load is the nominal uniform load multiplied by the ratio of the fully-braced theoretical flexural capacity of the cross section-to-the maximum negative moment from the stiffness analysis. The predicted failure load of the multi-span system is the minimum of the two calculated loads. Figure 1.1 summarizes the procedure.



w_{us} = failure load of single span test

M_{us} = Maximum moment of single span corresponding to w_{us}.

a) Single Span Base Test



M_{max}^{+} = Maximum positive moment at a nominal load of 100 plf.

M_{max}^{-} = Maximum negative moment at a nominal load of 100 plf., at either the interior or exterior of the lap splice.

b) Multi-Span Stiffness Analysis

M_{AISI} = 1986 AISI Allowable flexural capacity x 1.67

W_{p3} = Predicted failure load of the multi-span system

$$W_{p3} = \text{minimum of} \begin{cases} \dfrac{M_{us}}{M_{max}^{+}} \times 100 \text{ plf} \\ \text{or} \\ \dfrac{M_{AISI}}{M_{max}^{-}} \times 100 \text{ plf} \end{cases}$$

c) Predicted Failure load

FIGURE 1.1 BASE TEST METHOD

The following restriction applies to the method: the panels, clips, purlins, and bracing configuration used in the base test must be identical to those which will be used in the multi-span systems. For this reason, a base test must be performed for each combination of deck, clip, bracing, and purlin size that will be designed using the method.

CHAPTER II

TEST DETAILS

2.1 Test Components

Components used in the testing were supplied by several different manufacturers belonging to the Metal Building Manufacturers Association. Identical panels, clips, and purlins were used in constructing the single span and three span tests that composed each test set. Table 2.1 shows the configurations used in the test program.

Test Identification System. The following are examples of the method used to identify the tests.

Example 1 C-R-R/S-1

Example 2 Z-T-P/F-3 (0)

- A C or Z indicates a C- or a Z-purlin.
- The second letter is R or T, indicating rafter only bracing (R) or rafter and third point bracing (T).
- The third letter is R or P, indicating rib (R) or pan (P) type panels.
- The fourth letter is S or F, indicating a two piece sliding clip (S) or a one piece fixed clip (F).
- The number at the end indicates the number of spans (1 or 3).
- (0) at the end of an identification indicates that the purlin flanges were opposing each other, otherwise the flanges were facing the same direction.

Purlins. Two types of purlins were used in the test sequences; Z-purlins and C-purlins. Depth, flange width, edge stiffener, thicknesses and other dimensions varied between test sets. Appendices A and B contain sheets

TABLE 2.1

MATRIX OF TEST CONFIGURATIONS

Test Identification	Purlin Type	Bracing	Panel Type	Clip Type	Purlin Orientation	Lap Length in 3-Span Tests
Z-R-R/S	Z-	Rafter	Rib	Sliding	Facing	4 ft. 0 in.
Z-R-R/F	Z-	Rafter	Rib	Fixed	Facing	3 ft. 0 in.
Z-R-P/F	Z-	Rafter	Pan	Fixed	Facing	3 ft. 0 in.
Z-R-P/S	Z-	Rafter	Pan	Sliding	Facing	3 ft. 4 3/4 in.
C-R-P/S	C-	Rafter	Pan	Sliding	Facing	4 ft. 9 in.
Z-R-R/F (0)	Z-	Rafter	Rib	Fixed	Opposed	3 ft. 0 in.
Z-T-P/F	Z-	Third*	Pan	Fixed	Facing	5 ft. 4 in.
Z-T-P/S	Z-	Third*	Pan	Sliding	Facing	4 ft. 5 1/2 in.
Z-T-R/S	Z-	Third*	Rib	Sliding	Facing	4 ft. 0 in.

*Bracing at rafters and intermediate third points of span.

Note: Lap length is total overlap at interior rafter location.

showing measured purlin dimensions for each test. Tensile coupon tests were conducted using material taken from the area of representative purlins for each set of tests.

Panels. The panels used in the tests were of two basic configurations; "pan" type panels, Figure 2.1, or "rib" type panels, Figure 2.2. The panel widths,, depths, corrugations, joint details, and seaming requirements varied from test set to test set. The panel lengths were 7 ft. 0 in. for the single spans and 14 ft. 4 3/4 in. for the three span tests.

Clips. The "standing seam clips" used in the tests were of two types; one piece fixed clips and two piece sliding clips. The exact clip detail varied among the sets of tests; representative configurations are shown in Figure 2.3.

Bracing. The bracing at the rafters consisted of 1/2 in. diameter tension rods connected to the purlin webs near the top flange and anchored to a rigid stand attached to the rafter. Figure 2.4 shows details of the rafter bracing system.

Bracing used in the interior of the spans consisted of a continuous angle bolted to the bottom flanges of the purlins. A set of rollers was attached to each end of the angles. The rollers were restricted to vertical movement by channels anchored to the laboratory floor. This system allowed the purlins to deflect in a vertical direction while providing lateral bracing at the third points of the spans. Figure 2.5 is a schematic of the bracing system.

Bracing locations are shown in Figures 2.6 and 2.7.

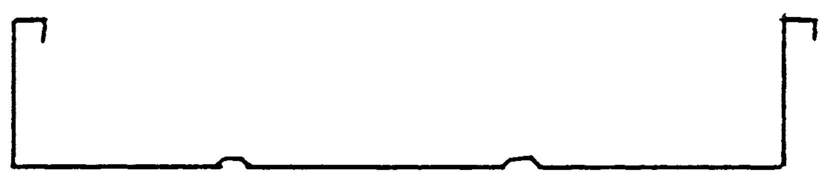
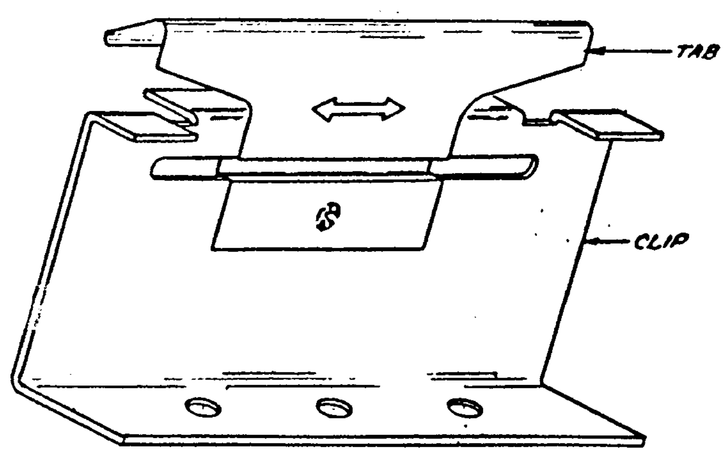
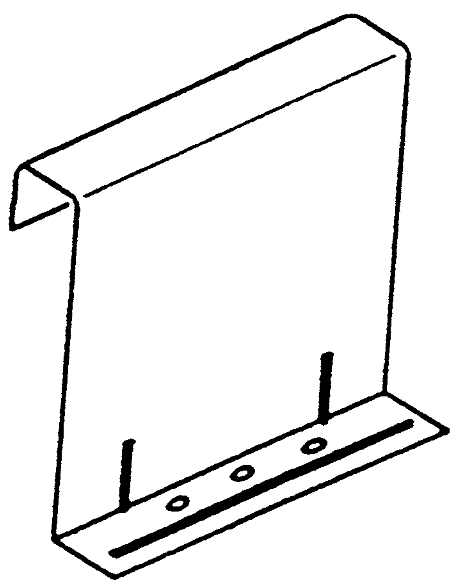


FIGURE 2.1 PAN TYPE PANEL PROFILES TESTED

FIGURE 2.2 RIB TYPE PANEL PROFILES TESTED



a) Two Piece Sliding Clip



b) One Piece Fixed Clip

FIGURE 2.3 REPRESENTATIVE CLIP CONFIGURATIONS

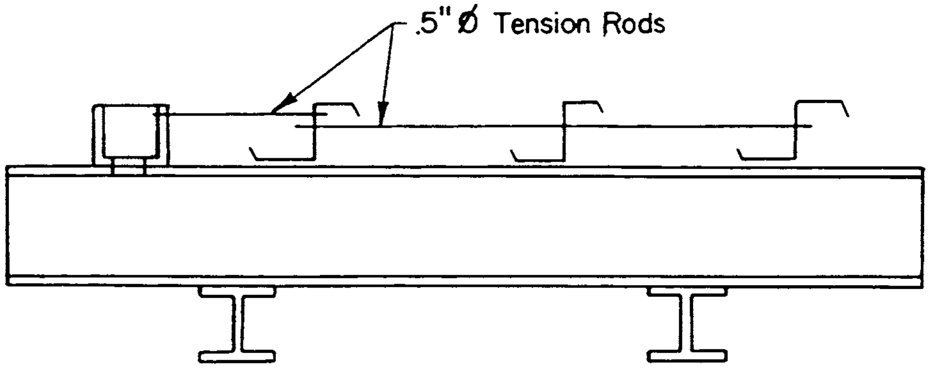


FIGURE 2.4 RAFTER BRACING DETAILS

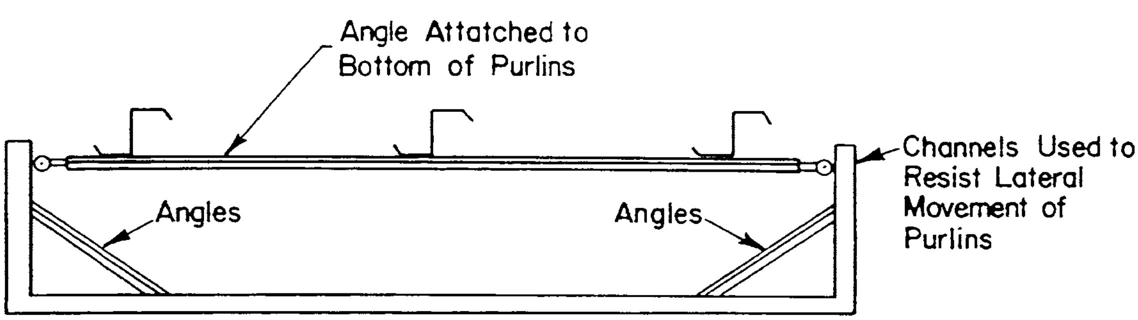
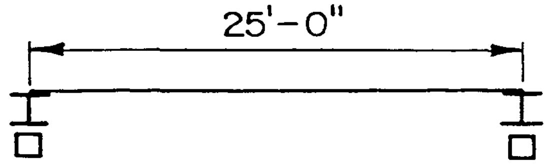
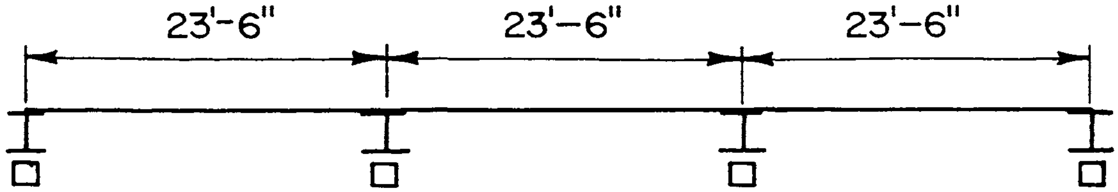


FIGURE 2.5 THIRD POINT BRACING DETAILS



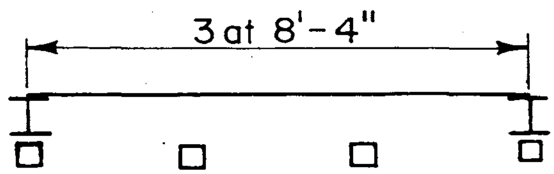
a) **Single Span Base Test**



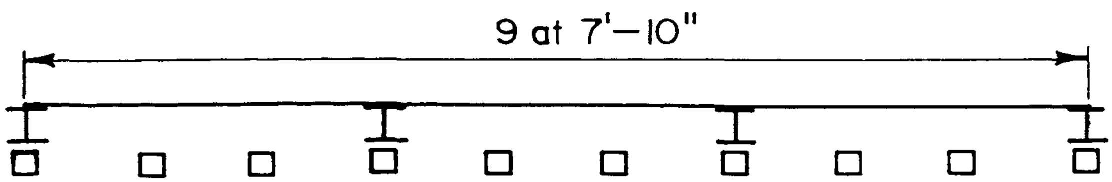
b) **Three Span Test**

□ – Indicates location of bracing

FIGURE 2.6 RAFTERS BRACING LOCATIONS



a) **Single Span Base Test**



b) **Three Span Test**

FIGURE 2.7 RAFTERS AND THIRD POINT BRACING LOCATIONS

2.2 Test Setup

The simulated gravity loading was applied by means of a vacuum chamber. The basic concept of a vacuum chamber is to construct an airtight space around the test setup and remove the air from the contained space, creating a pressure differential. Thus, the atmosphere loads the system.

The chamber was constructed as follows: A box 16 ft. x 72 ft. x 4 ft. was constructed from 4 ft. x 8 ft. galvanized steel panels. The joints between panels and between the panels and the floor were sealed with caulk. The test system was then constructed within the box. Since the actual test were smaller than 16 ft. in width, "dummy" setups were constructed to take up space as necessary. The configuration to be tested was then constructed. A sheet of polyethylene was spread across the top of the box and sealed with tape. This formed the airtight space. Air was evacuated by a motor driven blower and two auxiliary "shop-type" vacuum cleaners. When testing a single span, a temporary wall was constructed forming a 25 ft. box within the larger chamber.

The single span base tests consisted of two lines of purlins 5 ft. 0 in. on center with a span of 25 ft. 0 in. The purlins were bolted through the bottom flanges to the rafter. The panels used were 7 ft. 0 in. in length. This permitted a 1 ft. 0 in. overhang beyond the webs of the purlins. In some tests, the panel-to-purlin clips were bolted to the purlins with 1/4" bolts to simplify removal of the panels after testing, otherwise, self-drilling fasteners were used. A cold-formed angle was attached continuously to one edge of the panels to simulate the stiffness provided by an eave strut. Figure 2.8 is a cross section of the single span test.

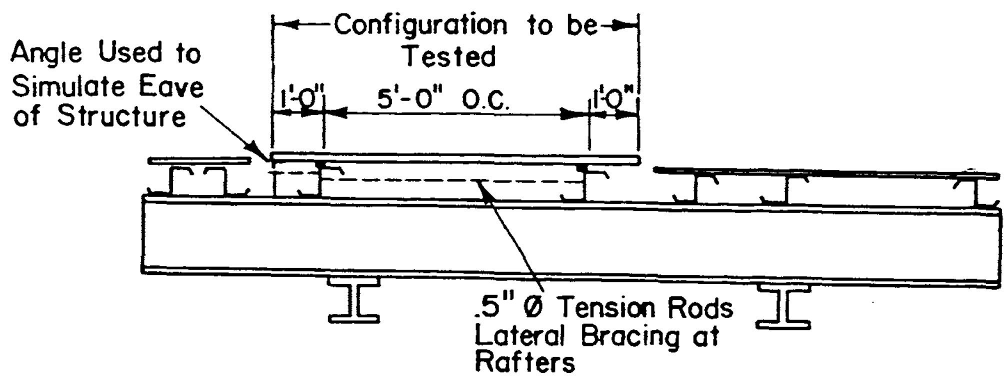


FIGURE 2.8 CROSS-SECTION OF SINGLE SPAN BASE TEST SETUP

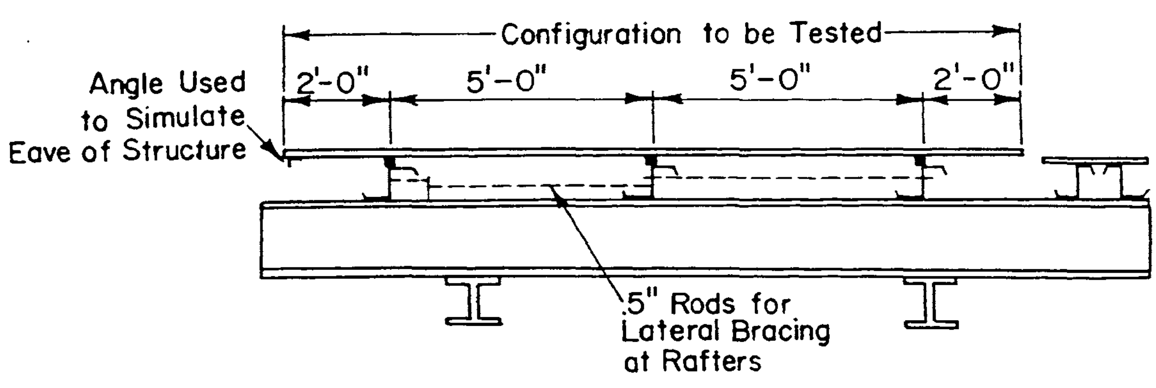


FIGURE 2.9 CROSS-SECTION OF THREE-SPAN TEST SETUP

The three span tests consisted of three or four lines of purlins depending on whether the purlin flanges were facing the same direction or opposing each other, respectively. Each of the three spans were 23 ft. 6 in. between rafters. The lap splices over the interior rafters varied between tests and were set by the manufacturer of the purlins. Lap lengths are listed in Table 2.1. The purlins were connected through their bottom flanges to the rafter. The panels were 14 ft. 4 3/4 in. in length. When three lines of purlins were used, the purlins were spaced 5 ft. 0 in. on center with a 2 ft. 2 3/8 in. overhang of the panels. When four purlin lines were used, the purlins were on a 3 ft. 7 in. spacing with an overhang of 1 ft 9 3/4 in. The clips were bolted to the purlins with 1/4 in. bolts to simplify removal of the panels after testing. A cold-formed angle was attached continuously to one edge of the panels to act as an eave. Figure 2.9 is a cross section of the three span test setup.

The simulated gravity loading was measured by a U-tube manometer. The manometer is calibrated in 0.1 in. of water increments and has an estimated accuracy equivalent to plus or minus 0.25 psf.

Linear displacement transducers were used to measure the midspan vertical deflections of the purlins. Measurements were made for both purlins in the single span tests and all purlins in both exterior bays of the three span tests.

Lateral movement of the system was measured at the midspan of the single span tests and at the midspan of both end bays of the three span tests. The device used was a weighted wire with an attached pointer. One end of the wire was attached to the system, while the pointer end was positioned in front of a scale. Lateral movement was determined from the difference between the initial reading and readings taken during the test.

CHAPTER III

TEST RESULTS

3.1 General

Individual results for each set of single span and three span tests are found in Appendices A and B. Each set of results includes a test summary sheet, measured cross-section dimensions, the allowable flexural capacity as computed according to the 1986 AISI Specification [2], plots of the load vs. midspan deflection, and plots of load vs. lateral movement.

Midspan theoretical deflections for the simple span tests were computed assuming constrained bending and elastic material properties. The midspan theoretical deflections for the external spans of the three span system were computed using standard stiffness analysis procedures assuming constrained bending, elastic material properties and full lap continuity.

3.2 Coupon Test Results

Standard ASTM tensile coupon tests were conducted by Butler Manufacturing Company using material taken from the web area of representative purlins used in each test. Two tests were made for each removed sample. Average values of measured yield stress, tensile strength and elongation are found in Table 3.1.

TABLE 3.1

COUPON TEST RESULTS

Identification	Thickness (in.)	Yield Stress* (ksi)	Tensile Strength* (ksi)	Elongation %
Z-R-R/S-1	0.078	63.21	79.27	22.75
Z-R-R/S-3	0.078	59.80	77.28	23.40
Z-R-R/F-1	0.058	67.53	85.52	21.50
Z-R-R/F-3	0.059	68.51	87.11	20.50
Z-R-P/F-1	0.060	57.61	80.35	20.25
Z-R-P/F-3	0.059	59.93	81.71	20.75
Z-R-P/S-1	0.072	62.45	77.82	25.75
Z-R-P/S-3	0.073	59.02	73.64	27.25
C-R-P/S-1	0.065	66.72	74.42	21.75
C-R-P/S-3	0.065	66.00	73.85	23.00
Z-R-R/F-1 (0)	0.058	66.15	82.16	20.50
Z-R-R/F-3 (0)	0.060	61.57	80.61	24.00
Z-T-P/F-1	0.078	53.59	75.77	28.25
Z-T-P/F-3	0.077	52.44	74.83	26.25
Z-T-P/S-1	0.074	63.65	76.76	26.75
Z-T-P/S-3	0.074	62.29	76.24	27.25
Z-T-R/S-1	0.074	63.51	79.73	21.25
Z-T-R/S-3	0.076	62.57	80.56	22.75

*Average of two tests.

3.3 Rafters Braced Test Results

The rafter braced sequence of tests consisted of six sets of tests with each set of tests including a single span base test and a three span confirming test. The bracing of the system was as shown in Figure 2.4 at the locations shown in Figure 2.7.

Four of the six sets of tests were conducted using Z-purlins facing the same direction. One set of tests was conducted using C-purlins facing the same direction in each bay, but opposite in adjoining bays. For these five test sets, three lines of purlins were used in the three span tests and two lines in the single span tests. The sixth set of tests used opposed Z-purlins. Two lines were used in the single span test and four lines of purlins were used in the three span test.

Appendix A contains complete test results for the rafter braced tests. Table 3.2 shows the failure load and failure mode for each test.

The failure mode for the Z-purlin tests that were conducted with flanges facing in the same direction, except Test Z-R-R/S-3, was cross-section failure after considerable lateral movement. The failure mode for Test Z-R-R/S-3 was local buckling approximately 1 ft. into the interior span from the end of the continuity lap. On close inspection of the failed purlins it was determined that damage during shipping or handling had occurred at this location which caused premature local buckling. Cross-section failure occurred near midspan in the base tests and approximately 10 ft. from one of the exterior rafter supports in the three continuous span tests (that is, in the positive moment region of an exterior span). Failure of the C-purlin and opposed Z-purlin tests was local lip/flange/web buckling. Relatively little lateral movement occurred before failure in these tests.

TABLE 3.2

SUMMARY OF RAFTER BRACED TEST RESULTS

Test Designation	No. of Spans	Failure Load (plf)	Failure Mode
Z-R-R/S	one	136.5	LM
	three	152.9	LM
Z-R-R/F	one	64.5	LM
	three	107.1	LM
Z-R-P/S	one	80.0	LM
	three	128.2	LM
Z-R-P/F	one	60.48	LM
	three	102.5	LM
C-R-P/S	one	119.0	LB
	three	217.0	LB
Z-R-R/F (0)	one	87.0	LB
	three	158.0	LB

LB = Local buckling of lip, flange, web.

LM = Failure of cross-section after considerable lateral movement.

3.4 Third Point Braced Test Results

The third point braced sequence of tests consisted of three sets of tests with each set containing a single span base test and a three span confirming test. The bracing of the systems was as shown in Figure 2.5 at locations shown in Figure 2.7.

The three sets of tests used Z-purlins facing the same direction. Two lines of purlins were used in the single span tests and three lines of purlins were used in the three span confirming test.

Appendix B contains complete test results for the third point braced tests. Table 3.3 is a summary of the test results, showing failure loads and failure modes.

The failure mode for all of the base tests was local lip/flange/web buckling after some lateral movement. Failure occurred near the midspan in each test.

The failure mode for the confirming tests Z-T-P/F and Z-T-R/S was local lip/flange/web buckling after some lateral movement. In confirming test Z-T-P/S, a lateral brace-to-purlin flange connection failed causing premature failure of the system.

TABLE 3.3

SUMMARY OF THIRD POINTS BRACED TEST RESULTS

Test Designation	No. of Spans	Failure Load (plf)	Failure Mode
Z-T-P/F	one	126.0	LB
	three	223.0	LB
Z-T-P/S	one	120	LB
	three	188.0	BR
Z-T-R/S	one	126.0	LB
	three	238.0	LB

LB = Local buckling of lip, flange, web.

LM = Failure of cross-section after considerable lateral movement.

BR = Failure of a lateral brace-to-purlin flange connection.

CHAPTER IV

EVALUATION OF RESULTS AND RECOMMENDATIONS

4.1 Evaluation of Results

Tables 4.1 and 4.2 show the predicted three continuous span failure loads, the actual failure loads, and the ratio of actual-to-predicted failure loads. The predicted failure loads were calculated using the procedure described in Section 1.2. For all tests, the predicted failure location was at the maximum moment location in the exterior spans of the three span confirming tests, that is, in the positive moment region. This location is also the location of the actual point of failure except for tests Z-R-R/S and Z-T-P/S. As described in Chapter III, the failure modes for the three span continuous tests in sets Z-R-R/S and Z-T-P/S were unrelated to the purposes of this study. Except for test sets Z-R-R/S and Z-T-P/S, the ratio of actual-to-predicted failure loads was between 0.87 and 1.02 with an average value of 0.95.

Table 4.3 shows results for two sets of base/confirming tests as reported in Reference 1. The confirming tests were two span continuous tests. The failure mode for all four tests was cross-section failure after considerable lateral movement. The failure location was near midspan, that is, the positive moment region, for all tests. The ratio of actual-to-predicted failure load for the two sets of tests was 0.92.

In summary, from the results of the nine valid sets of base/confirming tests shown in Tables 4.1, 4.2 and 4.3, the range of the ratio of actual-to-predicted failure loads was 0.87 to 1.02 with an average value of 0.94.

TABLE 4.1

ACTUAL AND PREDICTED RAFTER BRACED TEST RESULTS

	BASE TEST		THREE SPAN TEST									
Test Designation	w_u (plf)	M_{us} (in. kips)	F_y (ksi)	M_{AISI} (in. kips)	M_{max}^- (in. kips)	M_{max}^+ (in. kips)	w_{p3}^- (plf)	w_{p3}^+ (plf)	w_{p3} (plf)	w_u (plf)	w_u/w_{p3}
Z-R-R/S	136.5	128.0	59.80	197.0	40.10	50.70	491.3	252.4	252.4	152.9	0.61
Z-R-R/F	64.5	60.5	68.51	109.9	51.10	51.40	215.1	117.7	117.7	107.1	0.91
Z-R-P/F	60.5	56.7	59.93	105.4	46.40	51.20	227.2	110.7	110.7	102.5	0.93
Z-R-P/S	80.0	75.0	59.02	174.1	47.20	51.00	368.9	147.0	147.0	128.2	0.87
C-R-P/S	119.0	111.6	66.00	143.2	42.70	50.40	335.4	221.4	221.4	217.0	0.98
Z-R-R/F (0)	87.0	81.6	61.57	118.1	50.90	51.20	232.0	159.3	159.3	158.0	0.99

*Assumed yield stress.

M_{AISI} = allowable moment capacity x 1.67 (assuming constrained bending)

M_{us} = maximum moment from single span (base) test

M_{max}^- = maximum negative moment from stiffness analysis (100 plf)

M_{max}^+ = maximum positive moment from stiffness analysis (100 plf)

W_{p3}^- = predicted three span failue load if M_{max}^- controls

W_{p3+} = predicted three span failue load if M_{max}^+ controls

W_{p3} = minimum of W_{p3}^- and W_{p3}^+, e.g. predicted failure load

W_u = actual failure load

TABLE 4.2

ACTUAL AND PREDICTED THIRD POINT BRACED TEST RESULTS

	BASE TEST		THREE SPAN TEST								
Test Designation	w_u (plf)	M_{us} (in. kips)	F_y (ksi)	M_{AISI} (in. kips)	M_{max}^- (in. kips)	M_{max}^+ (in. kips)	w_{p3}^- (plf)	w_{p3}^+ (plf)	w_{p3} (plf)	w_u (plf)	w_u/w_{p3}
Z-T-P/F	126.0	118.1	52.44	133.2	40.10	50.20	332.2	235.3	235.3	223.0	0.95
Z-T-P/S	120.0	112.5	62.29	177.1	48.10	50.50	368.2	222.8	222.8	188.0	0.84
Z-T-R/S	126.0	118.1	62.57	196.8	46.20	50.70	426.0	232.9	232.9	238.0	1.02

*Assumed yield stress.

M_{AISI} = allowable moment capacity x 1.67 (assuming constrained bending)

M_{us} = maximum moment from single span (base) test

M_{max}^- = maximum negative moment from stiffness analysis (100 plf)

M_{max}^+ = maximum positive moment from stiffness analysis (100 plf)

W_{p3}^- = predicted three span failue load if M_{max}^- controls

W_{p3+} = predicted three span failue load if M_{max}^+ controls

W_{p3} = minimum of W_{p3}^- and W_{p3}^+, e.g. predicted failure load

W_u = actual failure load

TABLE 4.3

ACTUAL AND PREDICTED TEST RESULTS FROM REFERENCE 3

	BASE TEST		TWO SPAN TEST								
Test Designation	w_u (plf)	M_{us} (in. kips)	F_y (ksi)	M_{AISI} (in. kips)	M_{max}^- (in. kips)	M_{max}^+ (in. kips)	w_{p2}^- (plf)	w_{p2}^+ (plf)	w_{p2} (plf)	w_u (plf)	w_u/w_{p2}
10Z14-P-1-1	91.0	85.31	65.92	207.3	79.30	50.50	261.4	168.9	168.9	155.0	0.92
10Z14-R-1-1	86.0	80.63	63.94	215.2	79.30	51.70	271.4	156.0	156.0	144.0	0.92

*Assumed yield stress.

M_{AISI} = allowable moment capacity x 1.67 (assuming constrained bending)

M_{us} = maximum moment from single span (base) test

M_{max}^- = maximum negative moment from stiffness analysis (100 plf)

M_{max}^+ = maximum positive moment from stiffness analysis (100 plf)

W_{p2}^- = predicted two span failue load if M_{max}^- controls

W_{p2+} = predicted two span failue load if M_{max}^+ controls

W_{p2} = minimum of W_{p2}^- and W_{p2}^+, e.g. predicted failure load

W_u = actual failure load

4.2 Recommendation

The testing programs described in this report encompassed a wide range of metal building standing seam roof systems. Pan-type and rib-type panels, sliding and fixed clips, and C- and Z-purlins were included in the study. The test results clearly show that the "base test method" is a valid experimental/analytical procedure to determine the strength of C- and Z-purlin supported standing seam roof systems. Its use is recommended with the following limitations:

1. The base test must be conducted using nominally identical panel, clip, insulation, and purlin components as are used in the actual standing seam roof system.

2. The failure moment determined from the base test can only be used to determine the capacity of roof systems using identical purlins.

3. The span of the base test must be greater than or equal to the largest span in the actual roof system.

4. The purlin line spacing in the base test must be greater than or equal to the purlin spacing in the actual roof system.

5. A factor of safety of 1.67 must be applied to the base test results.

4.3 Example Calculations

A proposed roof system is to be supported by six lines of equally spaced Z8 x 3 x 0.074, F_y = 50 ksi, purlins. Each purlin line consists of four equal 25 ft. spans. The purlin lines are 5 ft. 0 in. on center. Full moment continuity is assumed at each rafter. The top flanges of all purlins are facing in the direction of the ridge. The standing seam panels are connected to the eave strut with self-drilling fasteners at 12 in. on center. Four inch "metal building insulation" is specified for the project.

A simple span base test was conducted using two purlin lines spaced 5 ft. 0 in. on center. The purlins were oriented with top flanges facing in the same direction. A cold-formed base angle was attached at the "eave" end of the panels using self-drilling fasteners at 12 in. on center. The base angle was used to simulate eave strut effects. The base test was constructed using standing seam panels, clips and insulation identical to what will be used in the proposed building. The base test span was 25 ft. and the failure load per purlin line was 110 plf. The corresponding failure moment is $110\,(25)^2/8 = 8{,}594$ ft-lbs = 103.1 in-kips. The allowable capacity is then $103.1/1.67 = 61.7$ in-kips.

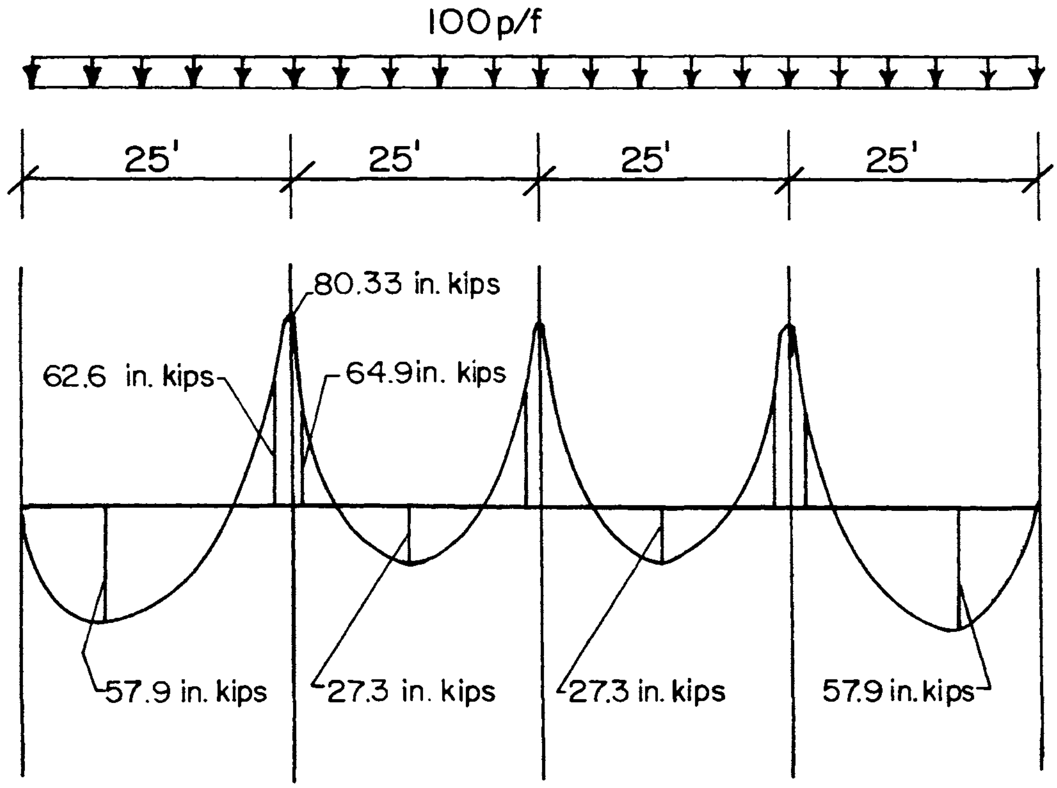
The flexural cross-section strength was determined using the provisions of the 1986 AISI Specification [2]. The allowable moment capacity for the section is 82.1 in-kips.

Next, a stiffness analysis of a four span purlin line was conducted. The resulting moment diagram for a 100 plf nominal load is shown in Figure 4.1. The controlling positive moment is 57.9 in-kips and the controlling negative moment is 64.9 in-kips both per purlin.

Using the base test method, the allowable capacity of the proposed roof system is then

$$w = \min \left| \begin{array}{l} \text{Positive moment region:} \\ 61.7/57.9 \times 100 = 106.6 \text{ plf} \\ \\ \text{Negative moment region:} \\ 82.1/64.9 \times 100 = 126.5 \text{ plf} \end{array} \right.$$

Assuming the positive moment region controls (106.6 plf), the negative moment region capacity is recalculated considering shear plus bending effects and found to be 119.7 plf. Thus, the capacity of the proposed standing seam roof system per purlin line is 106.6 plf.



Note: Moments are representative and are not for an actual purlin line configuration.

FIGURE 4.1 MOMENT DIAGRAM FOR EXAMPLE CALCULATIONS

REFERENCES

1. Carballo, M., S. Holzer and T. M. Murray, "Strength of Z-Purlin Supported Standing Seam Roof Systems under Gravity Loading", Research Progress Report CE/VPI-ST89/03, The Charles E. Via Department of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, January 1989, 198 pages. (unpublished).

2. "Specification for the Design of Cold-Formed Members", American Iron and Steel Institute, Washington, D.C., July 1986.

APPENDIX A

RAFTER BRACED TEST RESULTS

Z-R-R/S-1
Test Summary

Test Date: January 20, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	.077"	--	.077"
Sweep	0.5"	--	0.5"

Parameters: Gravity Loading, Bracing @ End (Supports) Only
Two Purlin Lines 5'-0" O.C. 1'-0" overhang
Purlins facing same direction

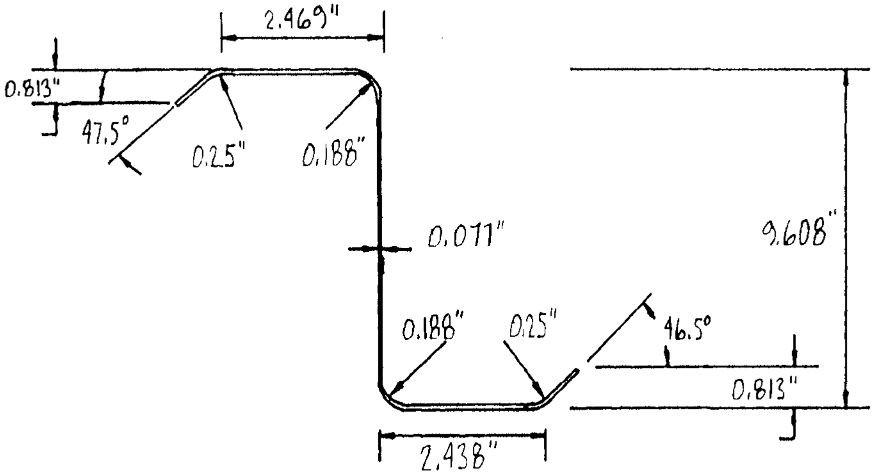
Failure Load: 136.5 plf Failure Mode: Lateral-Torsional Buckling /Local Buckling

Predicted Failure Loads: (F_y = 63.21 ksi)

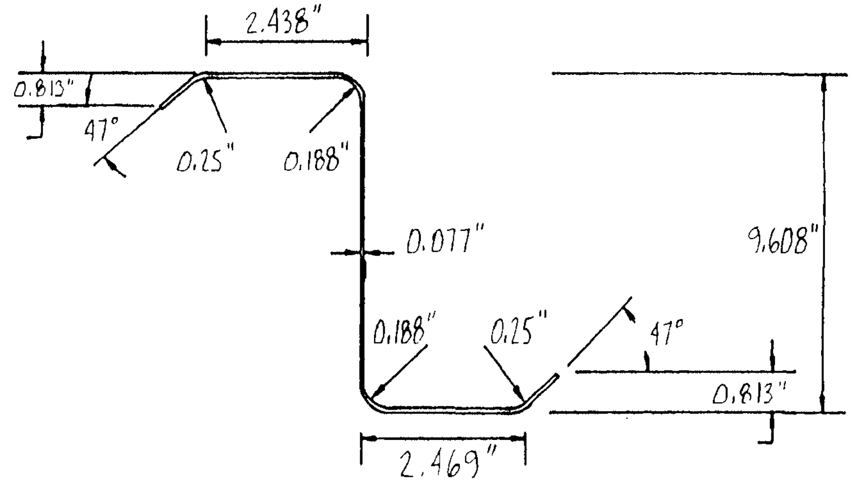
Constrained Bending:	M_n	187.3	in-kips	Load	199.8 plf
Base Test Method:	M(+)	NA	in-kips	Load	NA plf
	M(-)	NA	in-kips	Load	NA plf

Discussion:

- Top and bottom flange widths the same
- Rib type roofing panels/with sliding clips
- Vacuum chamber used to test
- Manometer with water (62.4 plf) used to measure load
- Load deflection response was essentially linear
- Final positions of clips show movement prior to failure
- Evidence of local buckling of compression flange @ clips near center of span
- Failure was in ridge purlin by lateral torsional buckling followed by local buckling of the compression flange.



Ridge Purlin



Eave Purlin

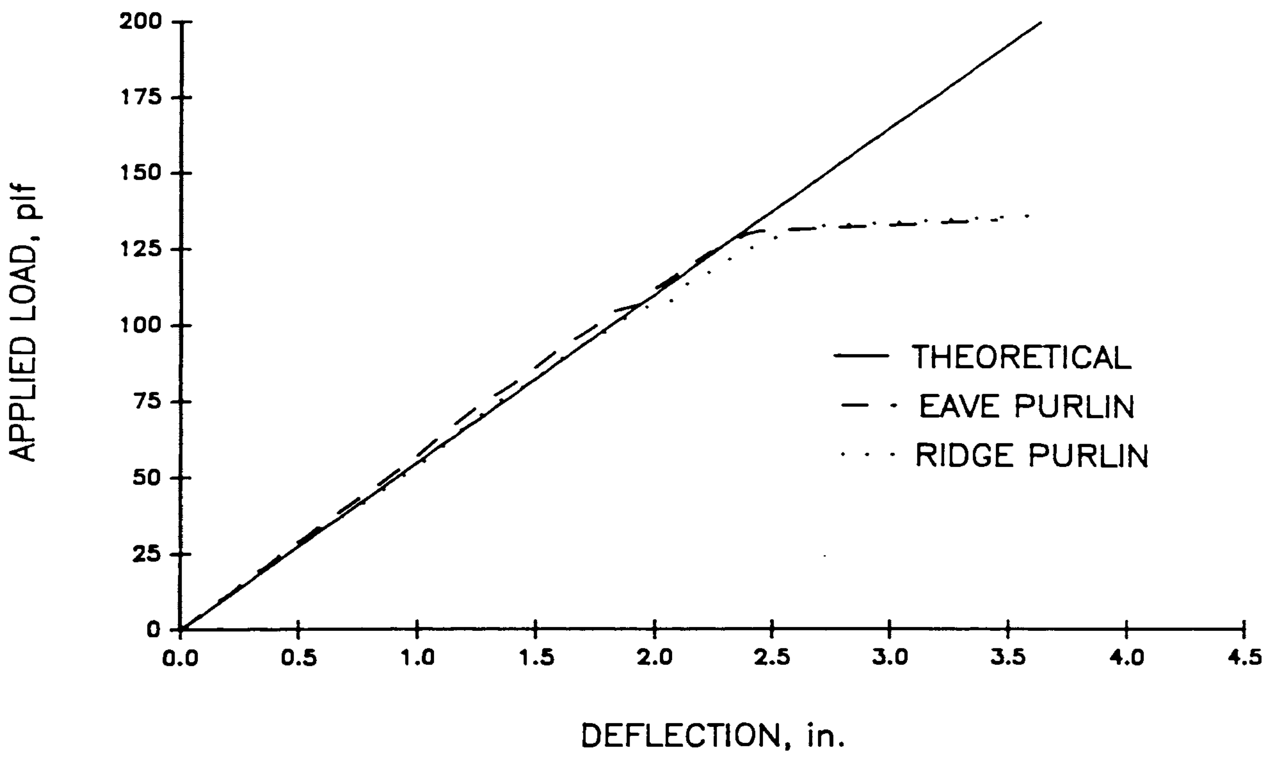
BASE TEST

TEST Z-R-R/S-1

TEST Z-R-R/S-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span: Ridge	Single Span: Eave
TOP		
Vertical Lip		
Dimension (inches)	0.813	0.813
Lip Angle (degree)	47.5	47.0
Flange Width (inches)	2.469	2.438
Radii (inches)		
Lip to Flange	0.25	0.25
Flange to Web	0.1875	0.1875
BOTTOM		
Vertical Lip		
Dimension (inches)	0.813	0.813
Lip Angle (degree)	46.5	47.0
Flange Width (inches)	2.438	2.469
Radii (inches)		
Lip to Flange	0.25	0.25
Flange to Web	0.1875	0.1875
Total Depth (inches)	9.608	9.608
Thickness (inches)	0.077	0.077
Gross Moment of Inertia ($inches^4$)	16.68	16.68
Material Yield Stress (ksi)	63.21	63.21
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	187.3	205.0



LOAD VS. DEFLECTION, TEST Z–R–R/S–1

Z-R-R/S-3

Test Summary

Test Date: March 1, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	.077"	.077	.077"
	.077"	.077	.077"
	.077"	.077	.077"
Sweep	1"	1"	1"
	1"	1"	1"
	1"	1"	1"

Parameters: Gravity Loading, Bracing @ Ends (Supports) Only
Three Purlin Lines 5'-0" O.C. 2'-2" overhang
Purlins facing same direction

Failure Load: 152.9 plf Failure Mode: Lateral-Torsional Buckling

Predicted Failure Loads: (F_y = 59.80 ksi)

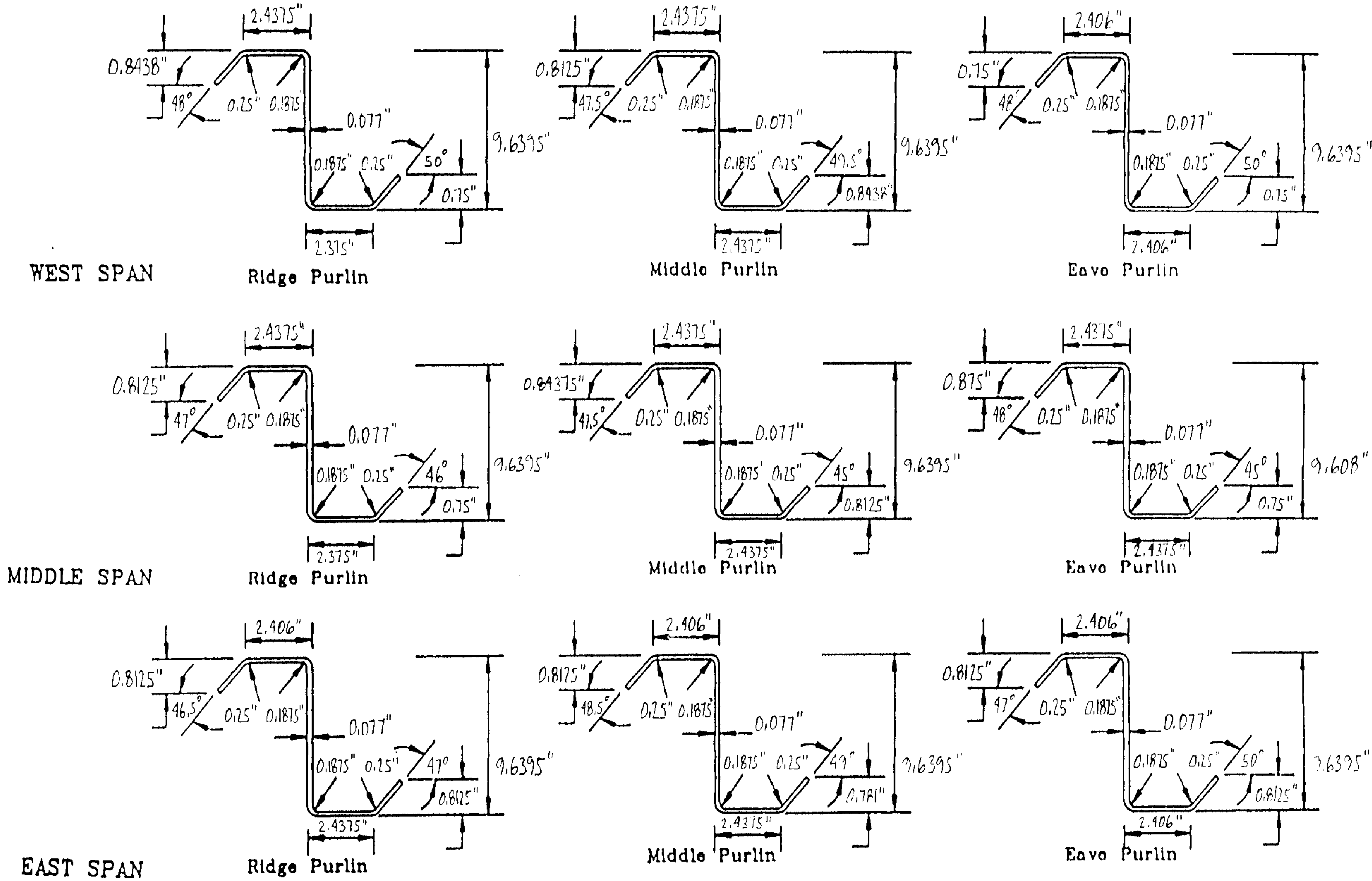
Constrained Bending:	M_n	197.0 in-kips	Load	NA	plf
Base Test Method:	M(+)	50.7 in-kips	Load	252.4	plf
	M(-)	40.1 in-kips	Load	491.3	plf

Discussion:

- Rib type roofing panels with sliding clips
- Load deflection curve response was essentially linear
- Failure was in ridge purlin of west span

Premature failure of the west span was unexpected. East and west end spans were almost identical in I's and were identical in support conditions and splice connections. East span was plotting close to theoretical load-deflection curve and showed no indication of approaching failure load. Failure of west span is believed to have been due to some type of flaw in the material or set up. The two identical end spans should have behaved closer together. This would indicate that premature failure should be contributed to something other than the method of predicting failure load.

Note: The failure load for the single span base test (Z-R-R/S-1) may have been overestimated due to rapid application of load resulting in slightly higher value of failure load. may be reason (partial) for premature failure of three span test.

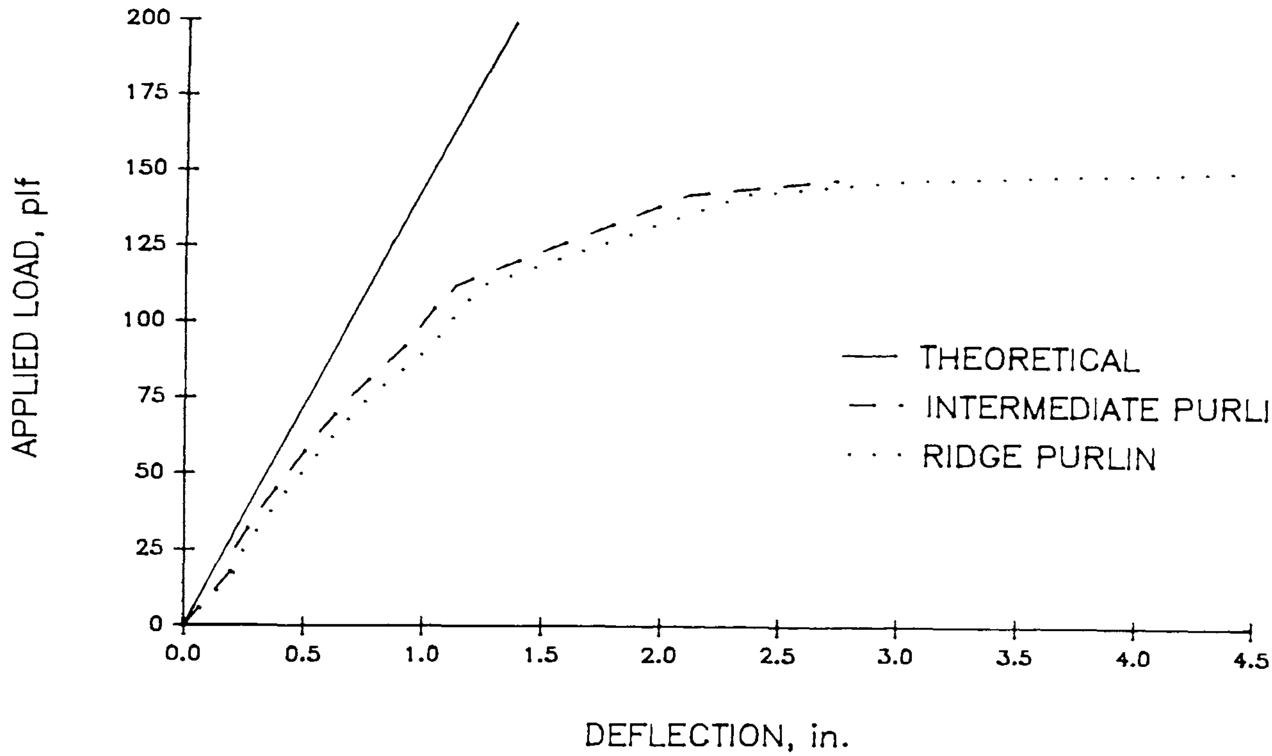

WEST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
MIDDLE SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin

TEST Z-R-R/S-3

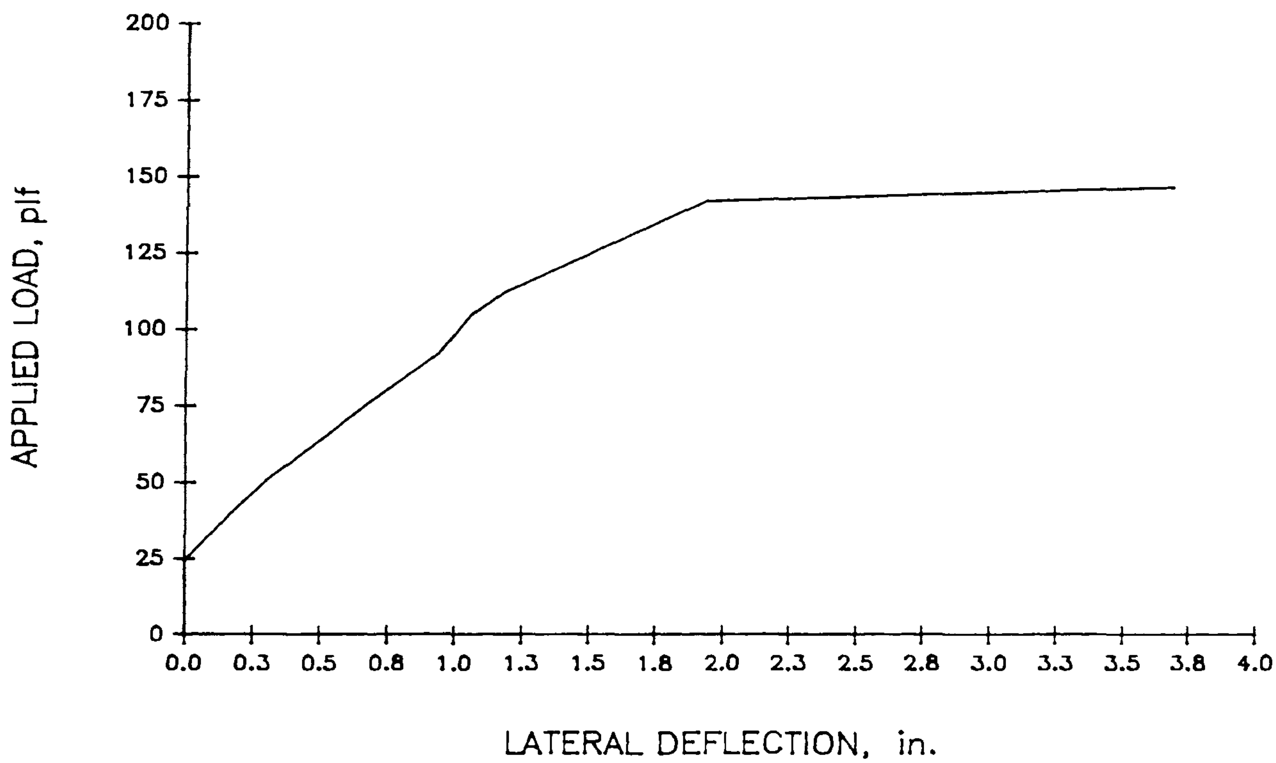
TEST Z-R-R/S-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

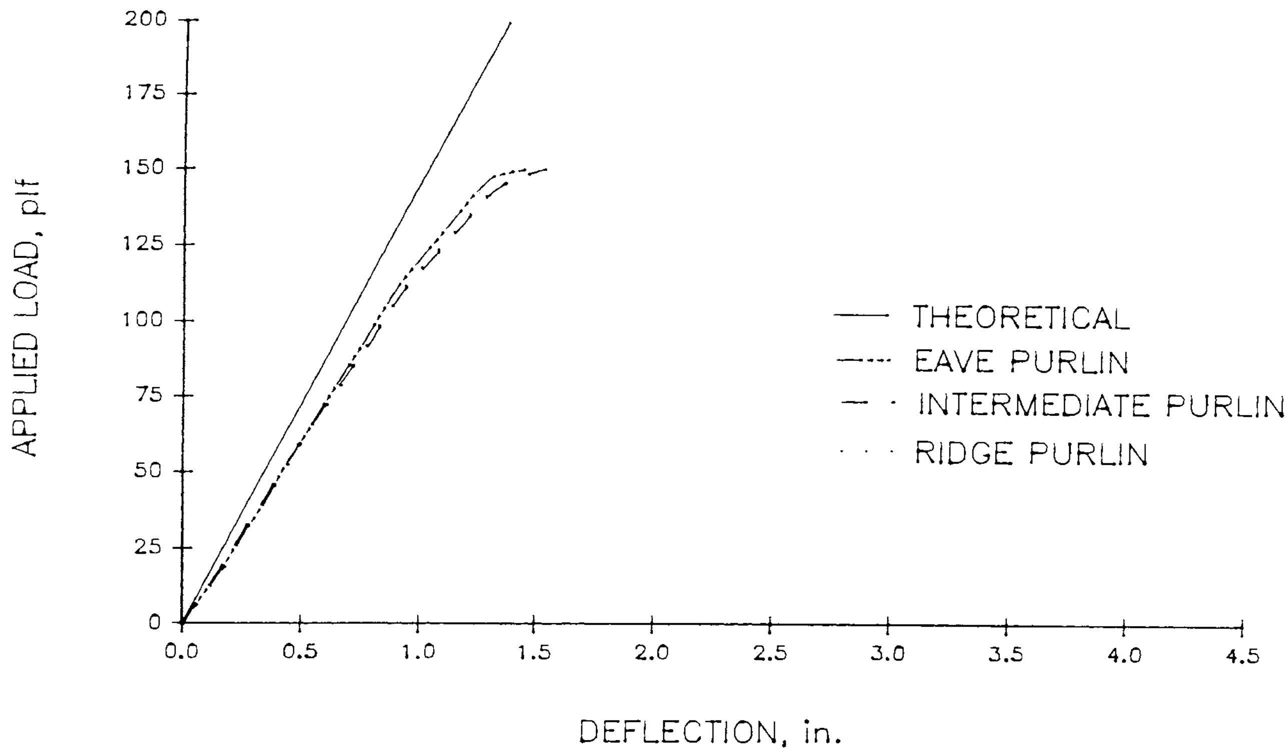
Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip									
Dimension (inches)	0.8125	0.8125	0.8125	0.8125	0.8438	0.875	0.8438	0.8125	0.75
Lip Angle (degree)	46.5	48.5	47.0	47.0	47.50	48.0	48.0	47.5	48.0
Flange Width (inches)	2.406	2.406	2.4060	2.4375	2.4375	2.4375	2.4375	2.4375	2.406
Radii (inches)									
Lip to Flange	0.25	0.25	0.25	0.25	0.250	0.25	0.25	0.25	0.25
Flange to Web	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
BOTTOM									
Vertical Lip									
Dimension (inches)	0.8125	0.781	0.8125	0.75	0.8125	0.75	0.75	0.8438	0.75
Lip Angle (degree)	47.0	49.0	50.0	46.0	45.0	45.0	50.0	49.5	50.0
Flange Width (inches)	2.4375	2.4375	2.4060	2.375	2.4375	2.4375	2.375	2.4375	2.4060
Radii (inches)									
Lip to Flange	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flange to Web	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
Total Depth (inches)	9.6395	9.6395	9.6395	9.6395	9.6395	9.608	9.6395	9.6395	9.6395
Thickness (inches)	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
Gross Moment of Inertia (inches^4)	16.71	16.55	16.56	16.56	16.85	16.65	16.49	16.72	16.33
Material Yield Stress (ksi)	59.8	59.8	59.8	59.8	59.8	59.8	59.8	59.8	59.8
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	197.74	196.64	197.23	197.74	198.41	197.71	197.00	198.56	192.65



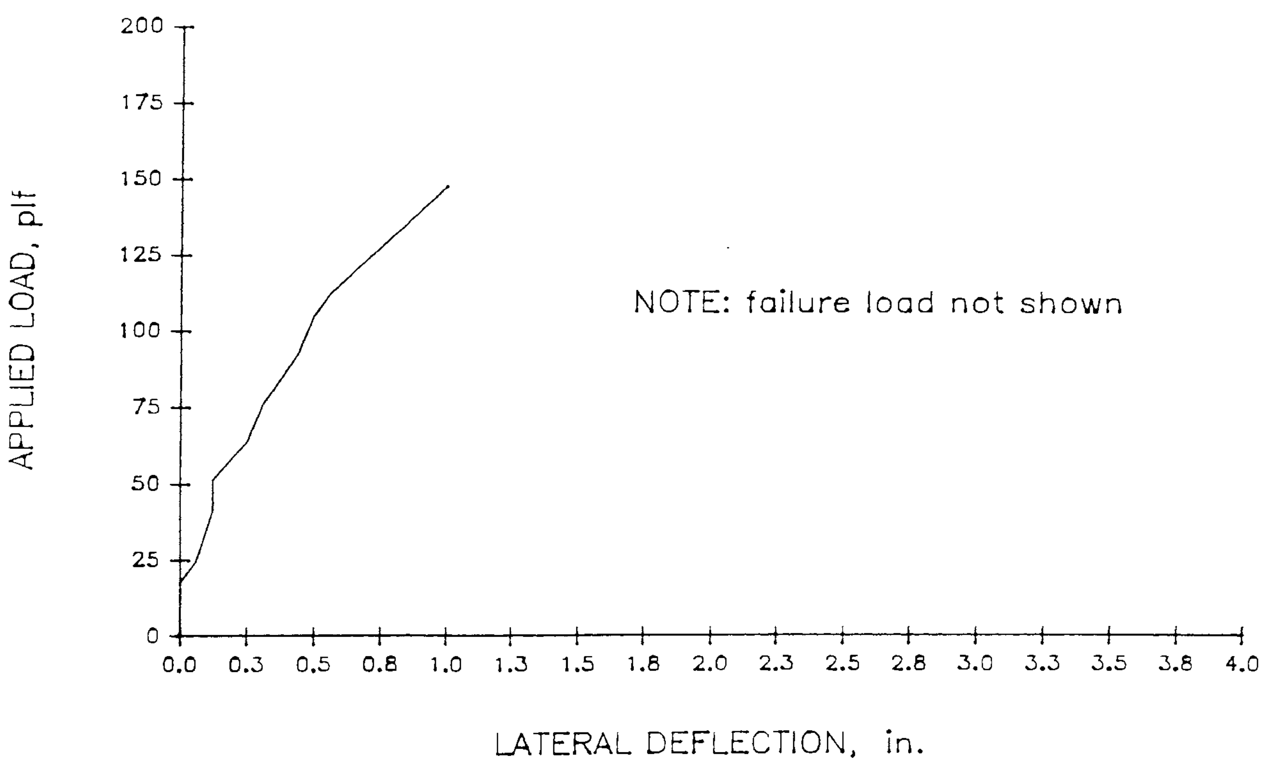
LOAD VS. DEFLECTION, TEST Z–R–R/S–3, WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/S–3, WEST SPAN



LOAD VS. DEFLECTION, TEST Z–R–R/S–3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/S–3, EAST SPAN

Z-R-R/F-1
Test Summary

Test Date: January 25, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	.059"	--	.059"
Sweep	2 1/8"	--	2 1/4"

Parameters: Gravity Loading, Bracing @ Supports Only
Two Purlin Lines 5'-0" O.C. 1'-0" overhang
Purlins Facing Same Direction

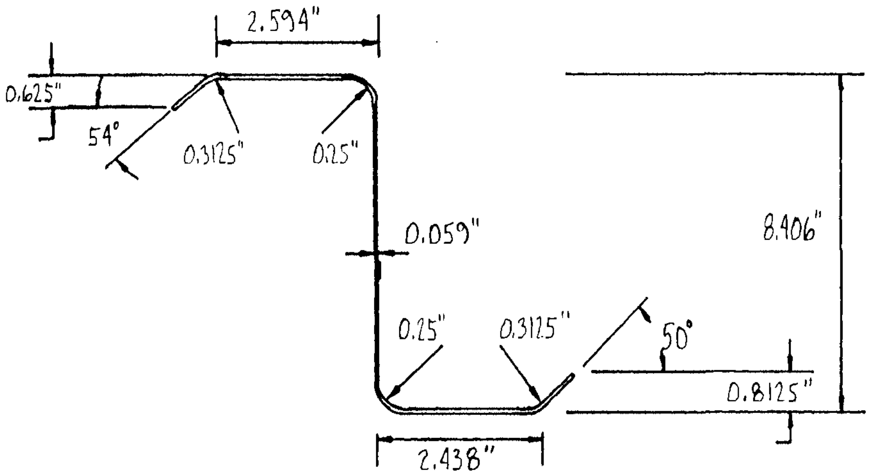
Failure Load: 64.5 plf Failure Mode: Lateral-Torsional Buckling /Local Buckling

Predicted Failure Loads: (F_y = 67.53 ksi)

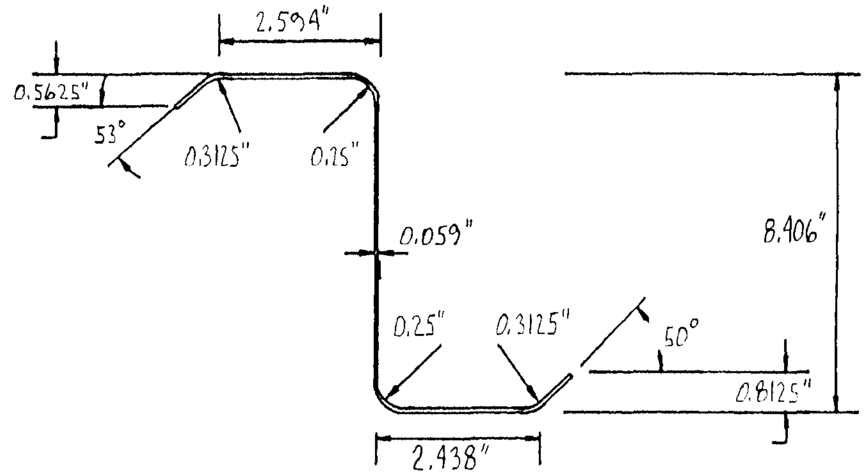
Constrained Bending:	M_n	107.6	in-kips	Load	114.8	plf
Base Test Method:	M(+)	NA	in-kips	Load	NA	plf
	M(-)	NA	in-kips	Load	NA	plf

Discussion:

- Top and bottom flange widths essentially the same
- Rib type roofing panels/with fixed clips
- Vacuum chamber used to test
- Manometer with water (62.4 plf) used to measure load
- Load deflection response was linear
- Final positions of clips show movement prior to failure
- Failure was in eave purlin by lateral torsional buckling followed by local buckling of compression flange



Ridge Purlin



Eave Purlin

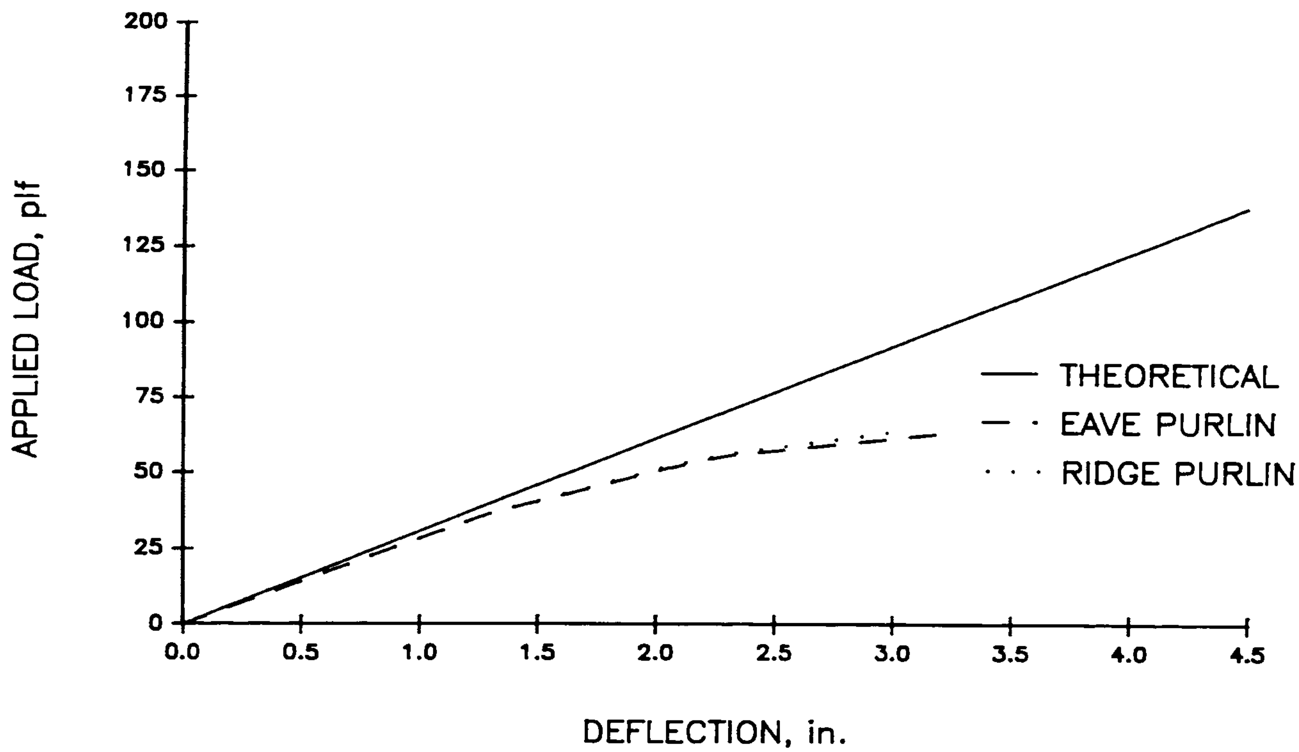
BASE TEST

TEST Z-R-R/F-1

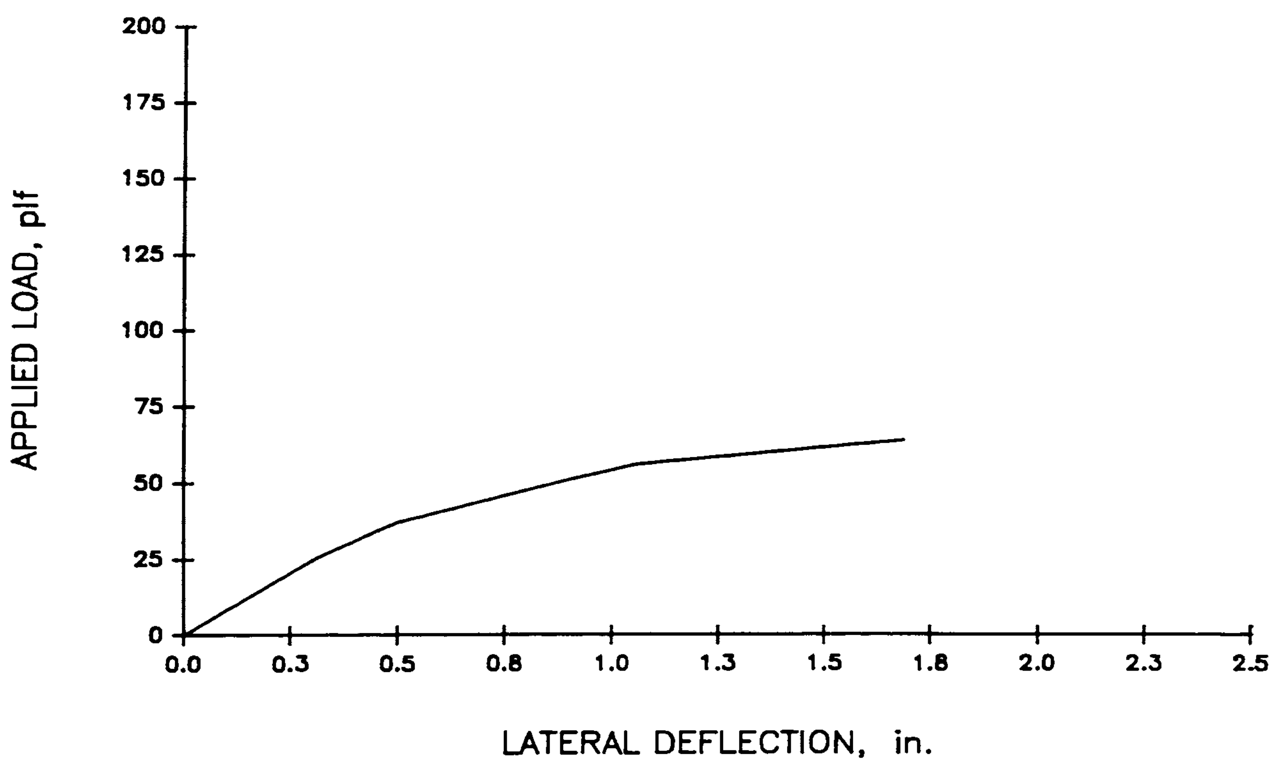
TEST Z-R-R/F-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span Ridge	Single Span Eave
TOP		
Vertical Lip		
Dimension (inches)	0.625	0.5625
Lip Angle (degree)	54.0	53.0
Flange Width (inches)	2.594	2.5940
Radii (inches)		
Lip to Flange	0.3125	0.3125
Flange to Web	0.25	0.25
BOTTOM		
Vertical Lip		
Dimension (inches)	0.8125	0.8253
Lip Angle (degree)	50.0	50.0
Flange Width (inches)	2.438	2.438
Radii (inches)		
Lip to Flange	0.3125	0.3125
Flange to Web	0.25	0.25
Total Depth (inches)	8.406	8.406
Thickness (inches)	0.059	0.059
Gross Moment of Inertia ($inches^4$)	9.16	9.11
Material Yield Stress (ksi)	67.53	67.53
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	110.9	107.6



LOAD VS. DEFLECTION, TEST Z–R–R/F–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/F–1

Z-R-R/F-3
Test Summary

Test Date: March 13, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.059"	0.059"	0.059"
	0.059"	0.059"	0.059"
	0.059"	0.059"	0.059"
Sweep	1"	1"	1 1/4"
	--	--	--
	1"	1/2"	1/2"

Parameters: Gravity Loading, Bracing @ Supports Only

Three Purlin Lines 5'-0" O.C. 2'-2" overhang

Purlins facing same direction

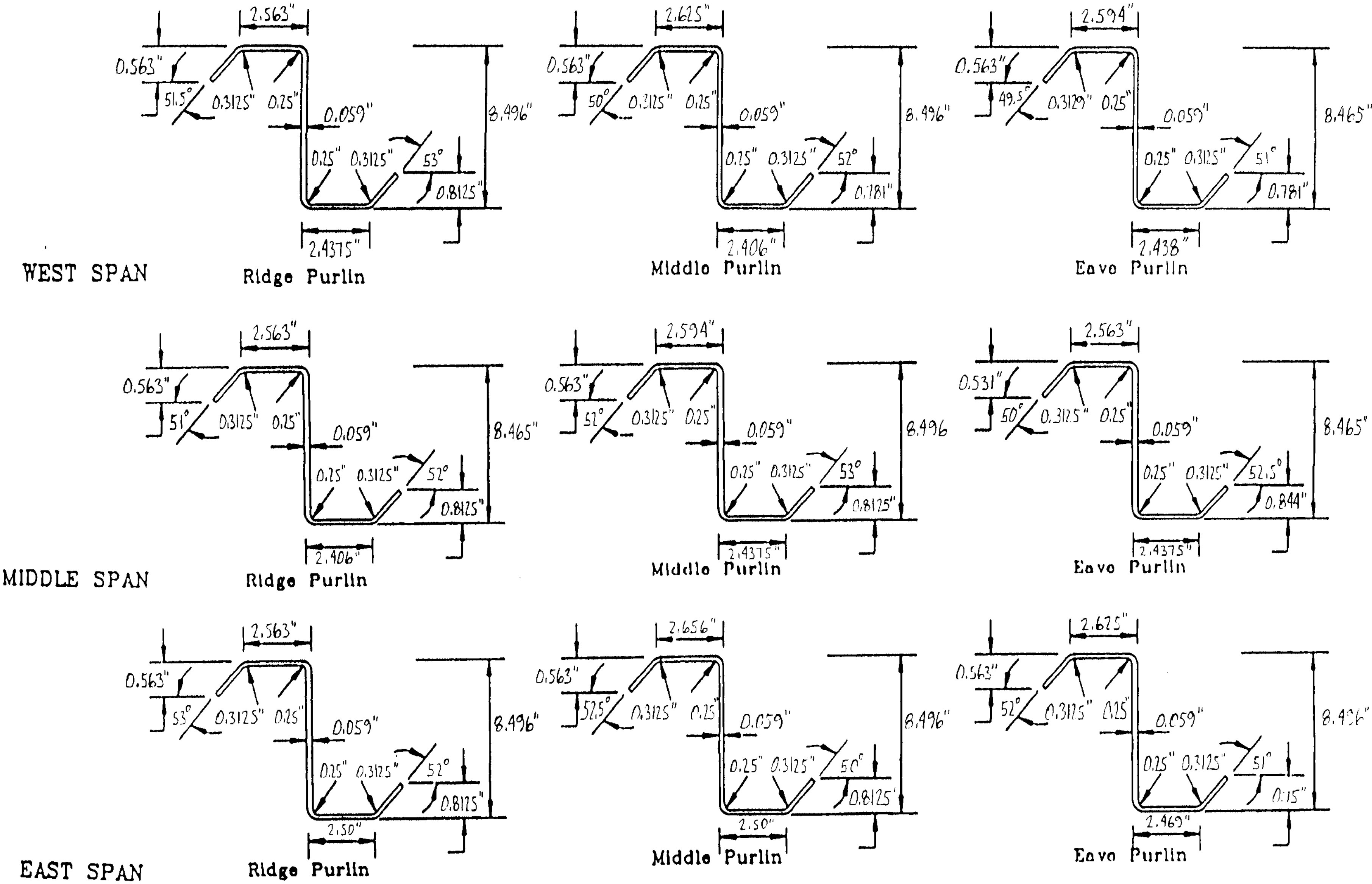
Failure Load: 107 plf Failure Mode: Lateral-Torsional Buckling

Predicted Failure Loads: (F_y = 68.51 ksi)

Constrained Bending:	M_n 109.9	in-kips	Load	N/A plf
Base Test Method:	M(+) 51.40	in-kips	Load	117.7 plf
	M(-) 51.10	in-kips	Load	215.1 plf

Discussion:

- Rib type roofing panels with fixed clip
- Load deflection response curve was essentially linear
- Vacuum chamber was used to load system
- Failure was in ridge purlin by lateral torsional buckling in the west bay
- Load deflection curve had flattened out for ridge purlin, at that time edge of deck hung up on lip of dummy purlins and halted deflection of ridge purlin. This shifted load to eave (believed to be true). Leading to final failure of eave. However ridge purlin did fail first. May hypothesize that failure load would have been slightly higher if had not hung up.

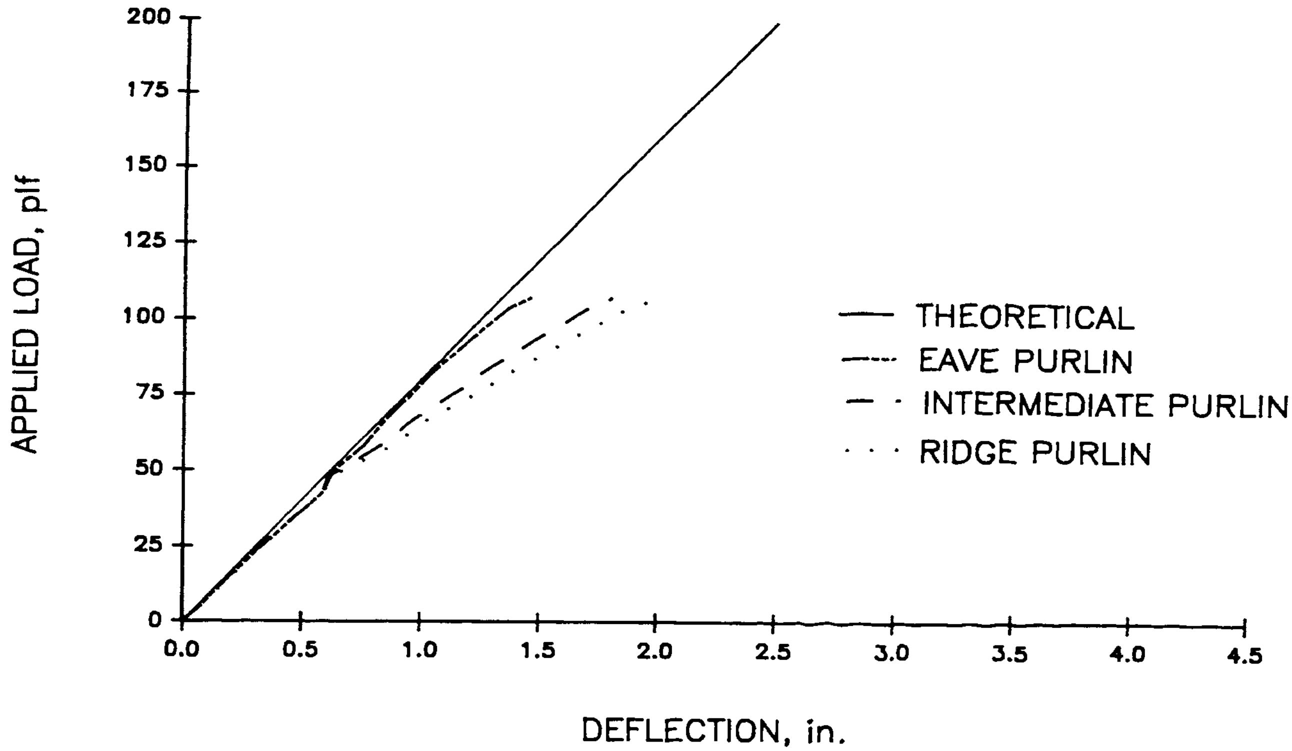

WEST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
MIDDLE SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin

TEST Z-R-R/F-3

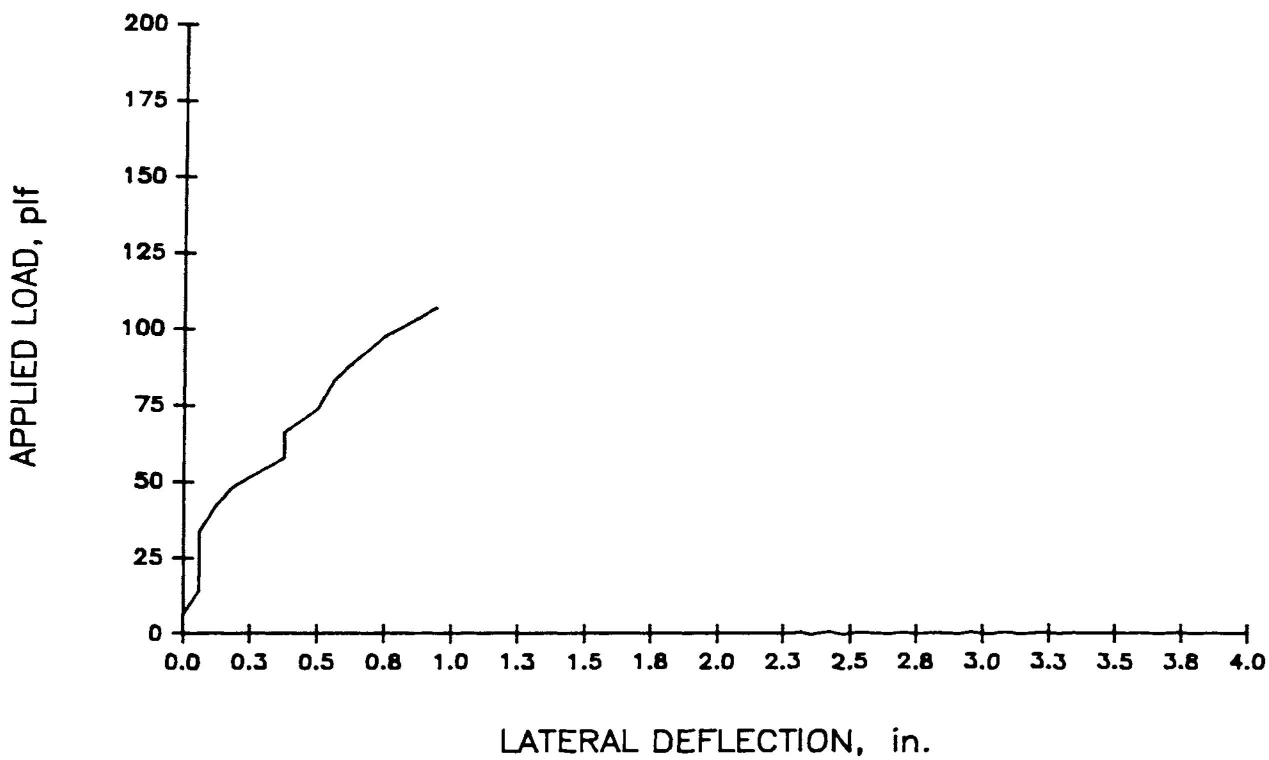
TEST Z-R-R/F-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

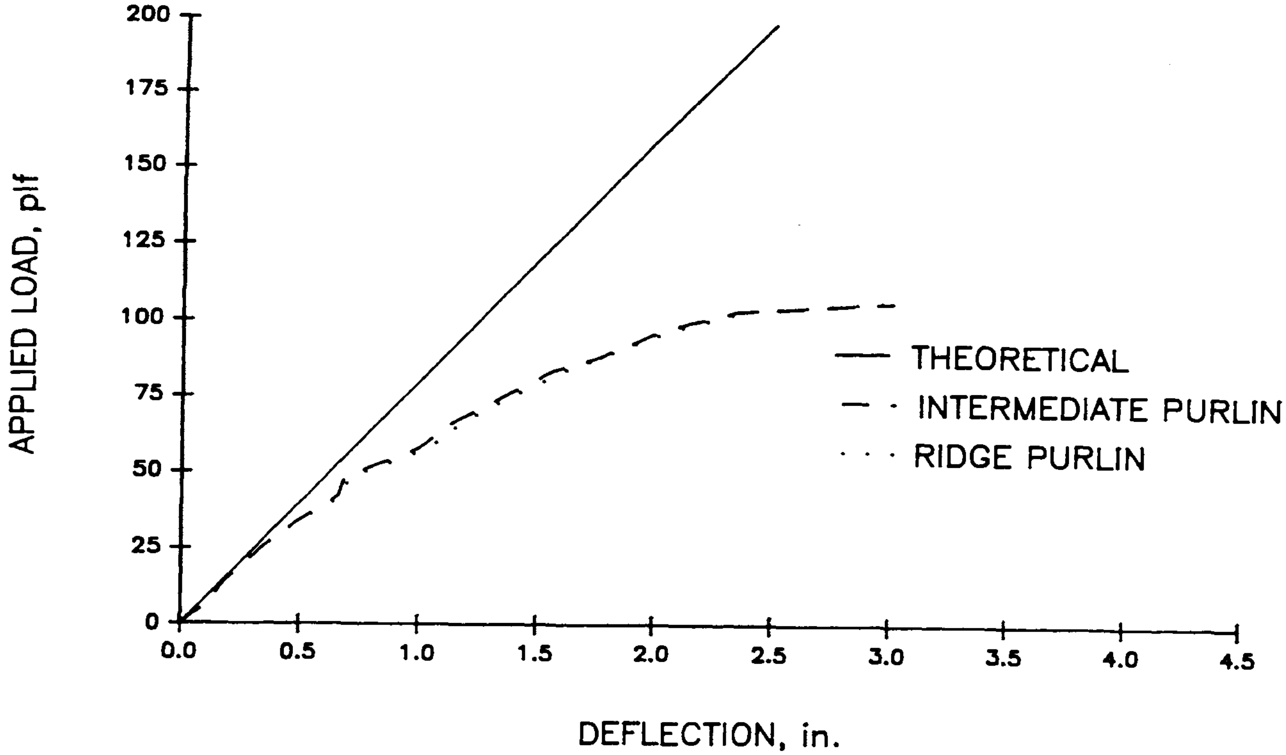
Parameter	East Bay Ridge	East Bay Intermediate	East Bay Eave	Center Bay Ridge	Center Bay Intermediate	Center Bay Eave	West Bay Ridge	West Bay Intermediate	West Bay Eave
TOP									
Vertical Lip									
Dimension (inches)	0.563	0.563	0.563	0.563	0.563	0.563	0.563	0.563	0.563
Lip Angle (degree)	53.0	52.5	52.0	51.0	52.0	50.0	51.5	50.0	49.50
Flange Width (inches)	2.563	2.656	2.625	2.563	2.5940	2.563	2.563	2.625	2.5940
Radii (inches)									
Lip to Flange	0.3125	0.3125	0.3125	0.3125	0.31250	0.3125	0.3125	0.3125	0.3125
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM									
Vertical Lip									
Dimension (inches)	0.8125	0.8125	0.75	0.8125	0.8125	0.844	0.8125	0.7810	0.7810
Lip Angle (degree)	52.0	50.0	51.0	52.0	53.0	52.5	53.0	52.0	51.0
Flange Width (inches)	2.50	2.50	2.469	2.4060	2.4375	2.4375	2.4375	2.406	2.438
Radii (inches)									
Lip to Flange	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125
Flange to Web	0.250	0.250	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	8.496	8.4960	8.4960	8.465	8.4960	8.465	8.496	8.496	8.465
Thickness (inches)	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
Gross Moment of Inertia ($inches^4$)	9.34	9.47	9.34	9.19	9.31	9.21	9.28	8.31	9.25
Material Yield Stress (ksi)	68.51	68.51	68.51	68.51	68.51	68.51	68.51	68.51	68.51
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	109.5	110.1	110.2	109.6	110.0	108.00	109.9	110.7	110.3



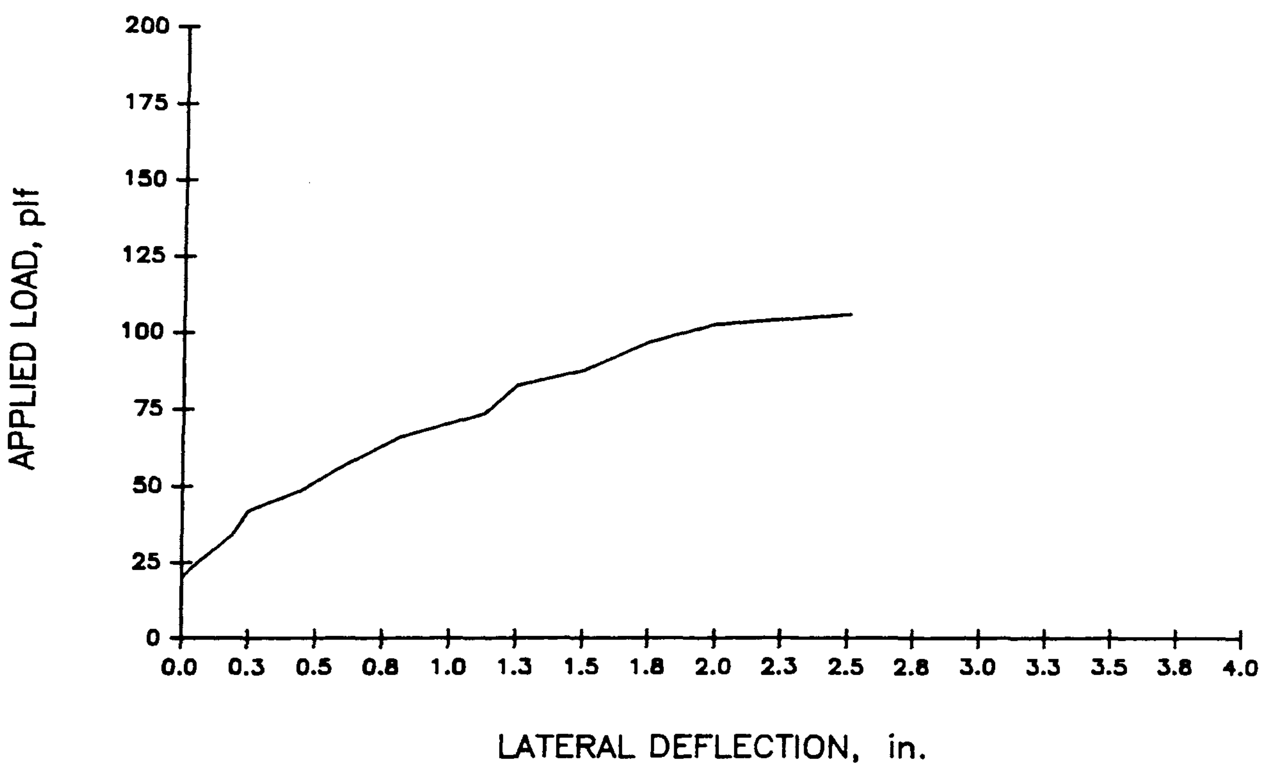
LOAD VS. DEFLECTION, TEST Z-R-R/F-3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z-R-R/F-3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z–R–R/F–3, WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/F–3, WEST SPAN

Z-R-P/F-1
Test Summary

Test Date: January 30, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.061"	--	0.061"
Sweep	1 3/4"	N/A	1 7/8"

Parameters: Gravity Loading, bracing @ supports only

Two Purlin Lines 5'-0" O.C. 1'-0" overhang

Purlins facing same direction

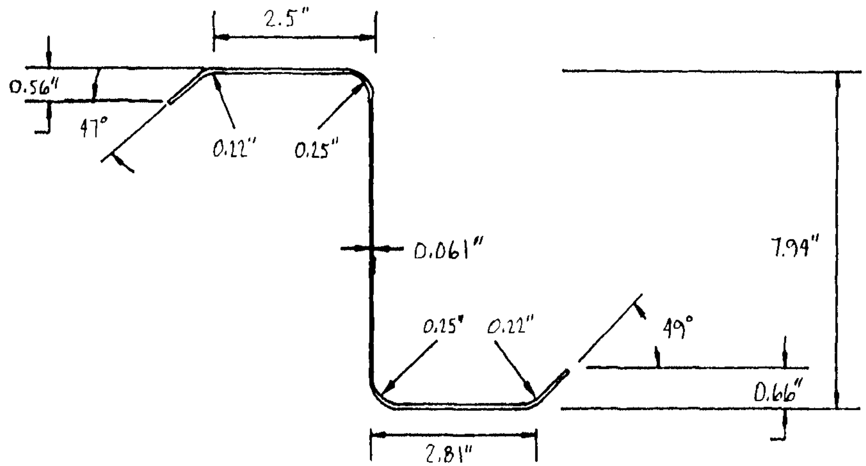
Failure Load: 60.48 plf   Failure Mode: Lateral-Torsional Buckling /Local Buckling

Predicted Failure Loads: (F_y = 57.61 ksi)

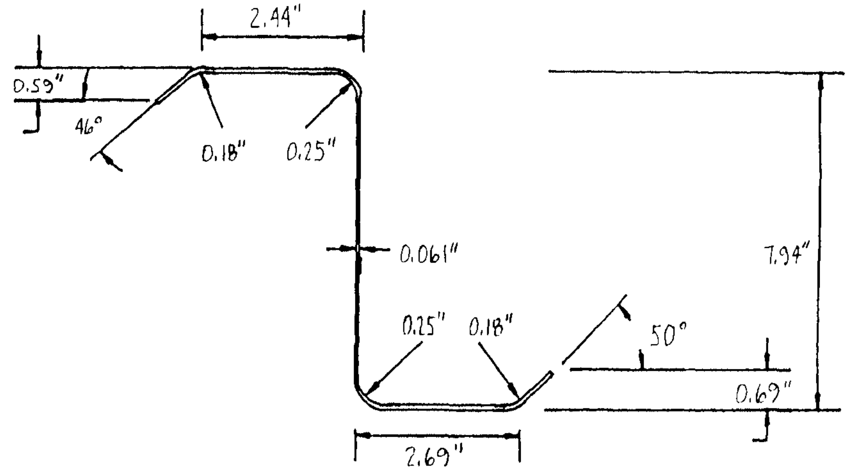
Constrained Bending:	M_n	98.9	in-kips	Load	105.5 plf
Base Test Method:	M(+)	NA	in-kips	Load	NA plf
	M(-)	NA	in-kips	Load	NA plf

Discussion:

- Top and bottom flange widths the same
- Pan type roofing panels with fixed clips
- Vacuum chamber used to test
- Manometer with water (62.4 pcf) used to measure load
- Load deflection response was essentially linear
- Measurement of deck movement showed deck moved prior to failure
- Failure was in ridge purlin by lateral torsional buckling



Ridge Purlin



Eave Purlin

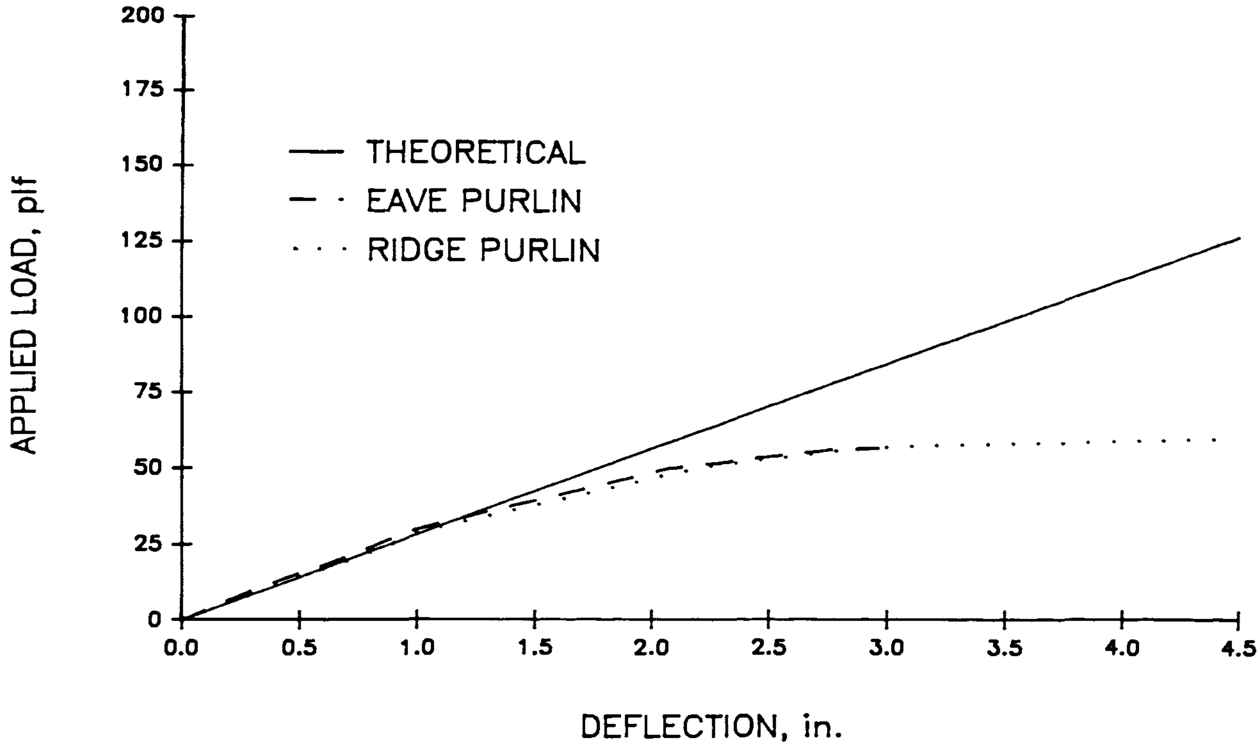
BASE TEST

TEST Z-R-P/F-1

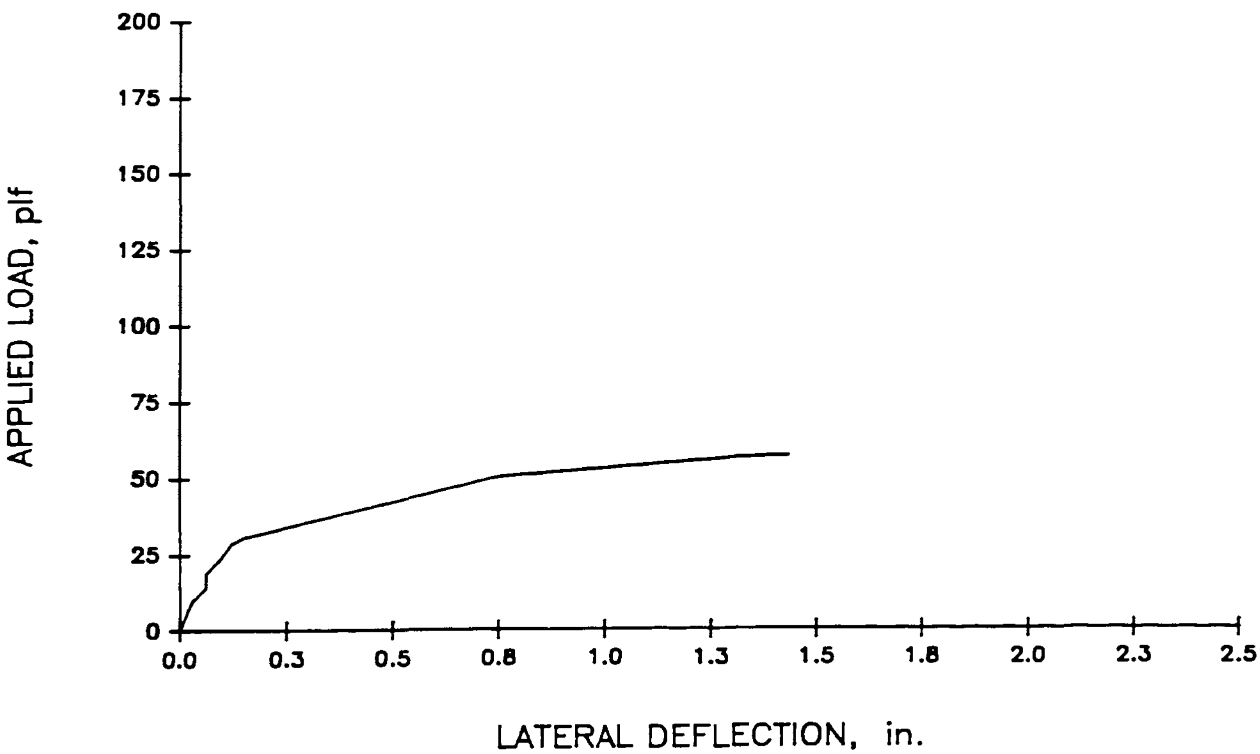
TEST Z-R-P/F-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span Ridge	Single Span Eave
TOP		
Vertical Lip		
Dimension (inches)	0.5625	0.5938
Lip Angle (degree)	47	46
Flange Width (inches)	2.5	2.4375
Radii (inches)		
Lip to Flange	0.2188	0.18
Flange to Web	0.25	0.25
BOTTOM		
Vertical Lip		
Dimension (inches)	0.6563	0.6875
Lip Angle (degree)	49	50
Flange Width (inches)	2.8125	2.8875
Radii (inches)		
Lip to Flange	0.2188	0.18
Flange to Web	0.25	0.25
Total Depth (inches)	7.936	7.936
Thickness (inches)	0.061	0.061
Gross Moment of Inertia ($inches^4$)	8.42	8.31
Material Yield Stress (ksi)	57.61	57.61
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	98.9	101.1



LOAD VS. DEFLECTION, TEST Z–R–P/F–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–P/F–1

Z-R-P/F-3

Test Summary

Test Date: February 17, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.061"	0.061"	0.061"
	0.061"	0.061"	0.061"
	0.061"	0.061"	0.061"
Sweep	0.5"	0.5"	0.5"
	0.5"	0.5"	0.5"
	0.5"	0.5"	0.5"

Parameters: Gravity Loading, Bracing @ Supports Only

Three Purlin Lines 5'-0" O.C. 2'-2" overhang

Purlins facing same direction

Failure Load: 103 plf Failure Mode: Lateral-Torsional Buckling

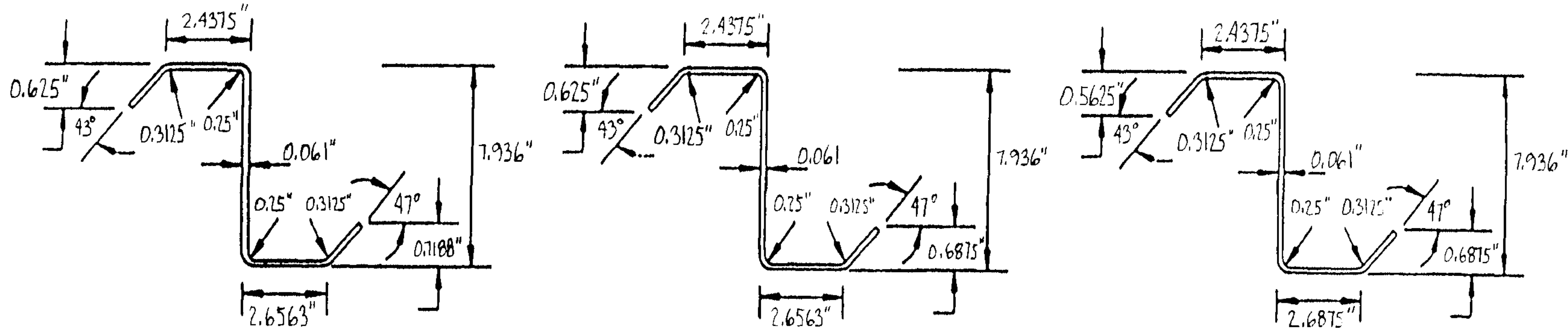
Predicted Failure Loads: (F_y = 59.93 ksi) assumed

Constrained Bending:	M_n 105.4	in-kips	Load	NA	plf
Base Test Method:	M(+) 51.2	in-kips	Load	110.7	plf
	M(-) 46.4	in-kips	Load	227.2	plf

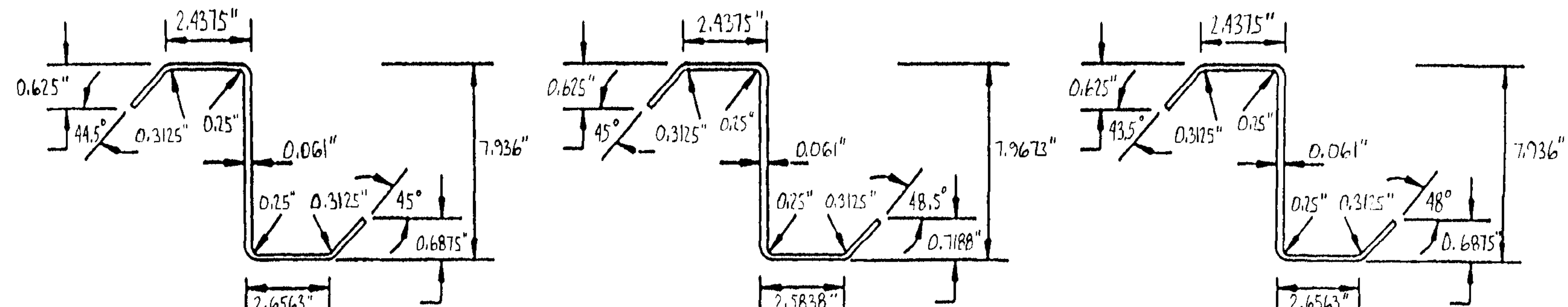
Discussion:

- Top and bottom flange widths the same
- Pan type roofing panel with fixed clips
- Vacuum chamber used to test
- Manometer (with water) used to measure load
- Load deflection response was essentially linear

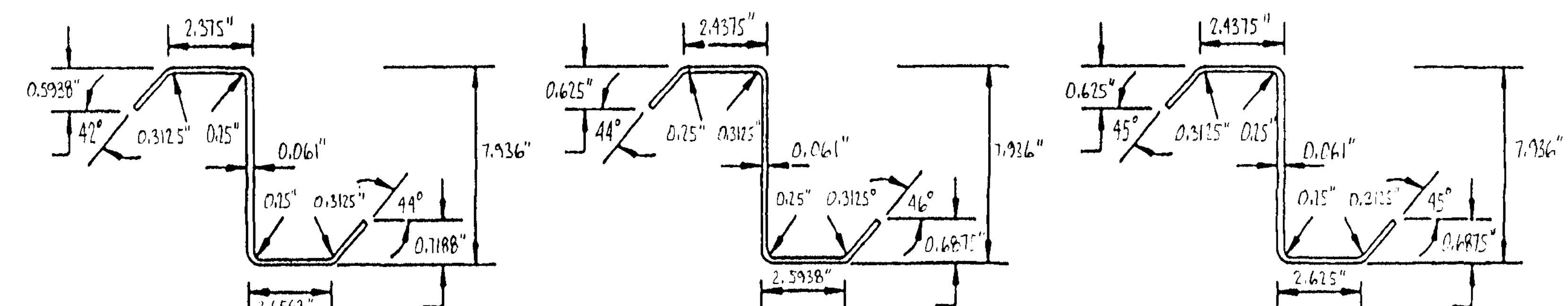
Note: Initial running of the test had to be stopped due to adverse weather conditions and loss of vacuum loading. However at that time the ridge and intermediate purlins of west span showed signs of eminent failure (load deflection curve had went horizontal). At time of test restart, east span had large amount of water and ice on deck (unknown at time) caused premature failure of east span. Since prior curves indicated that west span would have failed first (if not for additional water and ice load on east span), the failure load is based on the final load carried by the west span at time of initial test run. Ridge purlin failed.



WEST SPAN   Ridge Purlin   Middle Purlin   Eave Purlin



MIDDLE SPAN   Ridge Purlin   Middle Purlin   Eave Purlin



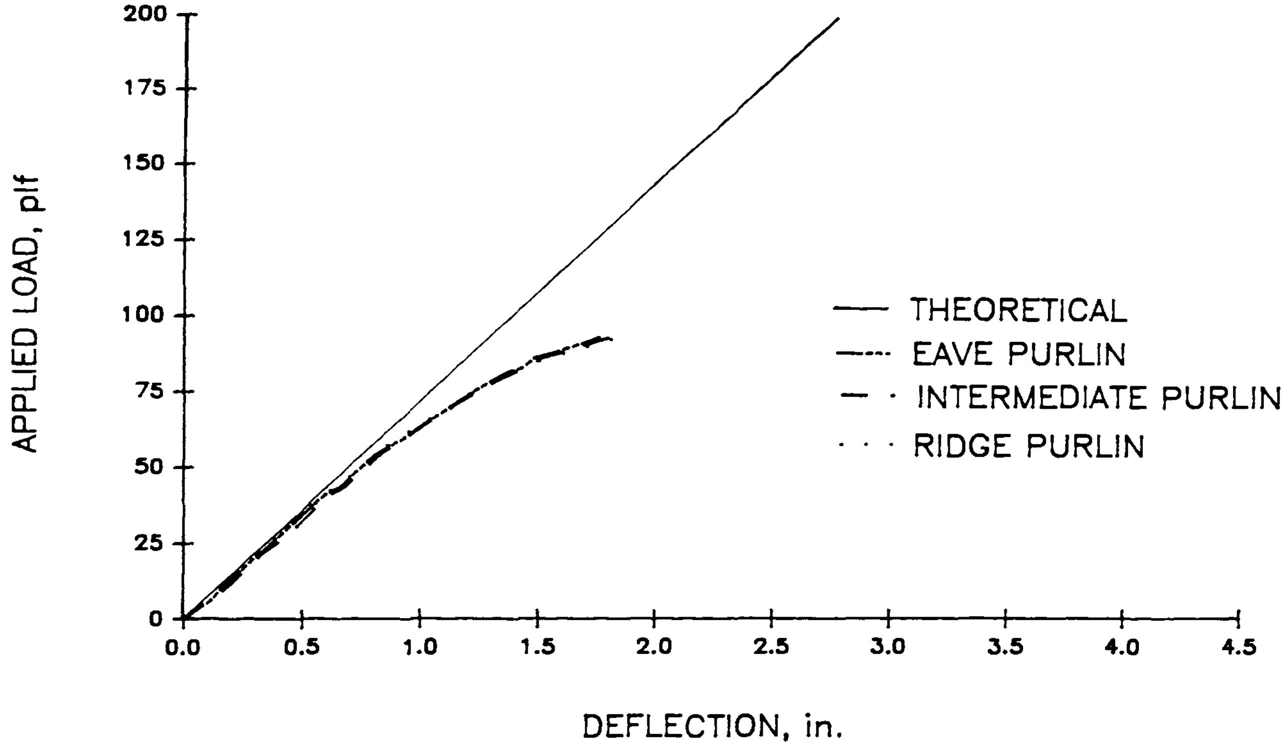
EAST SPAN   Ridge Purlin   Middle Purlin   Eave Purlin

TEST Z-R-P/F-3

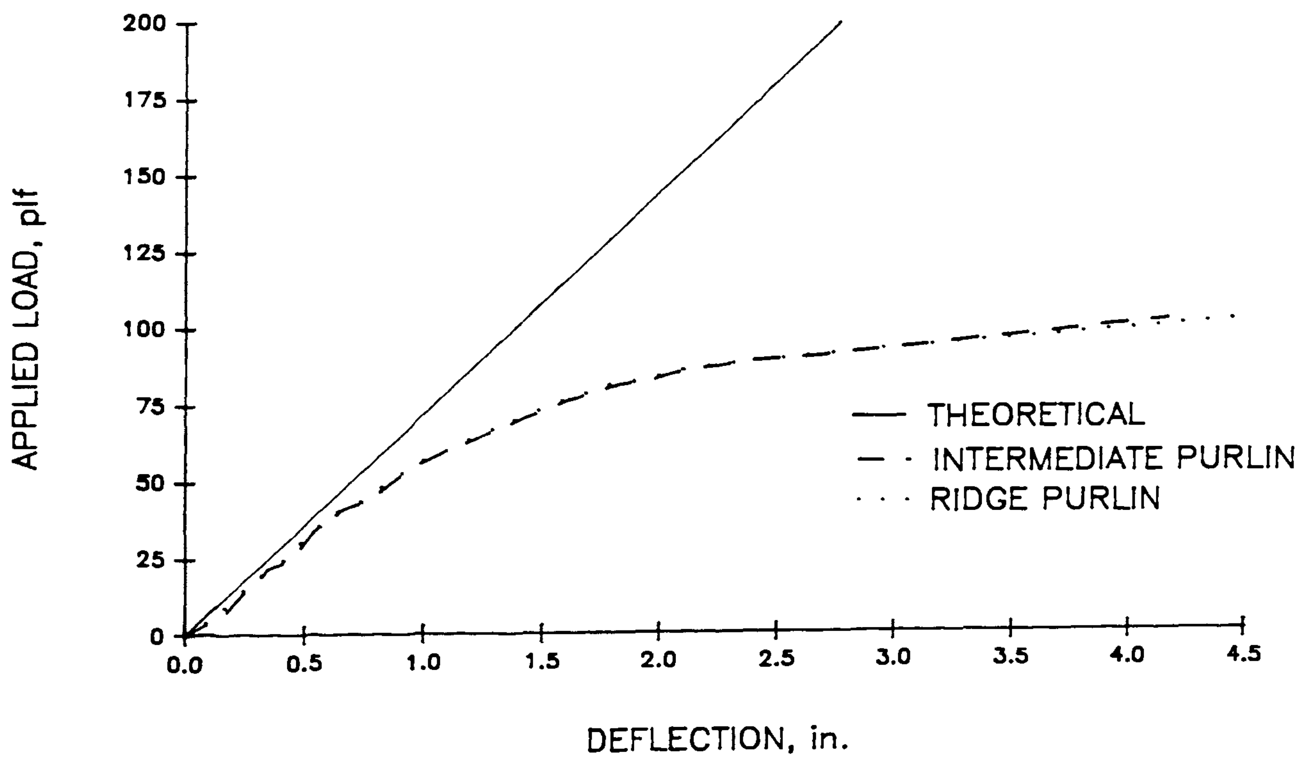
TEST Z-R-P/F-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	East Bay Ridge	East Bay Intermediate	East Bay Eave	Center Bay Ridge	Center Bay Intermediate	Center Bay Eave	West Bay Ridge	West Bay Intermediate	West Bay Eave
TOP									
Vertical Lip									
Dimension (inches)	0.5938	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625
Lip Angle (degree)	42.0	44.0	45.0	44.5	45.0	43.5	43.0	43.0	43.0
Flange Width (inches)	2.375	2.4375	2.4375	2.4375	2.4375	2.4375	2.4375	2.4375	2.4375
Radii (inches)									
Lip to Flange	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM									
Vertical Lip									
Dimension (inches)	0.7188	0.6875	0.6875	0.6875	0.7188	0.6875	0.7188	0.6875	0.6875
Lip Angle (degree)	44.0	46.0	45.0	45.0	48.5	48.0	47.0	45.0	45.0
Flange Width (inches)	2.6563	2.5938	2.625	2.6563	2.5983	2.6563	2.6563	2.6563	2.6875
Radii (inches)									
Lip to Flange	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125	0.3125
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	7.936	7.936	7.9360	7.936	71936	7.936	7.936	7.936	7.936
Thickness (inches)	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Gross Moment of Inertia ($inches^4$)	8.36	8.31	8.34	8.38	8.37	8.35	8.40	8.40	8.36
Material Yield Stress (ksi)	59.93	59.93	59.93	59.93	59.93	59.93	59.93	59.93	59.93
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	103.1	105.3	104.8	104.9	105.3	105.4	105.4	105.5	101.4



LOAD VS. DEFLECTION, TEST Z–R–P/F–3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z–R–P/F–3, WEST SPAN

Z-R-P/S-1
Test Summary

Test Date: April 4, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.074"	--	0.074"
Sweep	3/4"	N/A	1"

Parameters: Gravity Loading, bracing @ supports only

Two Purlin Lines 5'-0" O.C. 1'-0" overhang

Purlins facing same direction

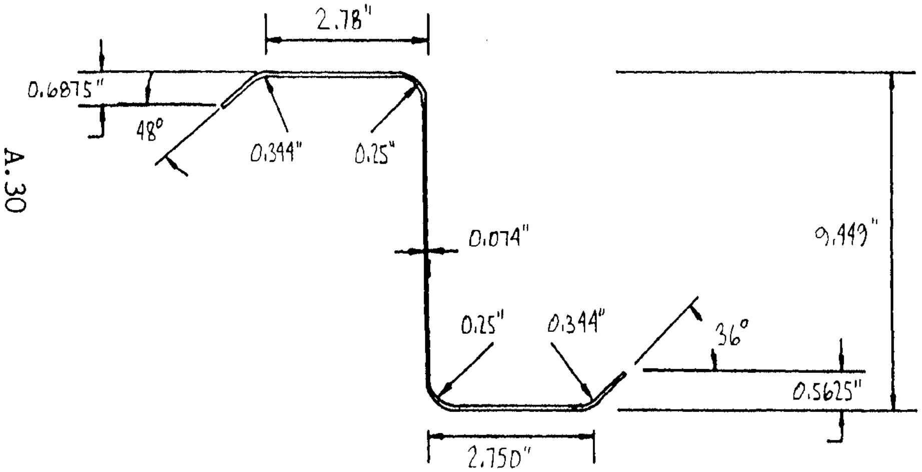
Failure Load: 80 plf Failure Mode: Lateral-Torsional Buckling

Predicted Failure Loads: (F_y = 67.45 ksi)

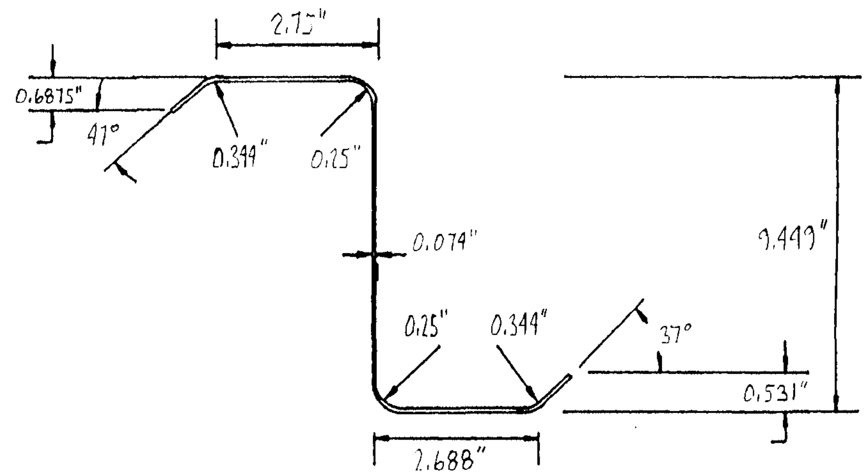
Constrained Bending:	M_n 179.2	in-kips	Load 191.2	plf
Base Test Method:	M(+) N/A	in-kips	Load N/A	plf
	M(-) N/A	in-kips	Load N/A	plf

Discussion:

- Pan type roofing panels with 2 piece siding clip
- Vacuum chamber used to test
- Manometer with water used to measure load
- Load deflection response was essentially linear
- Measurement of deck showed, deck moved prior to failure
- Failure was in eave purlin by lateral torsional buckling
- Due to flexibility of deck over two lines of purlins, weight of power seamer and person running it caused vertical deflection (swag) in deck
- Rib of deck was not only crimped but also bent over, due to flexibility of deck
- Believe state of deck increased friction on clips and caused failure load to be larger than would have been under normal conditions



Ridge Purlin



Eave Purlin

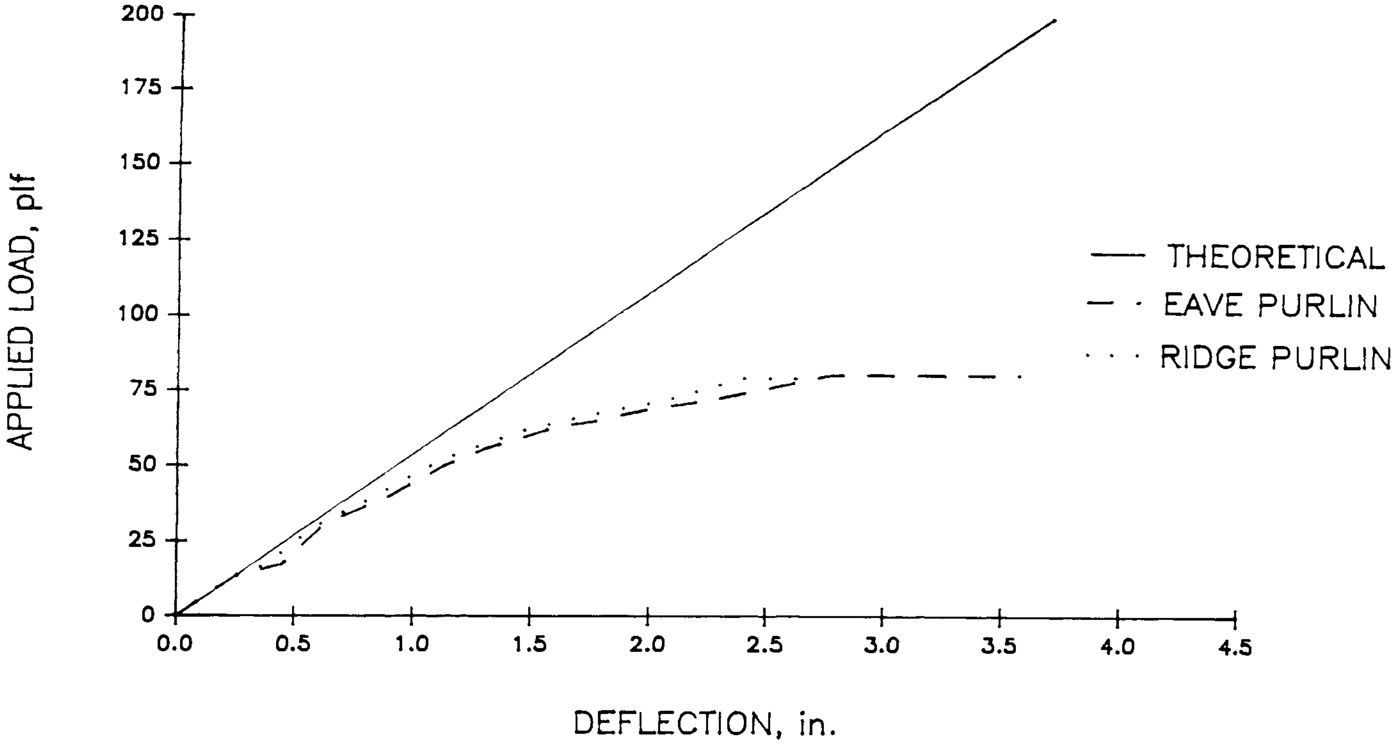
BASE TEST

TEST Z-R-P/S-1

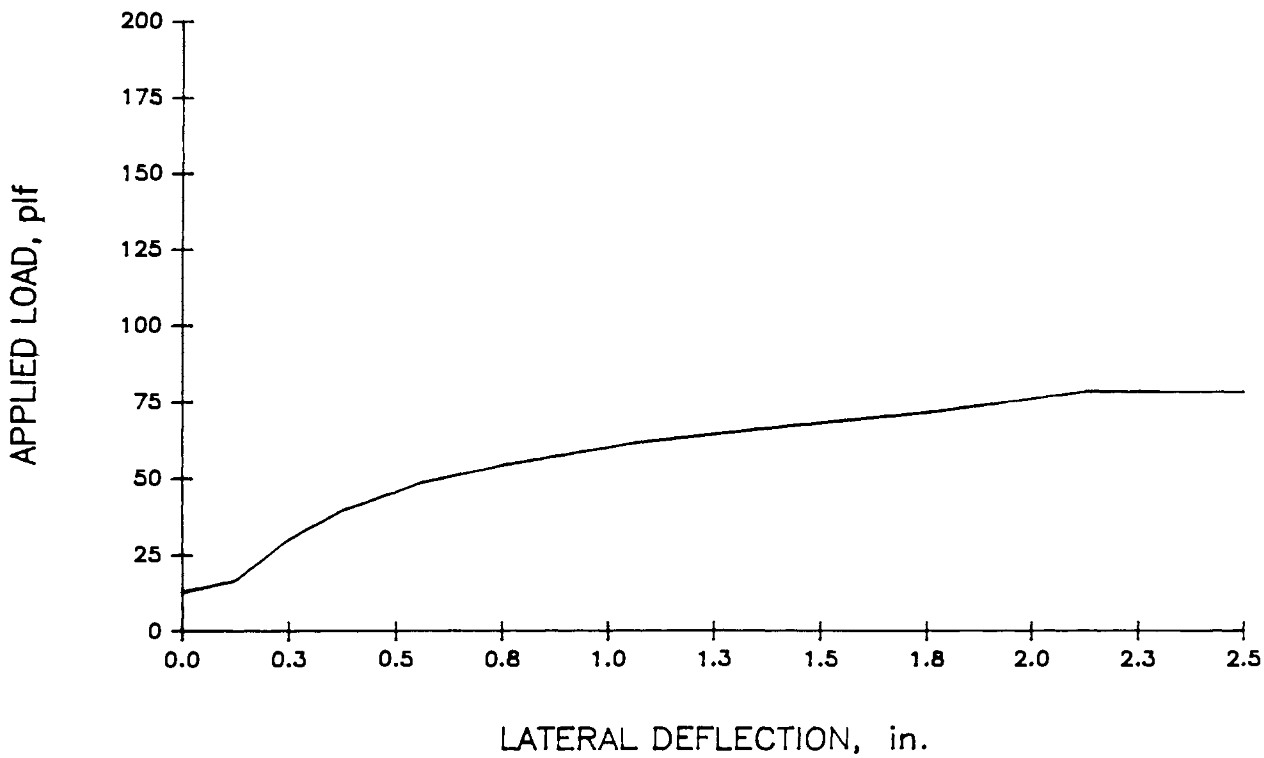
TEST Z-R-P/S-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.6875	0.6875
Lip Angle (degree)	48.0	47.0
Flange Width (inches)	2.78	2.75
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.25	0.25
BOTTOM		
Vertical Lip		
Dimension (inches)	0.5625	0.5310
Lip Angle (degree)	36.0	37.0
Flange Width (inches)	2.75	2.688
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.25	0.25
Total Depth (inches)	9.449	9.449
Thickness (inches)	0.074	0.074
Gross Moment of Inertia ($inches^4$)	15.98	15.75
Material Yield Stress (ksi)	67.45	67.45
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	178.2	191.2



LOAD VS. DEFLECTION, TEST Z–R–P/S–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–P/S–1

Z-R-P/S-3
Test Summary

Test Date: March 22, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.074"	0.074"	0.074"
	0.074"	0.074"	0.074"
	0.074"	0.074"	0.074"
Sweep	1 1/4"	1 1/4"	1"
	--	--	--
	1"	1"	1/2"

Parameters: Gravity Loading, Bracing @ Supports Only
Three Purlin Lines 5'-0" O.C. 2'-2" overhang
Purlins facing same direction

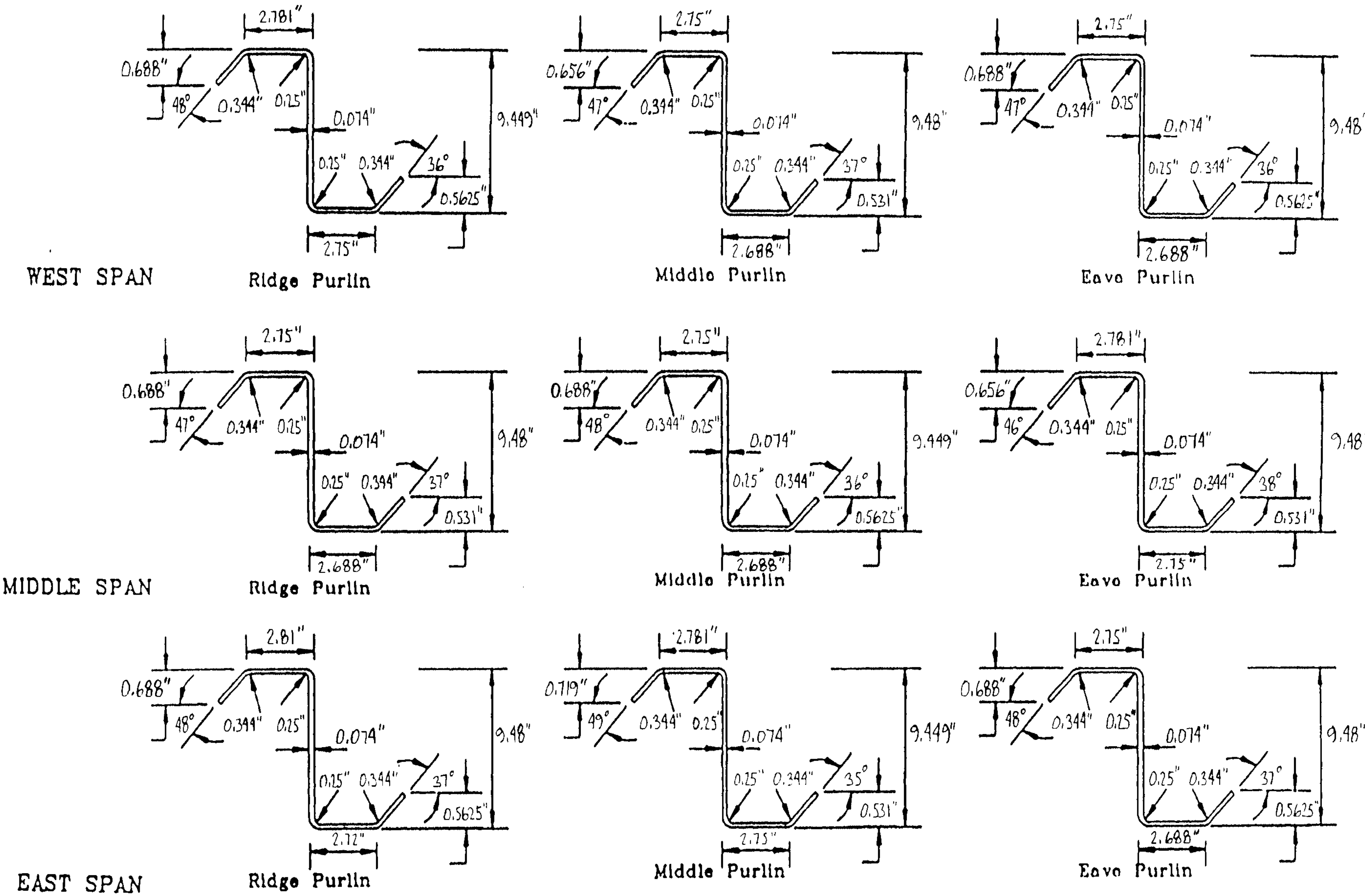
Failure Load: 128.22 plf   Failure Mode: Lateral-Torsional Buckling

Predicted Failure Loads: (F_y = 59.02 ksi)

Constrained Bending:	M_n 174.1	in-kips	Load	N/A plf
Base Test Method:	M(+) 51.0	in-kips	Load	147 plf
	M(-) 47.20	in-kips	Load	368.9 plf

Discussion:

- Pan type roofing panels with sliding clip
- Load deflection response curve was essentially linear
- Vacuum chamber was used to load system
- Failure was in the eave purlin of west span. Failed by lateral torsional buckling
- Clips were damaged by sliding action of deck
- Final position of clips indicated movement between purlins and deck prior to failure

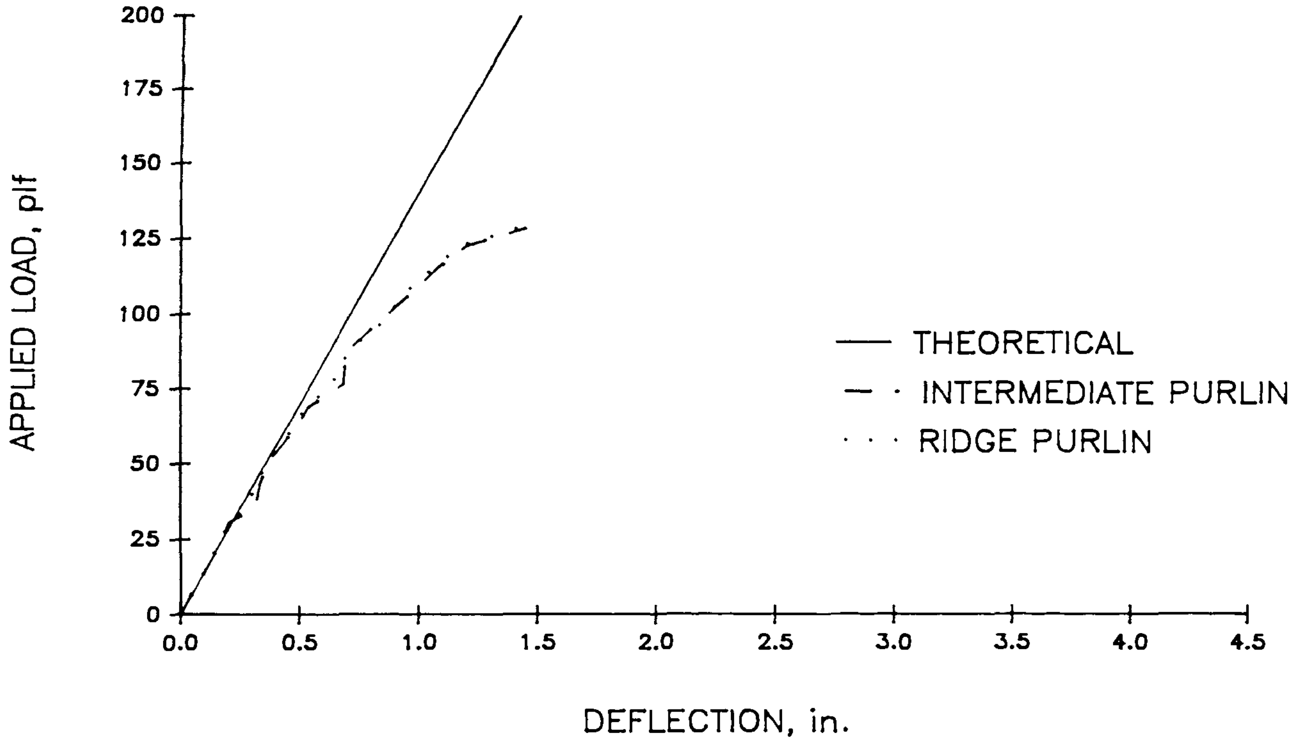

WEST SPAN
Ridge Purlin
2.781"
0.688"
48°
0.344"
0.25"
0.074"
9.449"
0.25"
0.344"
36°
0.5625"
2.75"
Middle Purlin
2.75"
0.656"
47°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
37°
0.531"
2.688"
Eave Purlin
2.75"
0.688"
47°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
36°
0.5625"
2.688"
MIDDLE SPAN
Ridge Purlin
2.75"
0.688"
47°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
37°
0.531"
2.688"
Middle Purlin
2.75"
0.688"
48°
0.344"
0.25"
0.074"
9.449"
0.25"
0.344"
36°
0.5625"
2.688"
Eave Purlin
2.781"
0.656"
46°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
38°
0.531"
2.75"
EAST SPAN
Ridge Purlin
2.81"
0.688"
48°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
37°
0.5625"
2.72"
Middle Purlin
2.781"
0.719"
49°
0.344"
0.25"
0.074"
9.449"
0.25"
0.344"
35°
0.531"
2.75"
Eave Purlin
2.75"
0.688"
48°
0.344"
0.25"
0.074"
9.48"
0.25"
0.344"
37°
0.5625"
2.688"

TEST Z-R-P/S-3

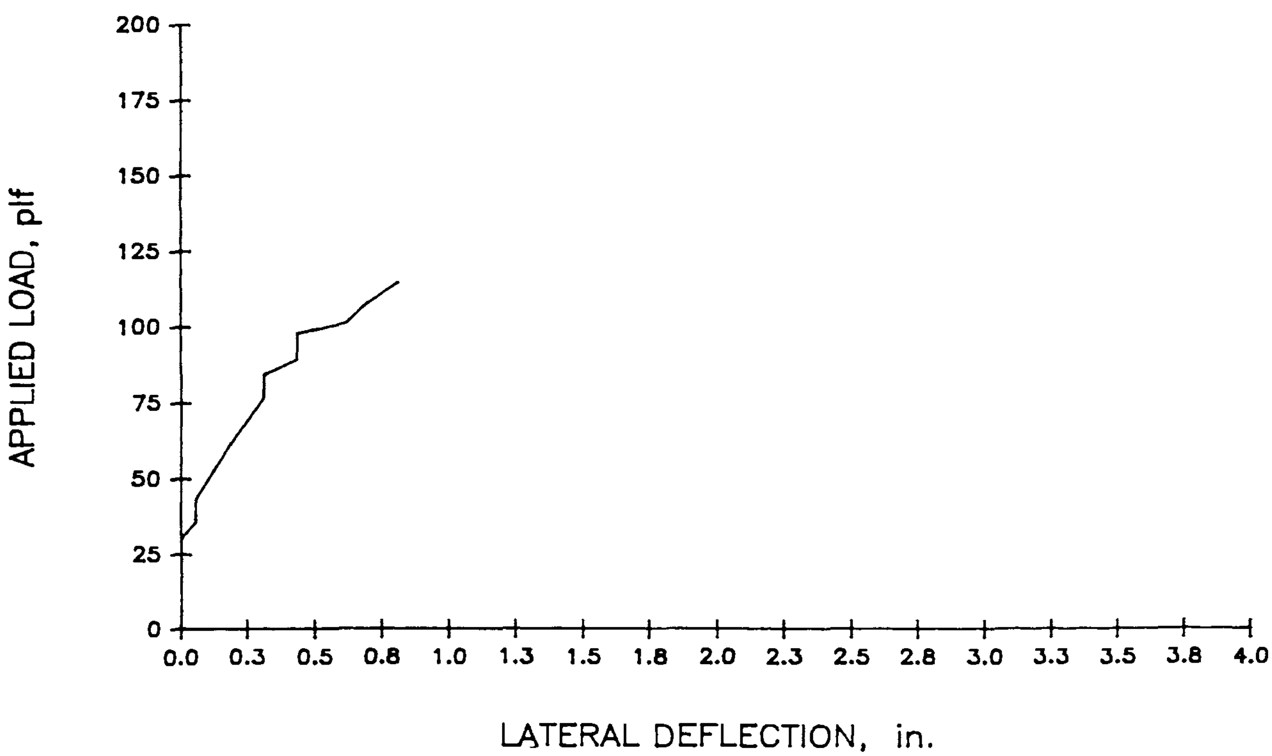
TEST Z-R-P/S-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

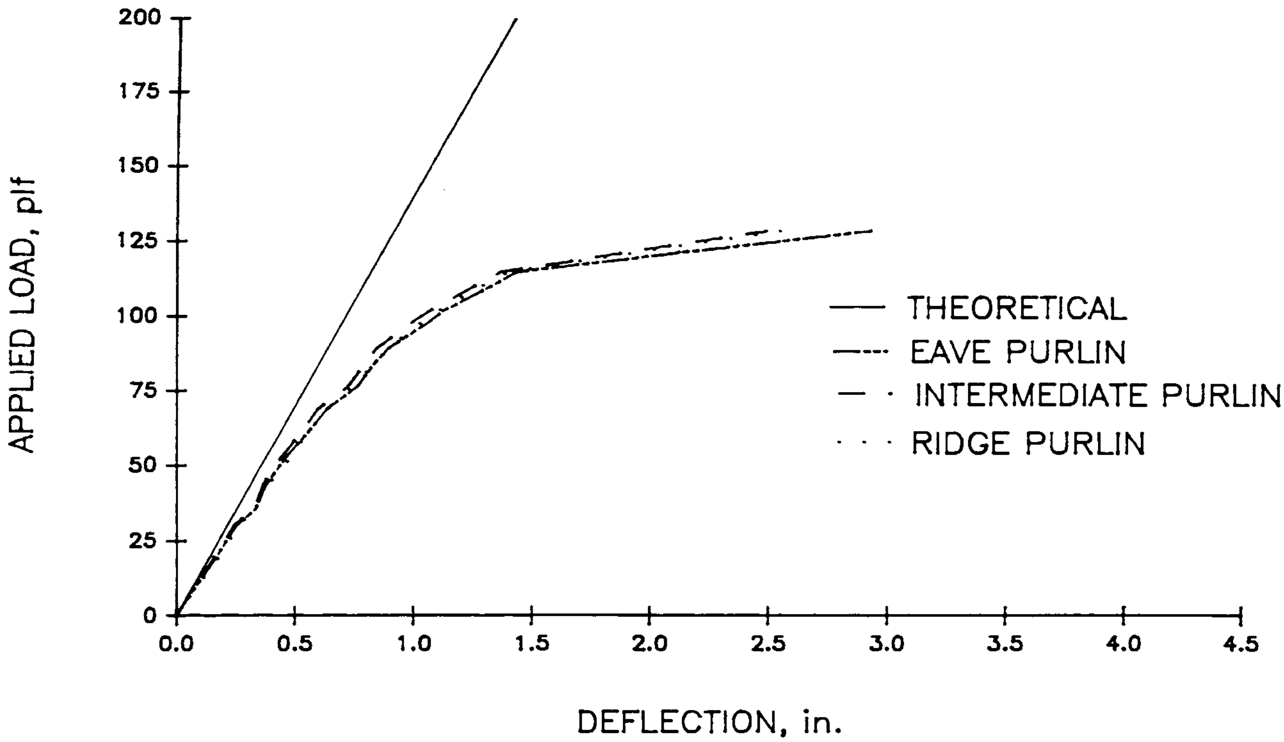
Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip									
Dimension (inches)	0.688	0.656	0.688	0.688	0.688	0.6560	0.688	0.714	0.688
Lip Angle (degree)	48.0	47.0	47.0	47.0	48.0	46.0	48.0	49.0	48.0
Flange Width (inches)	2.781	2.75	2.75	2.75	2.75	2.7810	2.81	2.781	2.750
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM									
Vertical Lip									
Dimension (inches)	0.5625	0.5310	0.5625	0.5310	0.5625	0.5310	0.5625	0.5310	0.5625
Lip Angle (degree)	36.0	37.0	36.0	37.0	36.0	38.0	37.0	35.0	37.0
Flange Width (inches)	2.75	2.688	2.688	2.688	2.688	2.750	2.72	2.750	2.688
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.3440	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	9.449	9.480	9.48	9.48	9.449	9.48	9.48	9.4490	9.48
Thickness (inches)	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
Gross Moment of Inertia ($inches^4$)	15.98	15.82	15.98	15.88	15.83	15.97	16.07	15.97	15.92
Material Yield Stress (ksi)	59.02	59.02	59.02	59.02	59.02	59.02	59.02	59.02	59.02
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	174.0	175.3	173.7	173.9	173.1	172.4	173.2	171.8	174.1



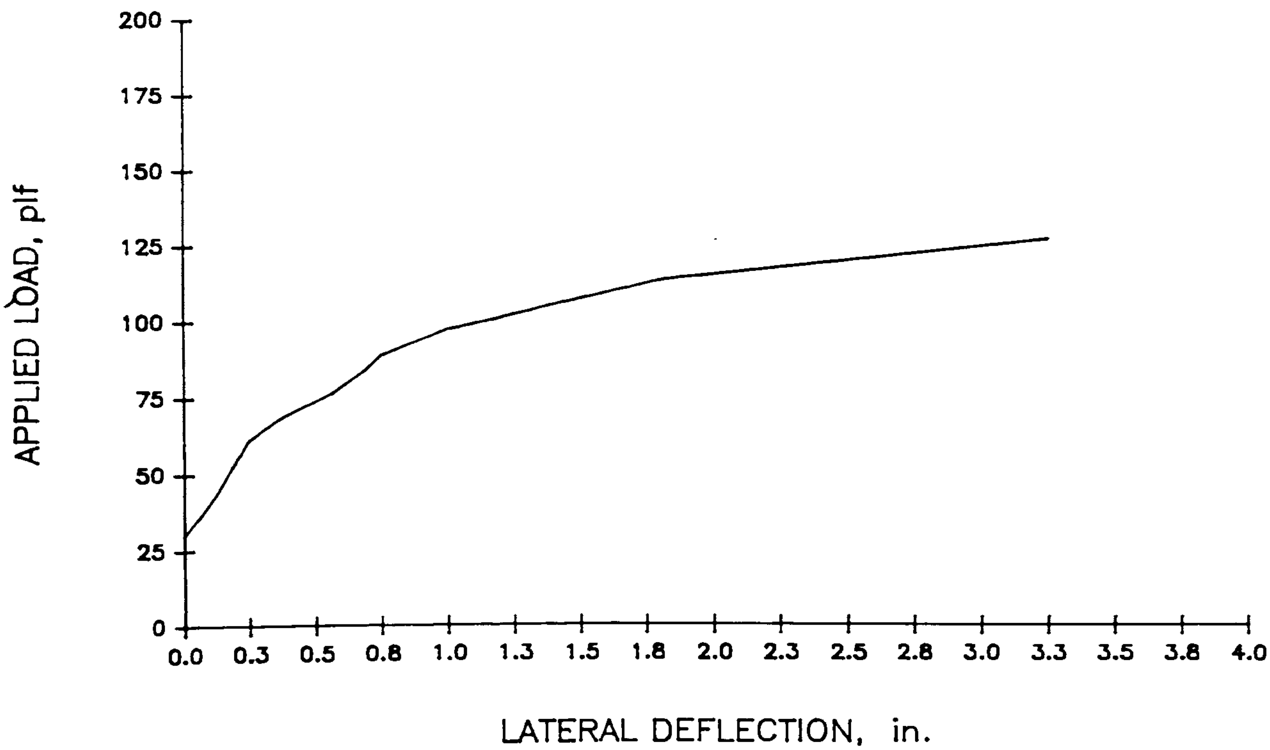
LOAD VS. DEFLECTION, TEST Z-R-P/S-3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z-R-P/S-3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z-R-P/S-3, WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z-R-P/S-3, WEST SPAN

C-R-P/S-1
Test Summary

Test Date: June 23, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.067"	--	0.067"
Sweep	negligible	--	negligible

Parameters: Gravity Loading, bracing @ supports only
Two Purlin Lines, 5'-0" O.C. 1'-0" overhang
Channels used, facing same direction

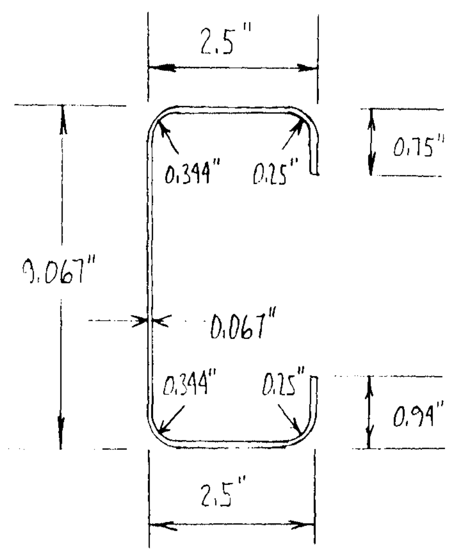
Failure Load: 119 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 66.72 ksi)

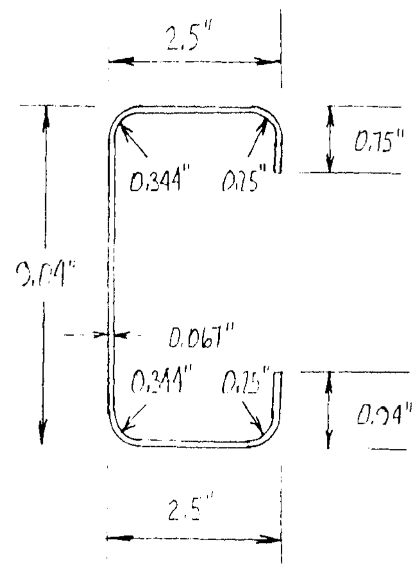
Constrained Bending:	M_n	140.9	in-kips	Load	150.3	plf
Base Test Method:	M(+)	NA	in-kips	Load	NA	plf
	M(-)	NA	in-kips	Load	NA	plf

Discussion:

- Pan type roofing panels with two piece sliding clip.
- Vacuum chamber used to load system.
- Load/deflection plot essentially linear.
- Load/deflection curve did not indicate failure prior to buckling.
- Failure was in ridge purlin by local buckling.
- Channel section was used.
- Total lateral movement was 5/16".



Ridge Purlin



Eave Purlin

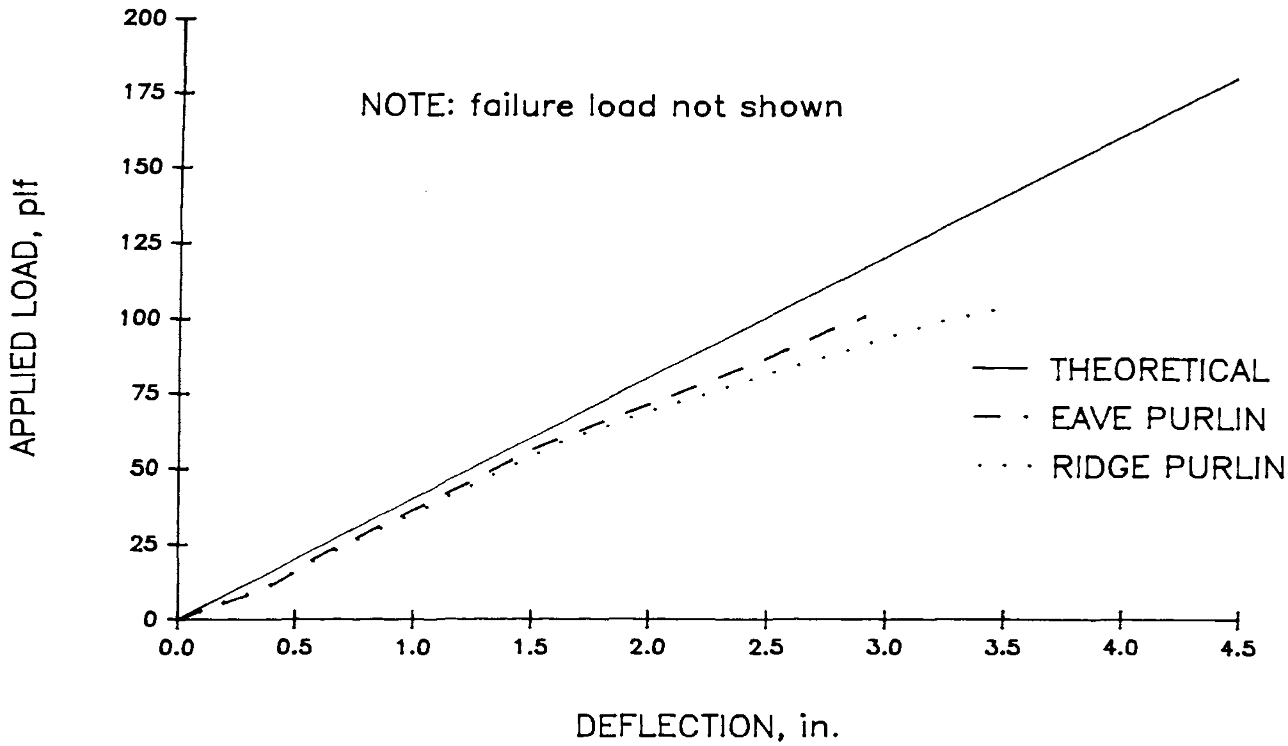
Base Test

TEST C-R-P/S-1

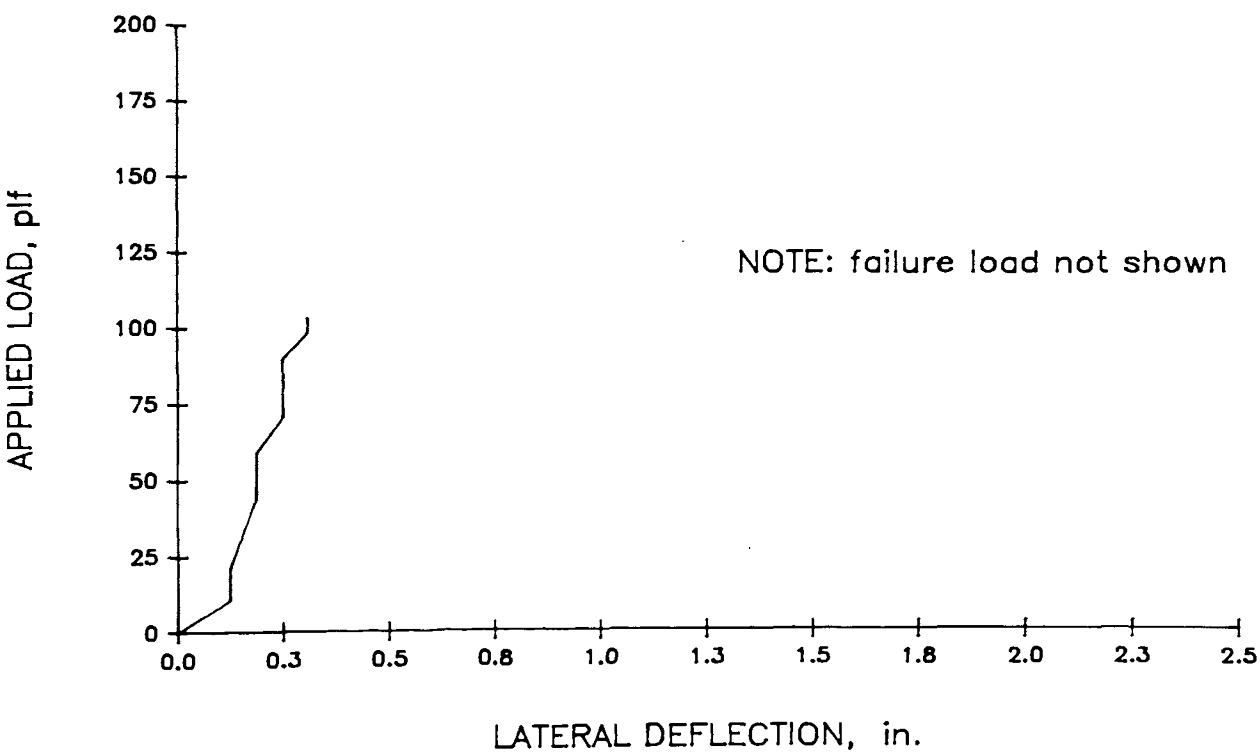
TEST C-R-P/S-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.75	0.75
Lip Angle (degree)	90.0	90.0
Flange Width (inches)	2.50	2.5
Radii (inches)		
Lip to Flange	0.25	0.25
Flange to Web	0.344	0.344
BOTTOM		
Vertical Lip		
Dimension (inches)	0.94	0.94
Lip Angle (degree)	90.0	90.0
Flange Width (inches)	2.50	2.50
Radii (inches)		
Lip to Flange	0.25	0.25
Flange to Web	0.344	0.344
Total Depth (inches)	9.067	9.04
Thickness (inches)	0.067	0.067
Gross Moment of Inertia (inches^4)	11.71	11.62
Material Yield Stress (ksi)	66.72	66.72
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	140.9	140.5



LOAD VS. DEFLECTION, TEST C–R–P/S–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST C–R–P/S–1

C-R-P/S-3
Test Summary

Test Date: June 13, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.067"	0.067"	0.067"
	0.067"	0.067"	0.067"
	0.067"	0.067"	0.067"
Sweep	negligible	negligible	negligible
	negligible	negligible	negligible
	negligible	negligible	negligible

Parameters: Gravity Loading, bracing @ supports only

Three Purlin Lines, 5'-0" O.C. 2'-2 1/4" overhang

Channels used, facing same direction in bay, flip-flopped from bay to bay.

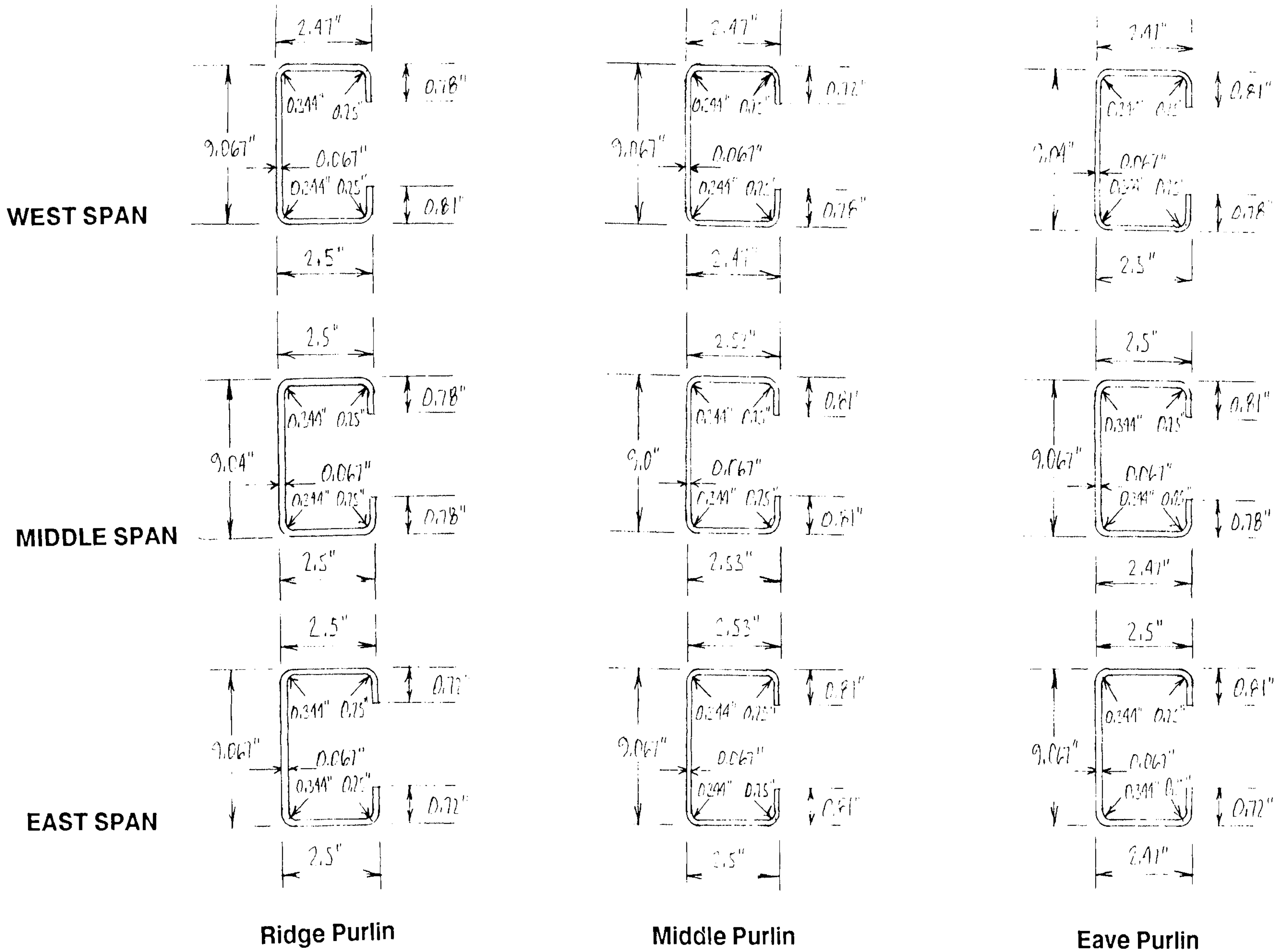
Failure Load: 217 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 66.00 ksi)

Constrained Bending:	M_n 143.2	in-kips	Load NA	plf
Base Test Method:	M(+) 50.40	in-kips	Load 221.4	plf
	M(-) 42.70	in-kips	Load 335.4	plf

Discussion:

- Pan type roof decking used w/ 2 piece clip.
- Loaded by vacuum chamber.
- Failure was in the ridge channel of the west span by local buckling. The intermediate purlin in same bay, also buckled after ridge buckled.
- Little lateral movement of deck/purlins was noted prior to failure.
- When near failure load, deck did come into contact with side of chamber. Is believed that this stiffened system may have introduced slight error (load may be slightly high) in failure load.

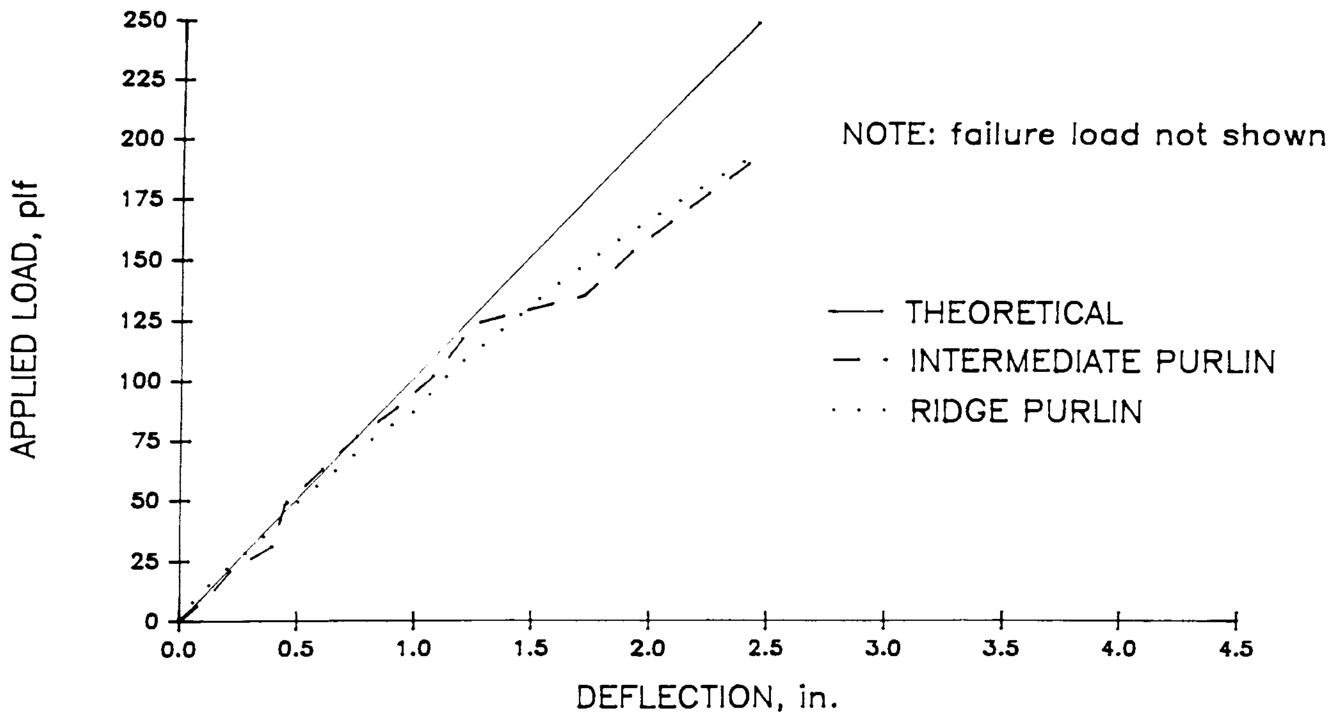

WEST SPAN
MIDDLE SPAN
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin

TEST C-R-P/S-3

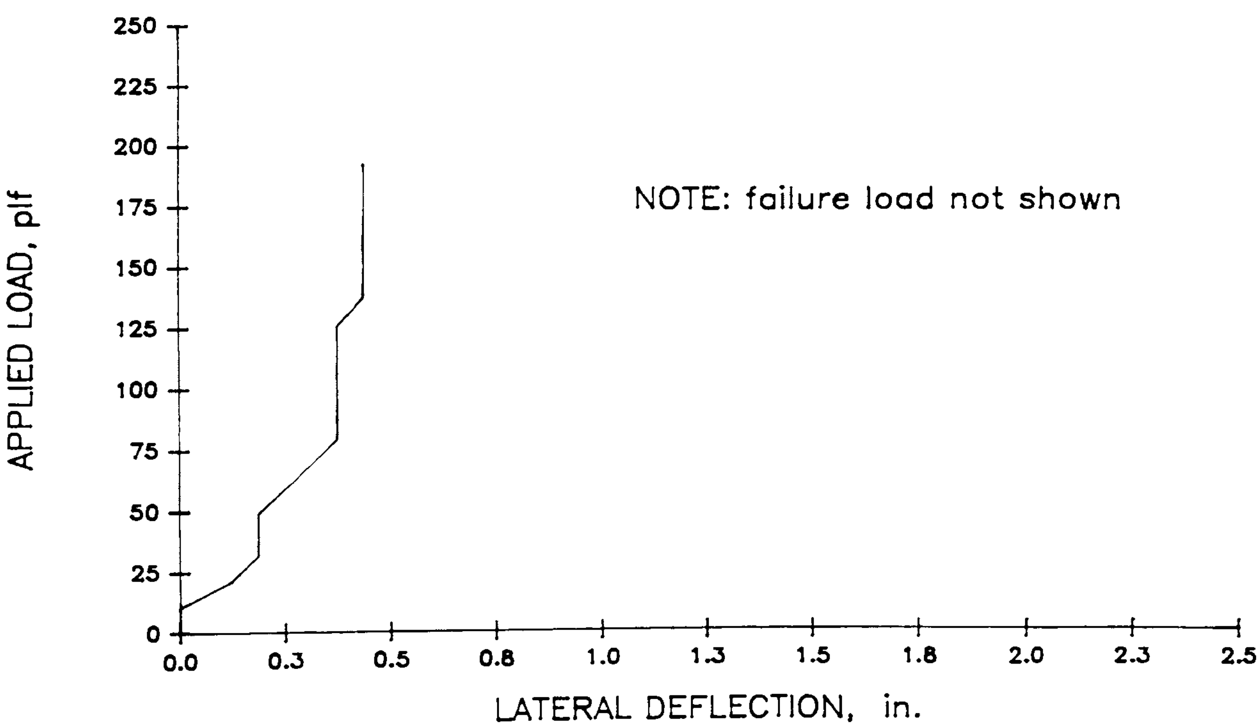
TEST C-R-P/S-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip									
Dimension (inches)	0.72	0.81	0.81	0.78	0.81	0.81	0.78	0.72	0.78
Lip Angle (degree)	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Flange Width (inches)	2.50	2.53	2.50	2.50	2.53	2.50	2.47	2.47	2.47
Radii (inches)									
Lip to Flange	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flange to Web	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
BOTTOM									
Vertical Lip Dimension (inches)	0.72	0.81	0.72	0.78	0.81	0.78	0.81	0.78	0.78
Lip Angle (degree)	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Flange Width (inches)	2.50	2.50	2.47	2.50	2.53	2.47	2.50	2.47	2.50
Radii (inches)									
Lip to Flange	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flange to Web	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Total Depth (inches)	9.067	9.067	9.067	9.040	9.00	9.067	9.067	9.067	9.04
Thickness (inches)	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Gross Moment of Inertia (inches^4)	11.48	11.69	11.52	11.51	11.52	11.58	11.58	11.45	11.47
Material Yield Stress (ksi)	66.00	66.00	66.00	66.00	66.00	66.00	66.00	66.00	66.00
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	139.1	144.5	145.4	142.5	143.4	145.1	143.2	139.2	143.2



LOAD VS. DEFLECTION, TEST C–R–P/S–3, EAST SPAN



LOAD VS LATERAL PANEL DEFLECTION, TEST C–R–P/S–3, EAST SPAN

Z-R-R/F-1 (0)
Test Summary

Test Date: June 26, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.061"	--	0.061"
Sweep	0.25"	--	0.00"

Parameters: Gravity Loading, bracing at supports only

Two Purlin Lines, 4'-10" O.C. 0'-13" overhang

Purlins opposing each other

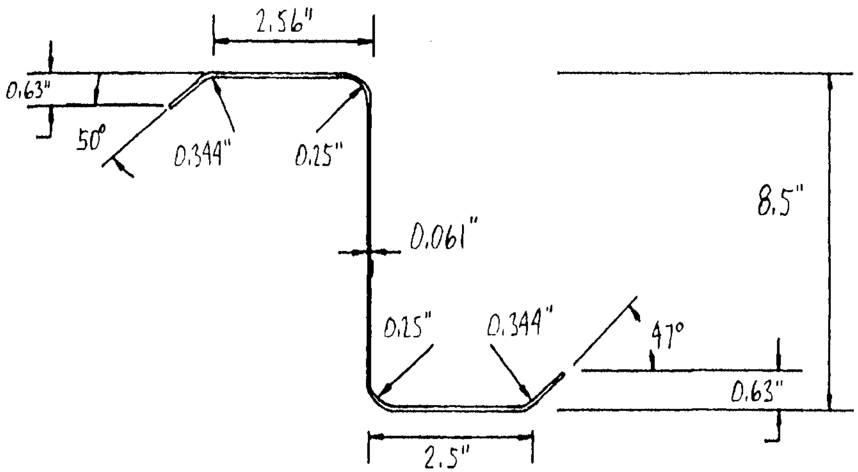
Failure Load: 87.0 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 66.15 ksi)

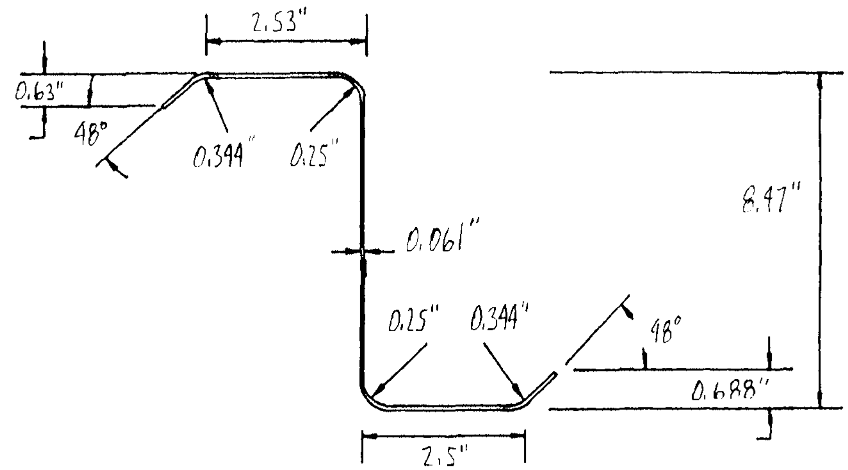
Constrained Bending:	M_n	118.2	in-kips	Load 126.1	plf
Base Test Method:	M(+)	NA	in-kips	Load NA	plf
	M(-)	NA	in-kips	Load NA	plf

Discussion:

- Rib type roofing panels with one piece clips.
- Vacuum chamber used to load system.
- Load deflection plot basically linear.
- Failure was in the ridge purlin by local buckling.
- Purlin reached 81% of theoretical capacity.
- Lateral movement was essentially zero (1/16" total).
- Load deflection curve did not flatten out prior to buckling.



Ridge Purlin



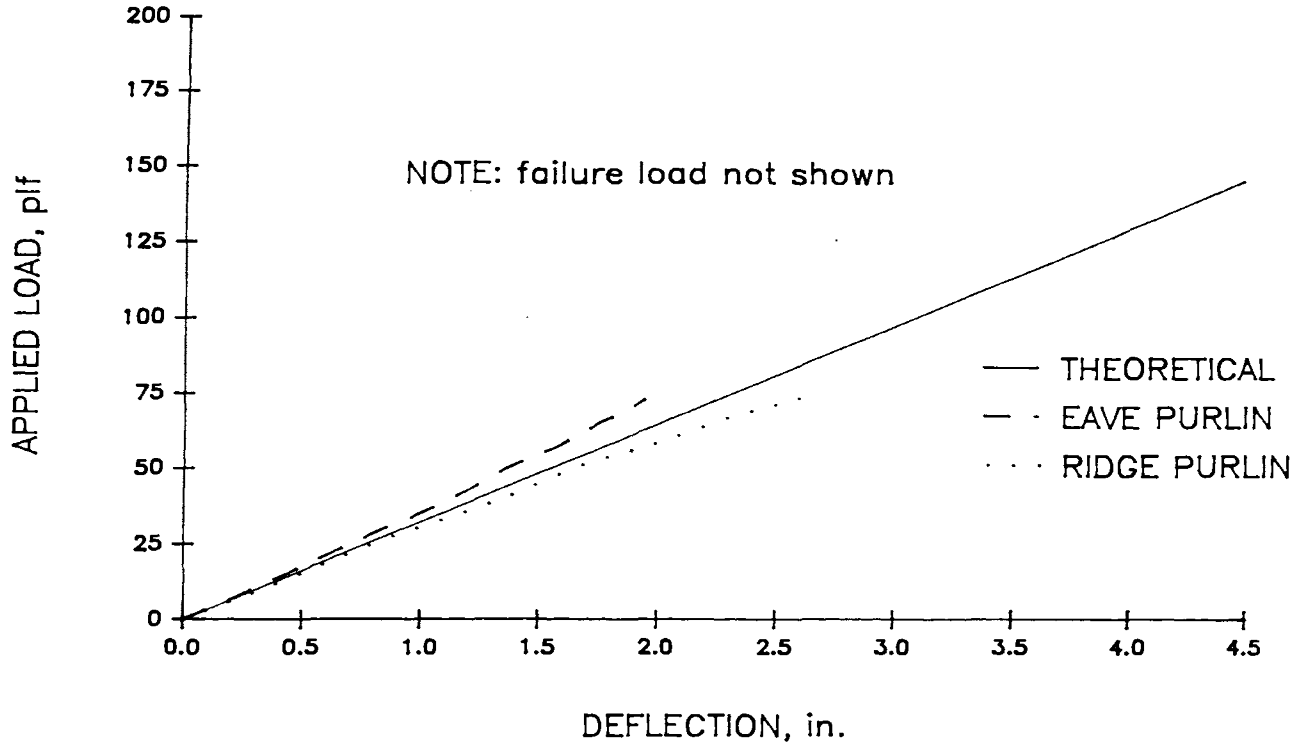
Eave Purlin

BASE TEST

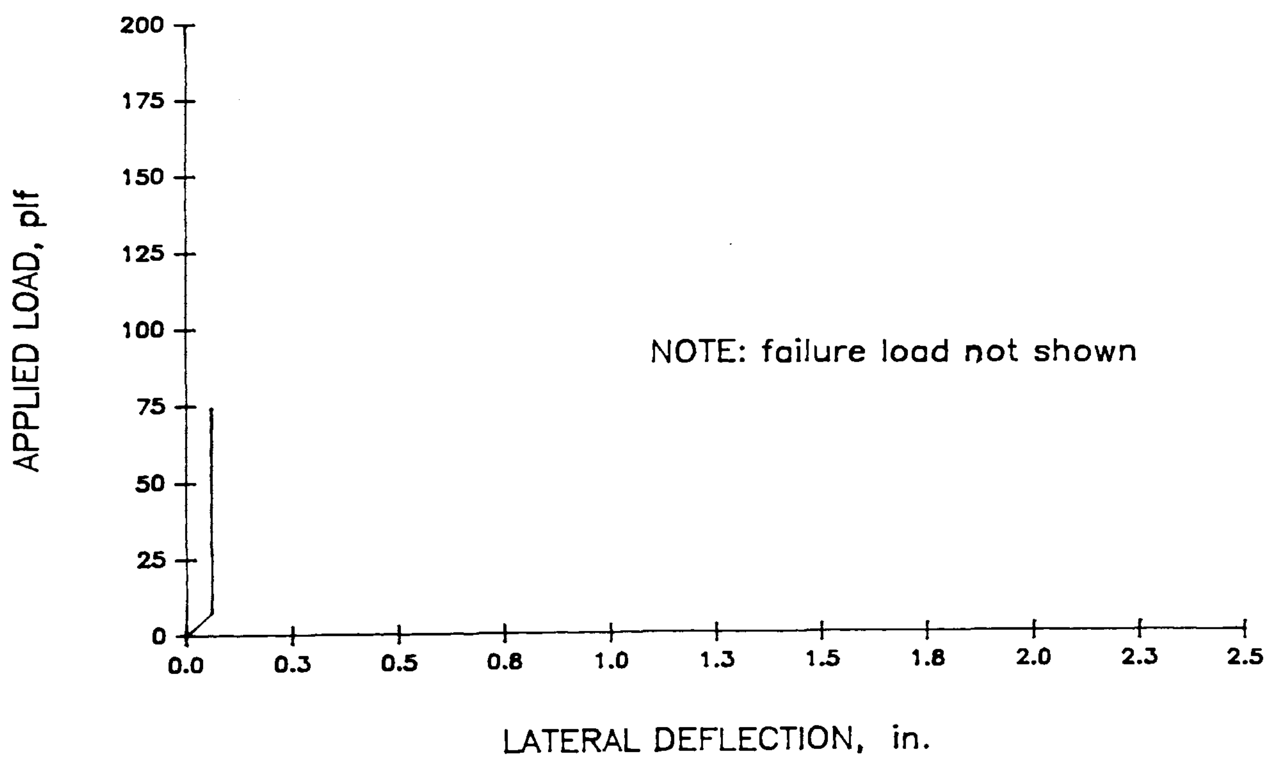
TEST Z-R-R/F-1 (0)

TEST Z-R-R/F-1 (0)
MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.63	0.63
Lip Angle (degree)	50.0	48.0
Flange Width (inches)	2.56	2.53
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.250	0.250
BOTTOM		
Vertical Lip		
Dimension (inches)	0.63	0.688
Lip Angle (degree)	47.0	48.0
Flange Width (inches)	2.50	2.50
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.25	0.25
Total Depth (inches)	8.50	8.47
Thickness (inches)	0.061	0.061
Gross Moment of Inertia ($inches^4$)	9.64	9.61
Material Yield Stress (ksi)	66.15	66.15
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	118.2	118.1



LOAD VS. DEFLECTION, TEST Z–R–R/F–1 (O)



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/F–1 (O)

Z-R-R/F-3 (0)
Test Summary

Test Date: June 19, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.061"	0.061"	0.061"
	0.061"	0.061"	0.061"
	0.061"	0.061"	0.061"
Sweep	negligible	negligible	negligible
	negligible	negligible	negligible
	negligible	negligible	negligible

Parameters: Gravity Loading, bracing @ supports only

Four Purlin Lines, 3'-7" O.C. 1'-9 3/4" overhang

Purlins opposing each other

Failure Load: 158 plf Failure Mode: Local Buckling

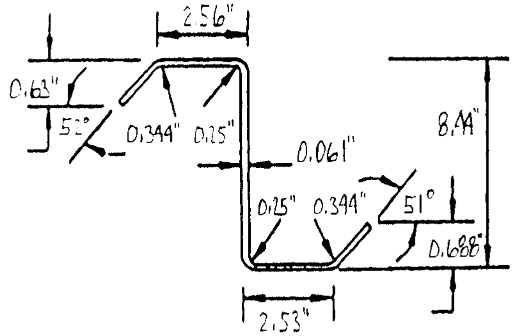
Predicted Failure Loads: (F_y = 61.57 ksi)

Constrained Bending:	M_n	118.1 in-kips	Load	NA plf
Base Test Method:	M(+)	51.2 in-kips	Load	159.3 plf
	M(-)	50.9 in-kips	Load	232.0 plf

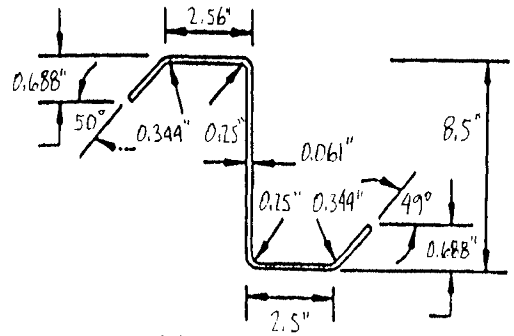
Discussion:

- Rib type roof panels with one piece clip.
- Vacuum chamber was used to load the system.
- Failure was in the ridge and two intermediate purlins of east bay. Failure mode was local buckling. Ridge purlin failed first and was followed by two intermediate purlins.
- Signs of buckling were also present at interior rafter of east bay on ridge and intermediate purlins.
- Purlins reached 74% of theoretical capacity at failure.

WEST SPAN

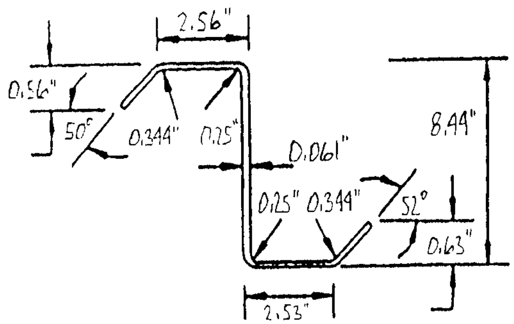


Ridge Purlin

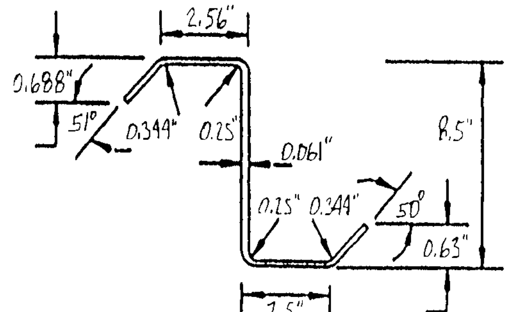


Middle Purlin

MIDDLE SPAN

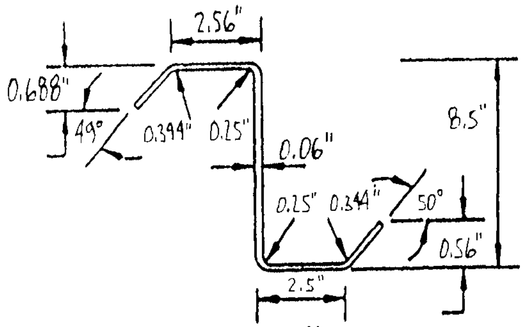


Ridge Purlin

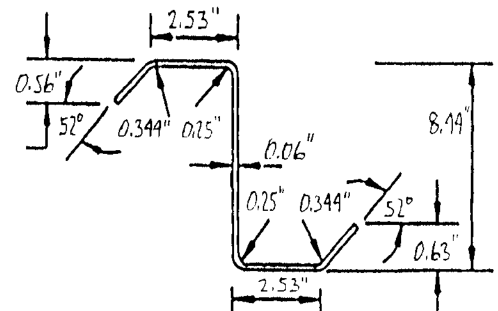


Middle Purlin

EAST SPAN



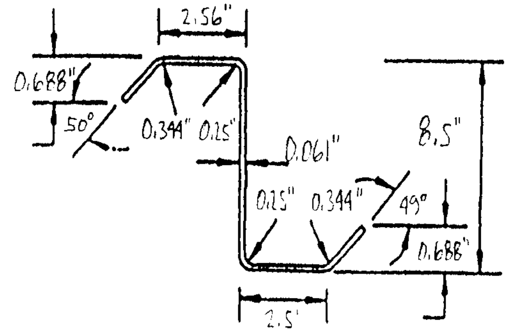
Ridge Purlin



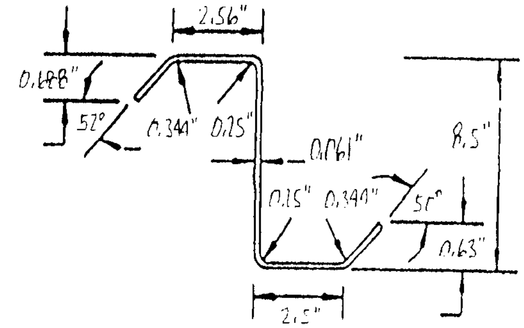
Middle Purlin

TEST Z-R-R/F-3 (0)

WEST SPAN

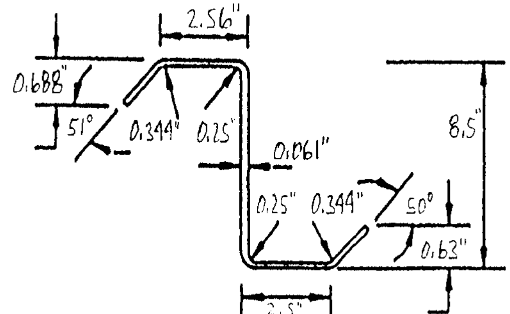


Middle Purlin

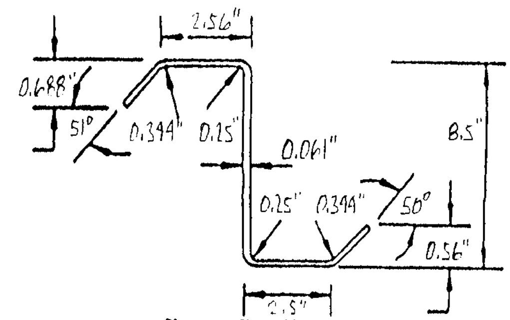


Eave Purlin

MIDDLE SPAN

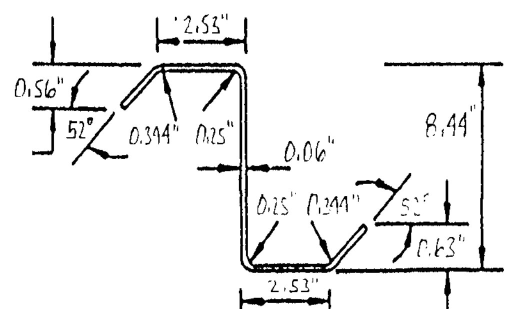


Middle Purlin

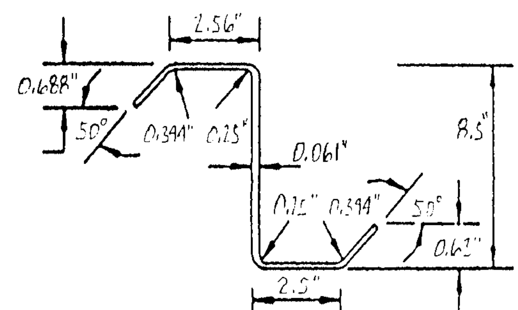


Eave Purlin

EAST SPAN



Middle Purlin



Eave Purlin

TEST Z-R-R/F-3 (0)

TEST Z-R-R/F-3 (0)

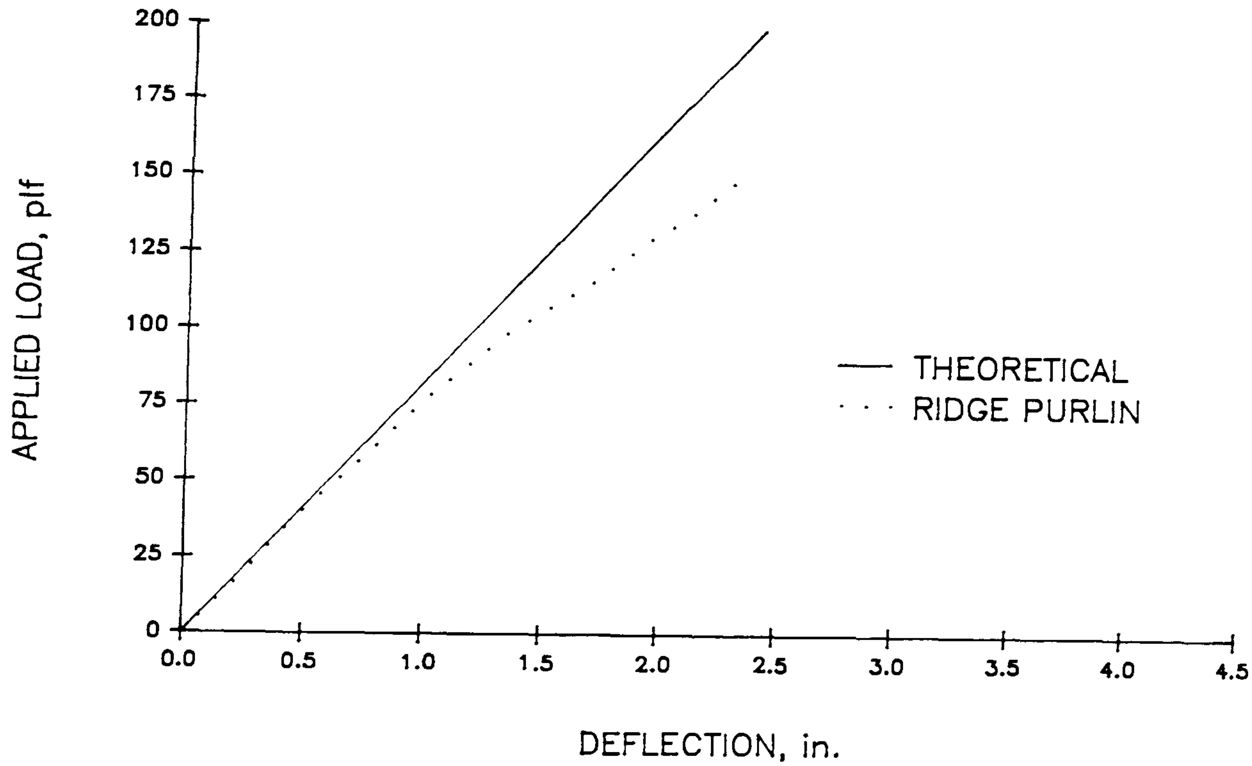
MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	East Bay				Center Bay			
	Ridge	Intermediate	Intermediate	Eave	Ridge	Intermediate	Intermediate	Eave
TOP								
Vertical Lip								
Dimension (inches)	0.688	0.56	0.56	0.688	0.56	0.688	0.688	0.688
Lip Angle (degree)	49.0	52.0	52.0	50.0	50.0	51.0	51.0	51.0
Flange Width (inches)	2.56	2.53	2.53	2.56	2.56	2.56	2.56	2.56
Radii (inches)								
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM								
Vertical Lip								
Dimension (inches)	0.56	0.63	0.63	0.63	0.63	0.63	0.63	0.56
Lip Angle (degree)	50.0	52.0	52.0	50.0	52.0	50.0	50.0	50.0
Flange Width (inches)	2.50	2.53	2.53	2.50	2.53	2.50	2.50	2.50
Radii (inches)								
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	8.50	8.50	8.50	8.50	8.44	8.50	8.50	8.50
Thickness (inches)	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Gross Moment of Inertia (inches^4)	9.60	9.48	9.48	9.66	9.38	9.65	9.65	9.57
Material Yield Stress (ksi)	61.57	61.57	61.57	61.57	61.57	61.57	61.57	61.57
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	118.1	108.7	108.7	117.4	108.7	117.0	117.0	117.3

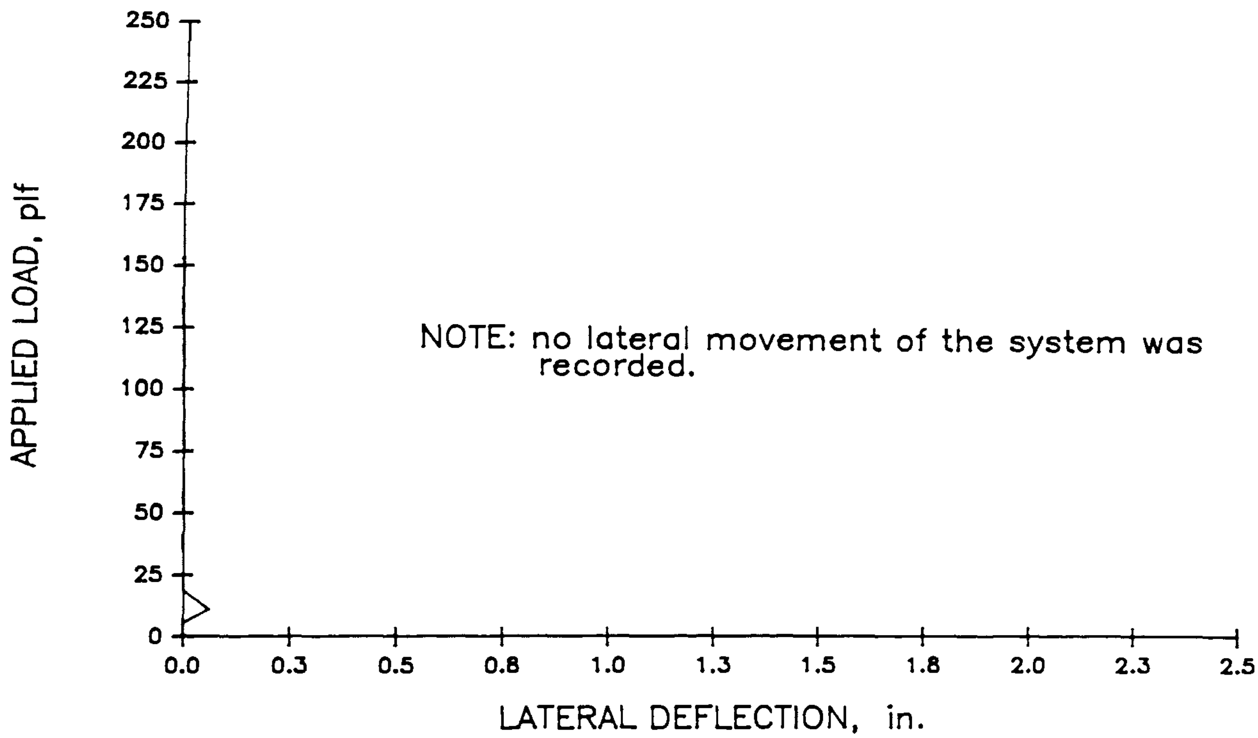
TEST Z-R-R/F-3 (0)

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

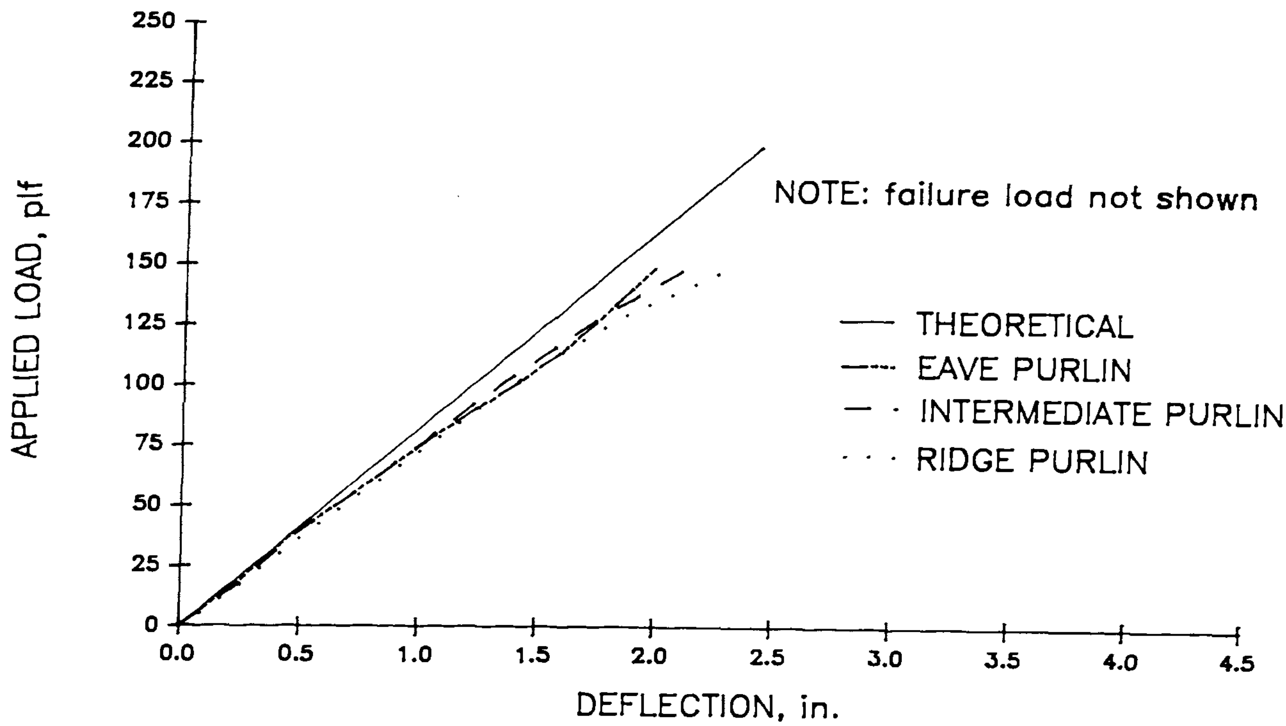
Parameter	West Bay			
	Ridge	Intermediate	Intermediate	Eave
TOP				
Vertical Lip				
Dimension (inches)	0.63	0.688	0.688	0.688
Lip Angle (degree)	52.0	50.0	50.0	52.0
Flange Width (inches)	2.56	2.56	2.56	2.56
Radii (inches)				
Lip to Flange	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25
BOTTOM				
Vertical Lip				
Dimension (inches)	0.688	0.688	0.688	0.630
Lip Angle (degree)	51.0	49.0	49.0	50.0
Flange Width (inches)	2.53	2.50	2.50	2.50
Radii (inches)				
Lip to Flange	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25
Total Depth (inches)	8.44	8.50	8.50	8.50
Thickness (inches)	0.061	0.061	0.061	0.061
Gross Moment of Inertia (inches^4)	9.50	9.74	9.74	9.64
Material Yield Stress (ksi)	61.57	61.57	61.57	61.57
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	112.0	117.1	117.1	116.6



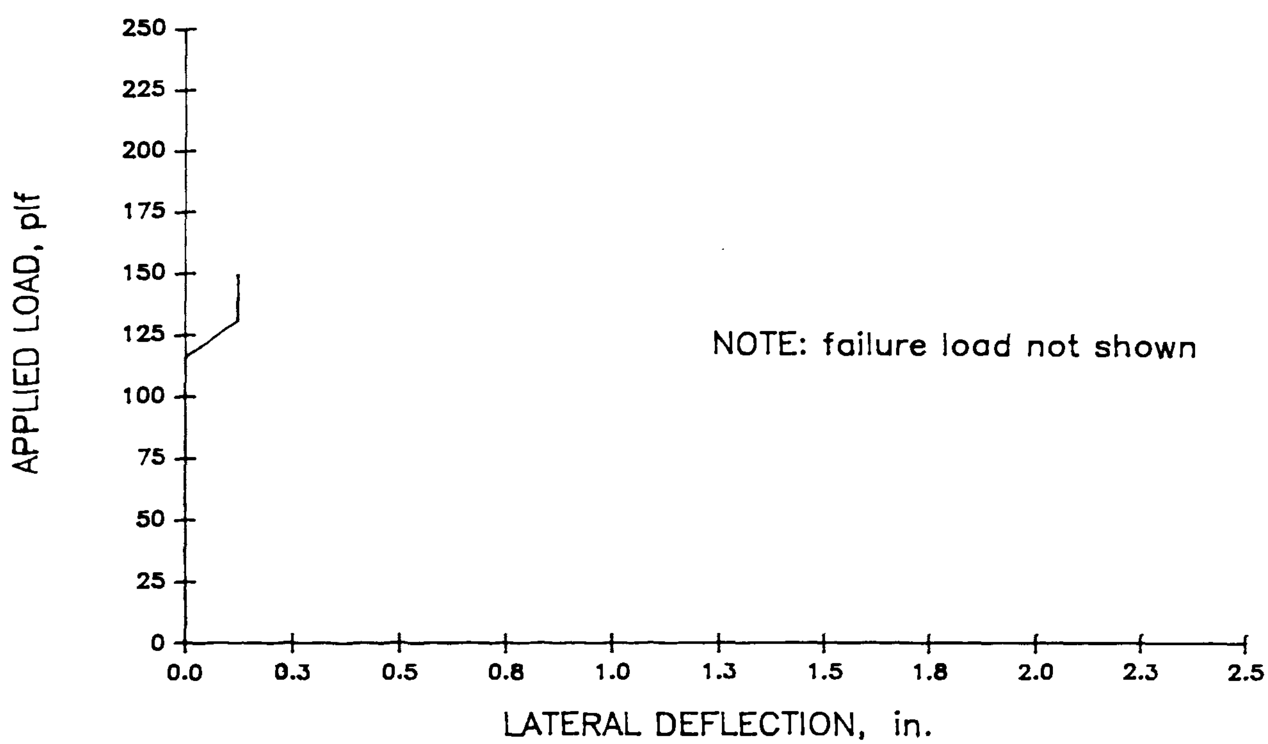
LOAD VS. DEFLECTION, TEST Z–R–R/F–3 (O), EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/F–3 (O), EAST SPAN



LOAD VS. DEFLECTION, TEST Z–R–R/F–3 (O), WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–R–R/F–3 (O), WEST SPAN

APPENDIX B

THIRD POINT BRACED TEST RESULTS

Z-T-PF-1

Test Summary

Test Date: April 25, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.078"	--	0.078"
Sweep	1/4"	--	1/4"

Parameters: Gravity Loading, 3rd point bracing

Two Purlin Lines 5'-0" O.C. 1'-0" overhang

Purlins facing same direction

Failure Load: 126 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 53.59 ksi)

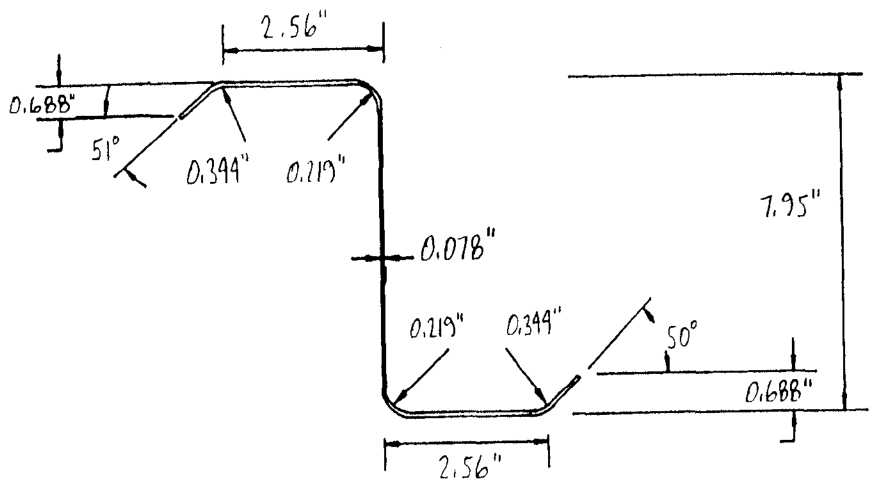
Constrained Bending: M_n 132.1 in-kips Load 140.9 plf

Base Test Method: M(+) NA in-kips Load NA plf

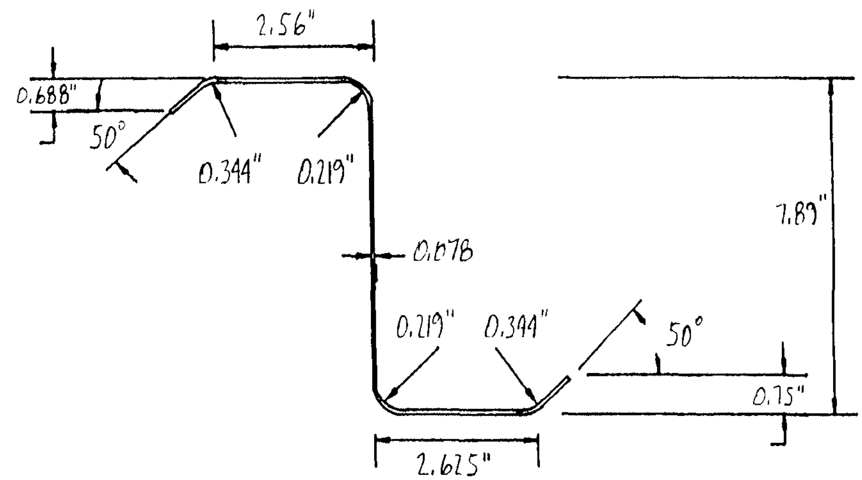
M(-) NA in-kips Load NA plf

Discussion:

- Pan type roofing panels with one piece clip
- Snap type deck, no seamer tool used
- Load deflection curve was essentially linear
- Very little lateral movement of deck, prior to or after failure (less than 1/2 inch)
- Increase in load capacity over same system without 3rd point bracing
- Failure was in the eave purlin, by local buckling of the compression flange



Ridge Purlin



Eave Purlin

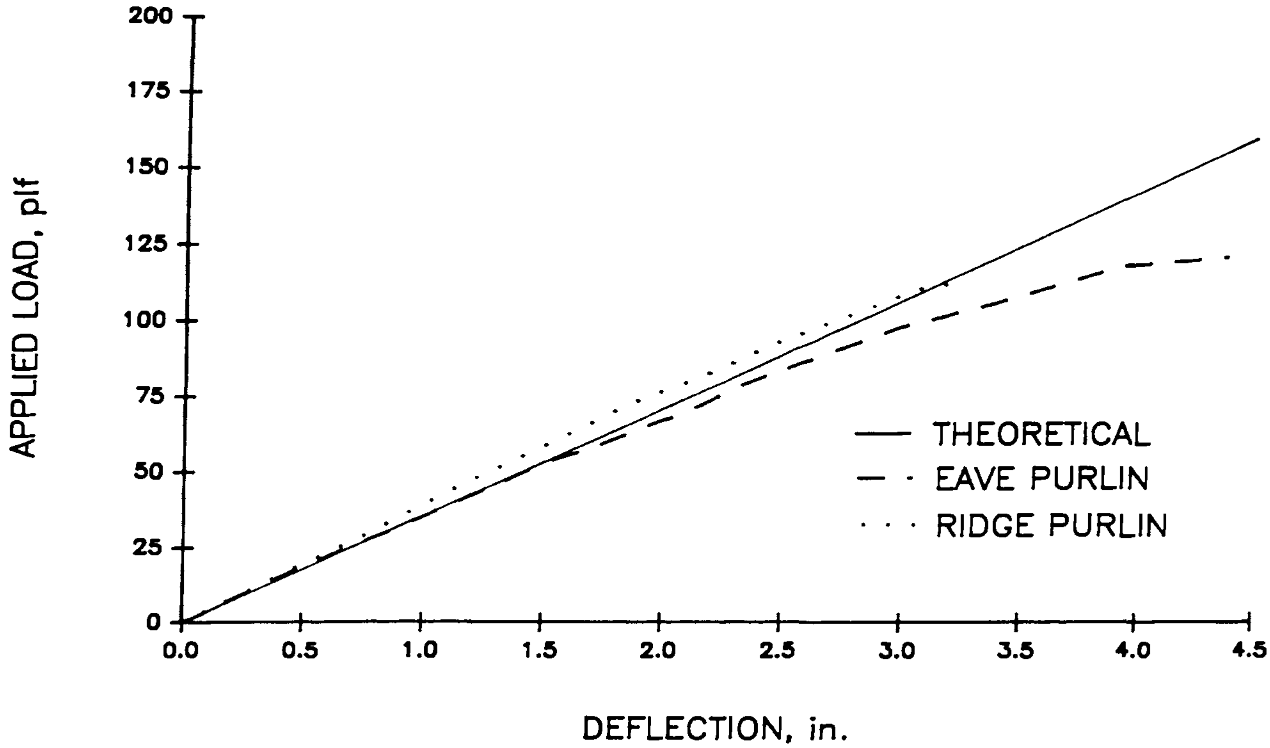
BASE TEST

TEST Z-T-P/F-1

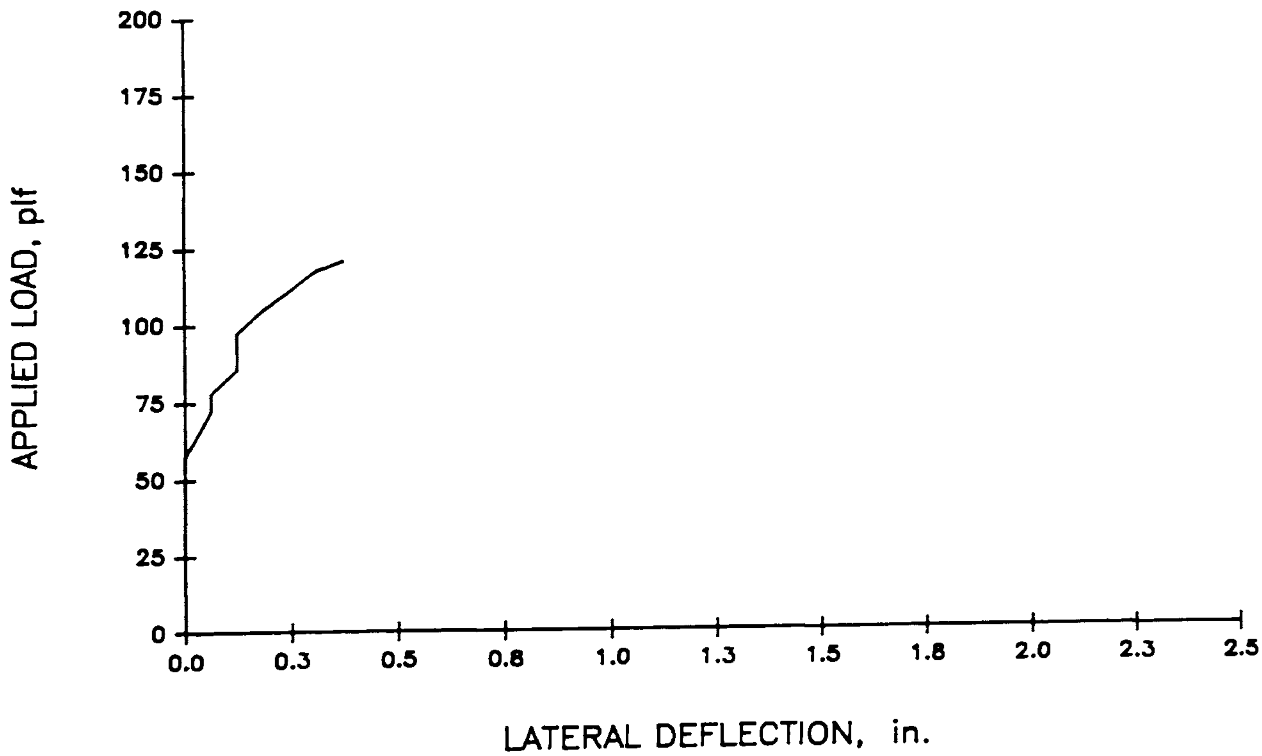
TEST Z-T-P/F-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.688	0.688
Lip Angle (degree)	50.0	51.0
Flange Width (inches)	2.56	2.56
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.219	0.219
BOTTOM		
Vertical Lip		
Dimension (inches)	0.75	0.688
Lip Angle (degree)	50.0	50.0
Flange Width (inches)	2.625	2.56
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.219	0.219
Total Depth (inches)	7.89	7.95
Thickness (inches)	0.078	0.078
Gross Moment of Inertia ($inches^4$)	10.57	10.60
Material Yield Stress (ksi)	53.59	53.59
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	132.4	132.1



LOAD VS. DEFLECTION, TEST Z–T–P/F–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–P/F–1

Z-T-P/F-3
Test Summary

Test Date: May 26, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.079"	0.079"	0.079"
	0.079"	0.079"	0.079"
	0.079"	0.079"	0.079"
Sweep	negligible	negligible	negligible
	negligible	negligible	negligible
	negligible	negligible	negligible

Parameters: Gravity Loading, 3rd point bracing

Three Purlin Lines, 5'-0" O.C. 2'-2 1/4" overhang

Purlins facing same direction

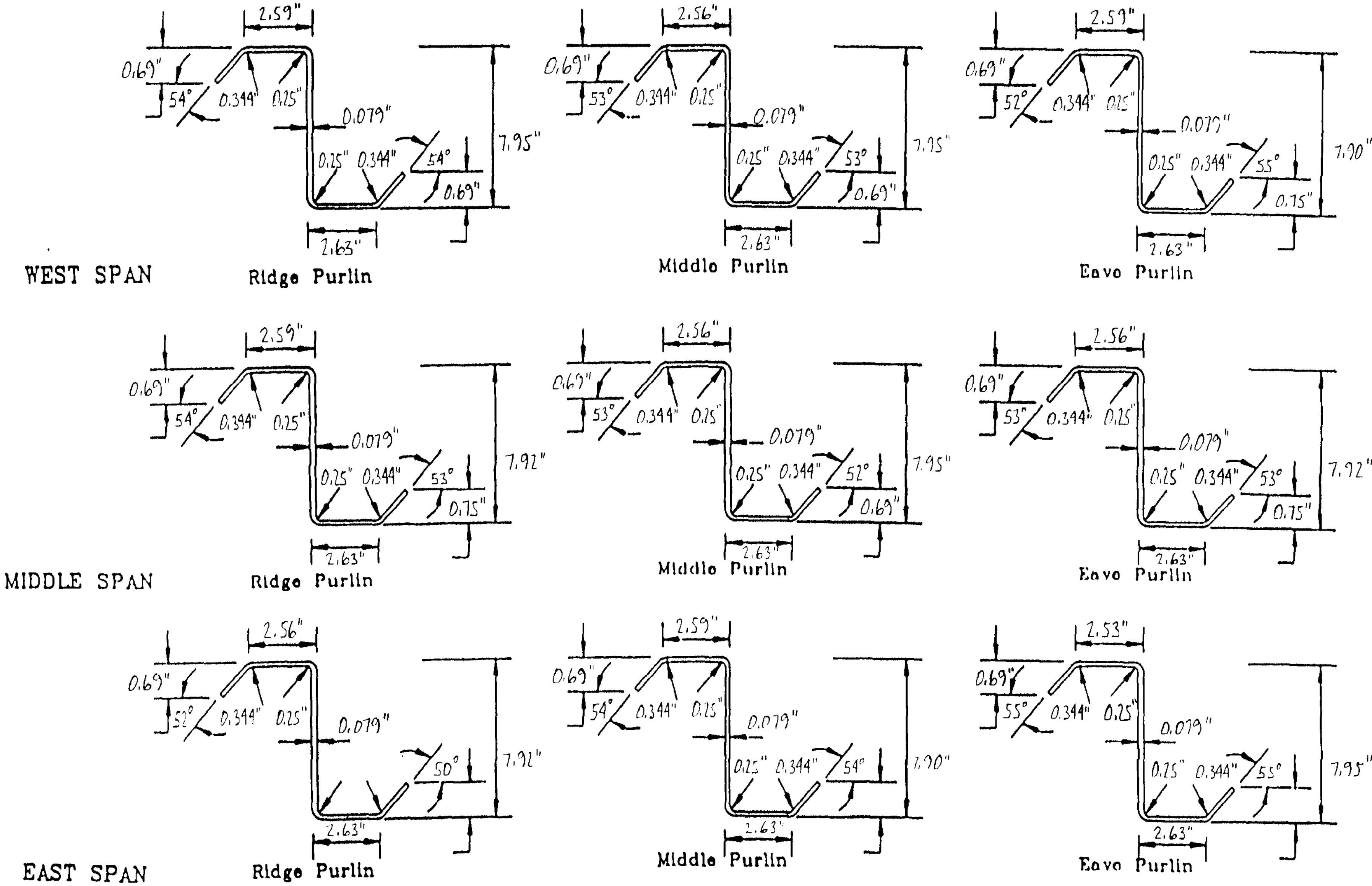
Failure Load: 223 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 52.44 ksi)

Constrained Bending:	M_n	132.2	in-kips	Load	NA	plf
Base Test Method:	M(+)	50.2	in-kips	Load	235.3	plf
	M(-)	40.1	in-kips	Load	329.7	plf

Discussion:

- Pan type roofing panels with one piece clip.
- Snap type deck used.
- Load deflection curve essentially linear.
- Failure was in the west bay by local buckling in all 3 purlins. Ridge purlin failed 1st, followed by other two.

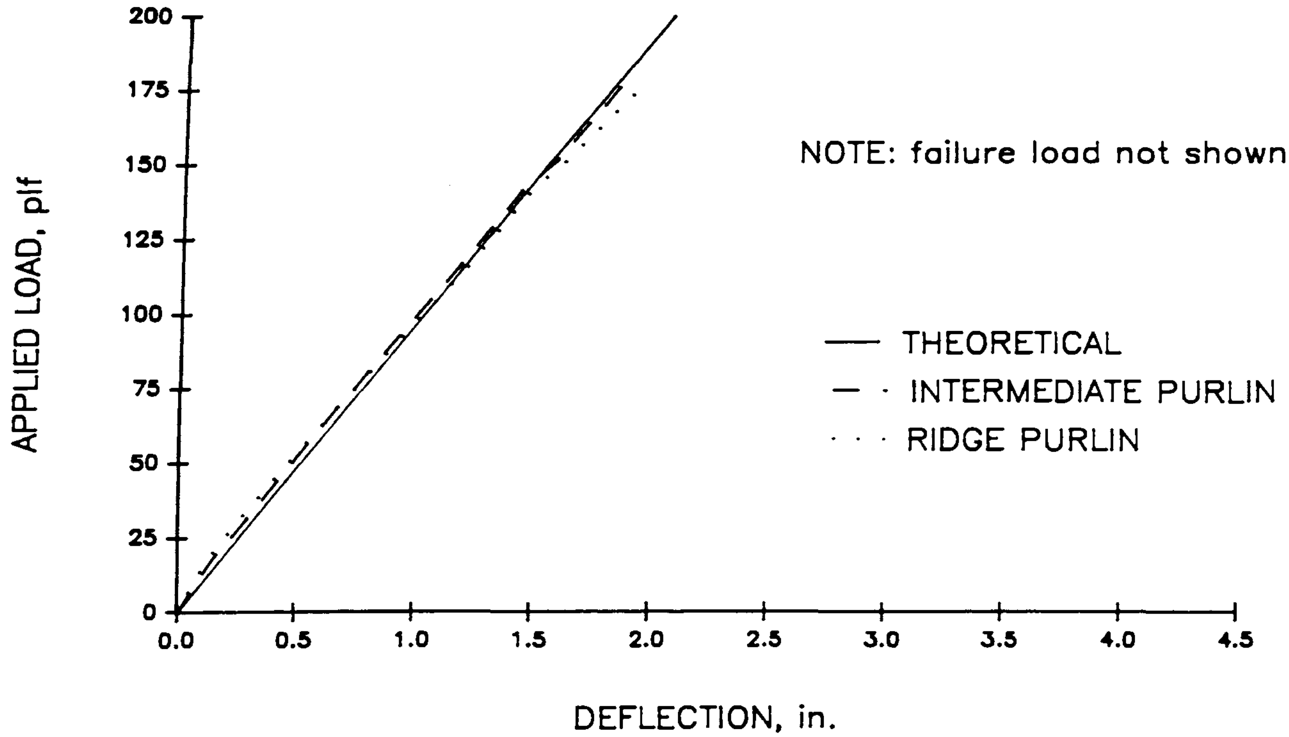

WEST SPAN
Ridge Purlin
2.59"
0.69"
54°
0.344"
0.25"
0.079"
0.25"
0.344"
54°
0.69"
7.95"
2.63"
Middle Purlin
2.56"
0.69"
53°
0.344"
0.25"
0.079"
0.25"
0.344"
53°
0.69"
7.95"
2.63"
Eave Purlin
2.59"
0.69"
52°
0.344"
0.25"
0.079"
0.25"
0.344"
55°
0.75"
7.90"
2.63"
MIDDLE SPAN
Ridge Purlin
2.59"
0.69"
54°
0.344"
0.25"
0.079"
0.25"
0.344"
53°
0.75"
7.92"
2.63"
Middle Purlin
2.56"
0.69"
53°
0.344"
0.25"
0.079"
0.25"
0.344"
52°
0.69"
7.95"
2.63"
Eave Purlin
2.56"
0.69"
53°
0.344"
0.25"
0.079"
0.25"
0.344"
53°
0.75"
7.92"
2.63"
EAST SPAN
Ridge Purlin
2.56"
0.69"
52°
0.344"
0.25"
0.079"
50°
7.92"
2.63"
Middle Purlin
2.59"
0.69"
54°
0.344"
0.25"
0.079"
0.25"
0.344"
54°
7.90"
2.63"
Eave Purlin
2.53"
0.69"
55°
0.344"
0.25"
0.079"
0.25"
0.344"
55°
7.95"
2.63"

TEST Z-T-P/F-3

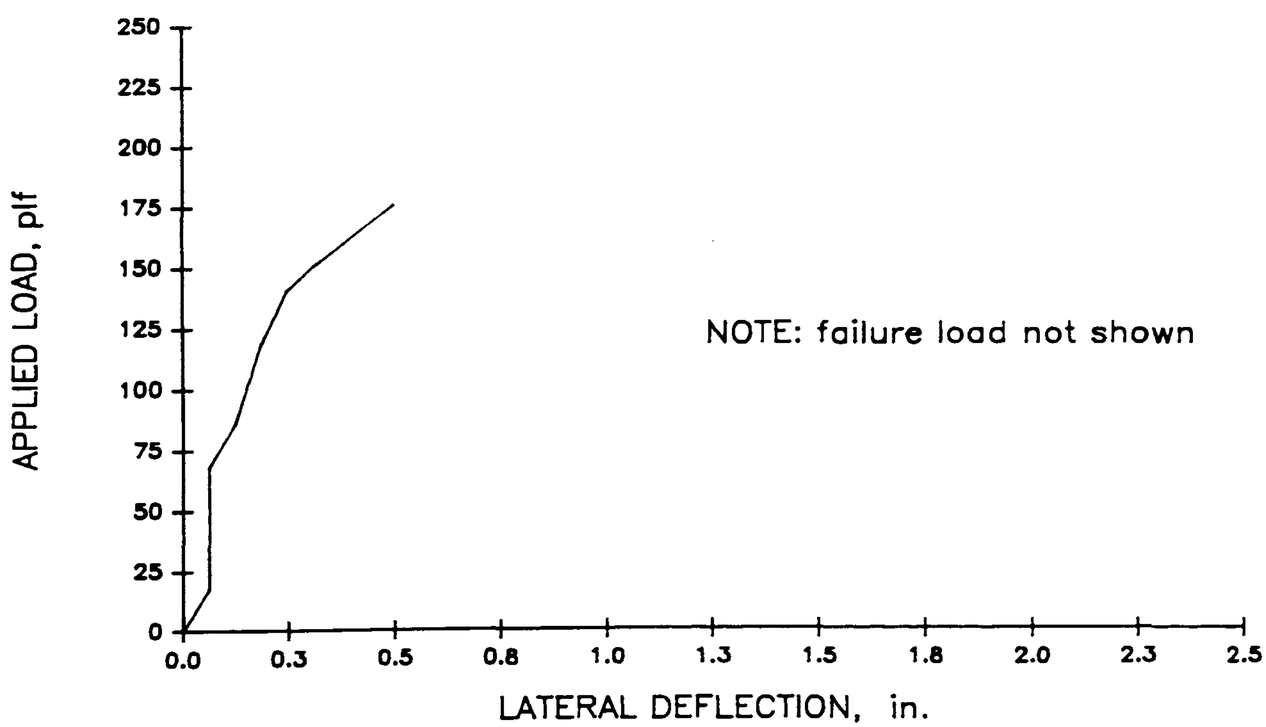
TEST Z-T-P/F-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

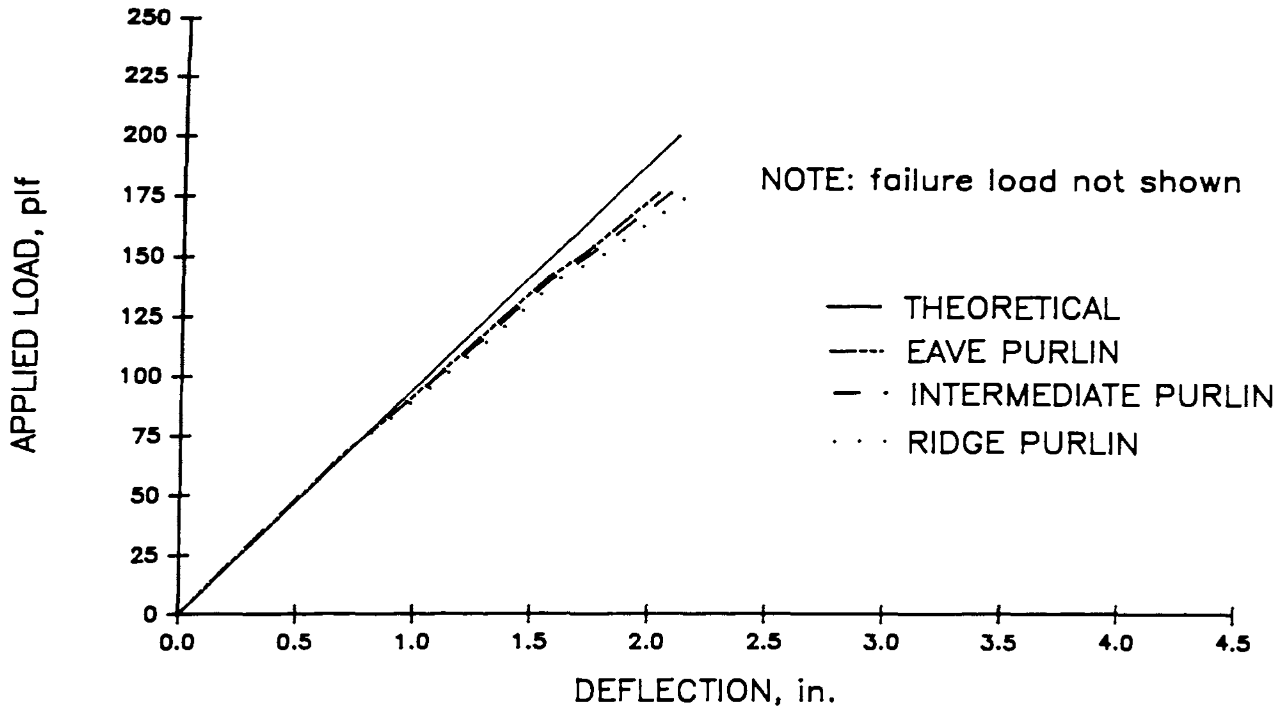
Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip									
Dimension (inches)	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Lip Angle (degree)	52.0	54.0	55.0	54.0	53.0	53.0	54.0	53.0	52.0
Flange Width (inches)	2.56	2.59	2.53	2.59	2.56	2.56	2.59	2.56	2.59
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM									
Vertical Lip									
Dimension (inches)	0.69	0.75	0.75	0.75	0.69	0.75	0.69	0.69	0.75
Lip Angle (degree)	50.0	54.0	57.0	53.0	52.0	53.0	54.0	53.0	55.0
Flange Width (inches)	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	7.92	7.90	7.95	7.92	7.95	7.92	7.95	7.95	7.90
Thickness (inches)	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079
Gross Moment of Inertia ($inches^4$)	10.68	10.63	10.66	10.70	10.73	10.68	10.72	10.71	10.64
Material Yield Stress (ksi)	52.44	52.44	52.44	52.44	52.44	52.44	52.44	52.44	52.44
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	133.2	131.3	132.8	131.8	133.3	132.7	132.2	133.2	132.1



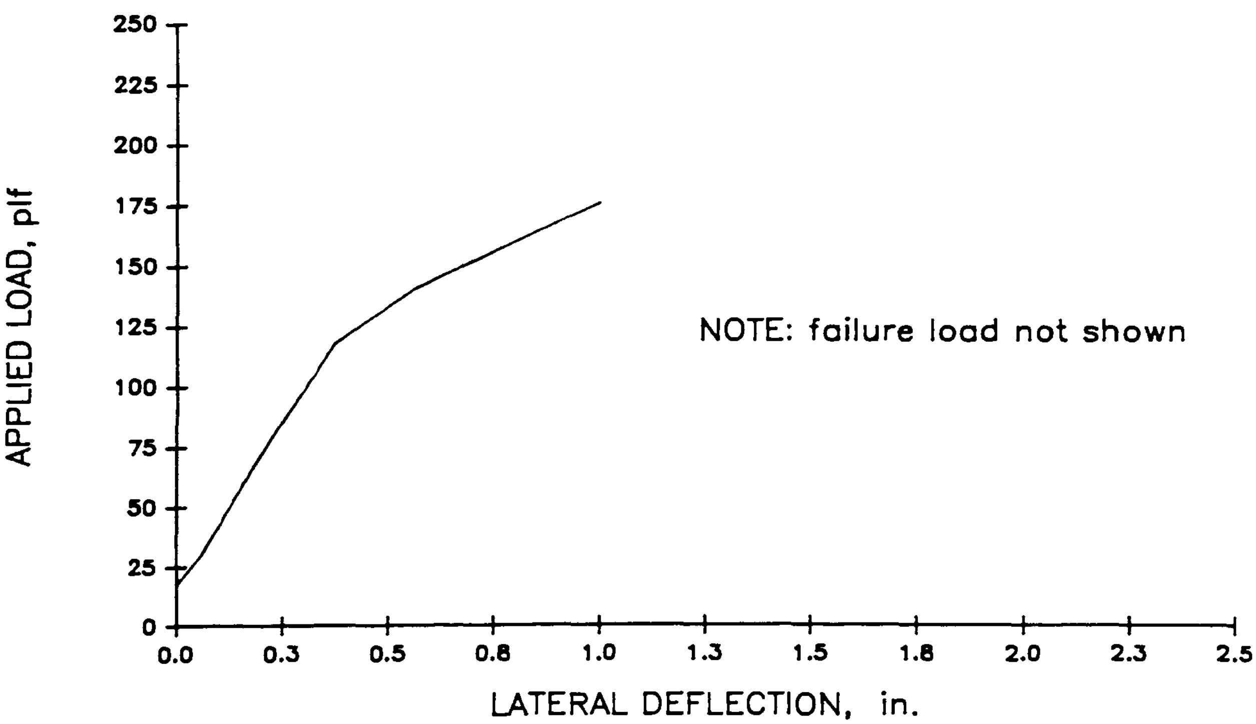
LOAD VS DEFLECTION, TEST Z–T–P/F–3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–P/F–3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z–T–P/F–3, WEST SPAN



LOAD VS LATERAL PANEL DEFLECTION, TEST Z–T–P/F–3, WEST SPAN

Z-T-P/S-1
Test Summary

Test Date: May 2, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.074"	--	0.074"
Sweep	negligible	--	negligible

Parameters: Gravity Loading, 3rd point bracing

Two Purlin Lines, 5'-0" O.C. 1'-0" overhang

Purlins facing same direction

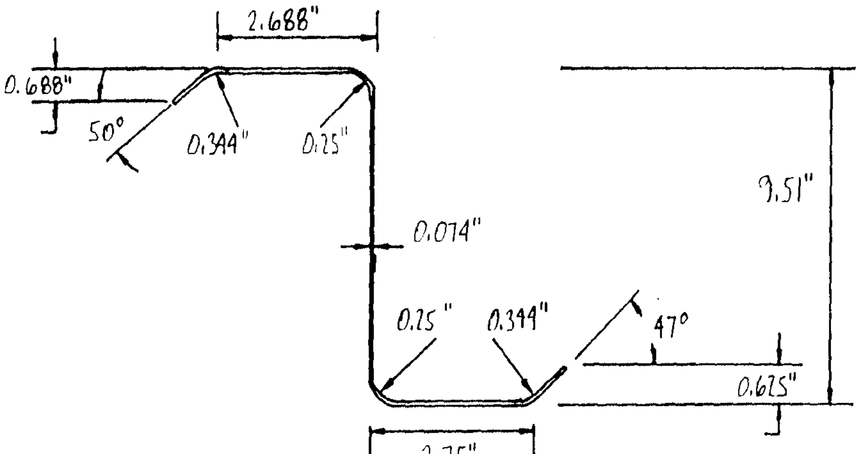
Failure Load: 120 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 63.65 ksi)

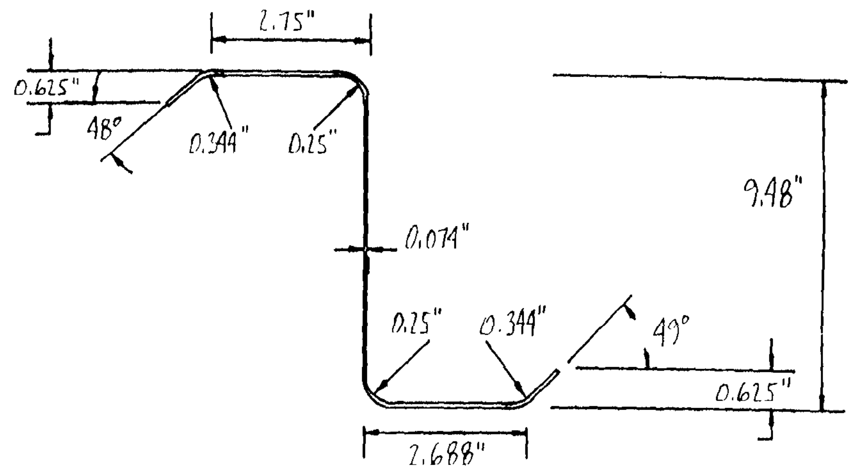
Constrained Bending:	M_n	176.1	in-kips	Load	187.8	plf
Base Test Method:	M(+)	NA	in-kips	Load	NA	plf
	M(-)	NA	in-kips	Load	NA	plf

Discussion:

- Pan type roofing panels with two piece clip.
- Load deflection curve was essentially linear.
- Lateral movement of deck prior to failure was measured (approximately 2 1/2").
- Failure was in the eave purlin, by local buckling of the compression flange. (Some torsional movement was present.)
- Clips showed signs of twisting and were damaged.
- Angle used as eave, attached to deck with screws, may be reason for movement of deck. The angle pulled the screws through deck prior to failure, this would have diminished the stiffness provided by the deck and not only resulted in movement laterally of purlins, but also allowed the purlins to rotate. (Purlins showed signs of twisting). Twisting of purlins, disengaged one of the purlins from the 3rd point bracing. All of the occurrences lead to the lateral movement of the deck. If the above had not happened, the failure load would have probably been higher.



Ridge Purlin



Eave Purlin

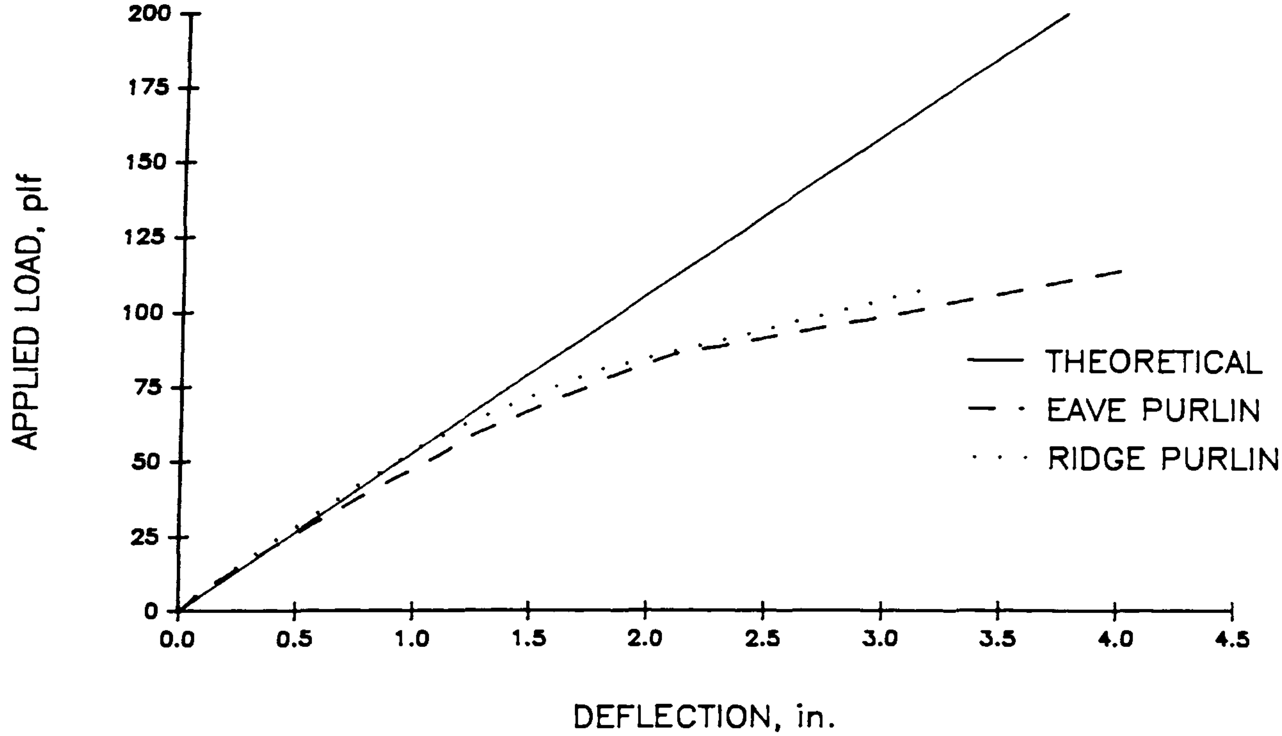
BASE TEST

TEST Z-T-P/S-1

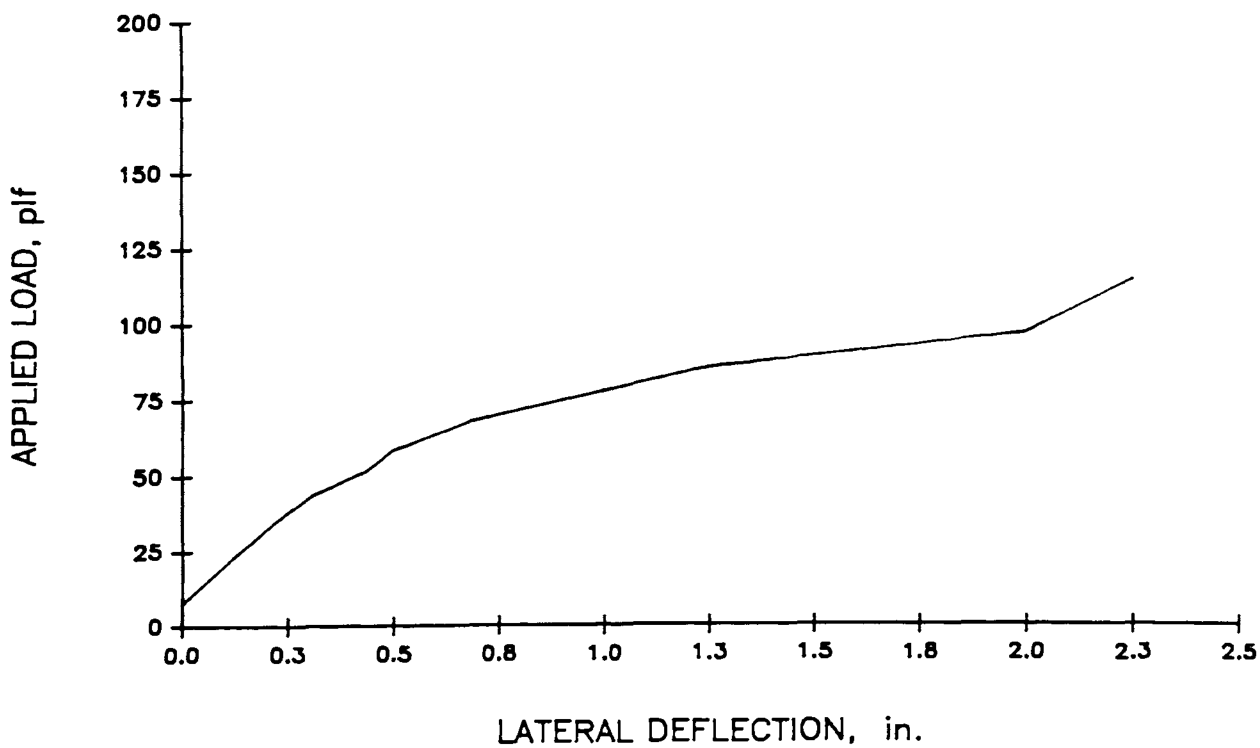
TEST Z-T-P/S-1

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.688	0.625
Lip Angle (degree)	50.0	48.0
Flange Width (inches)	2.688	2.75
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.25	0.25
BOTTOM		
Vertical Lip		
Dimension (inches)	0.625	0.625
Lip Angle (degree)	47.0	49.0
Flange Width (inches)	2.75	2.688
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.25	0.25
Total Depth (inches)	9.51	9.48
Thickness (inches)	0.074	0.074
Gross Moment of Inertia (inches^4)	15.86	15.64
Material Yield Stress (ksi)	63.65	63.65
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	179.9	176.1



LOAD VS. DEFLECTION, TEST Z–T–P/S–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–P/S–1

Z-T-P/S-3
Test Summary

Test Date: June 2, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.074"	0.074"	0.074"
	0.074"	0.074"	0.074"
	0.074"	0.074"	0.074"
Sweep	negligible	negligible	negligible
	negligible	negligible	negligible
	negligible	negligible	negligible

Parameters: Gravity Loading, 3rd point bracing

Three Purlin Lines, 5'-0" O.C. 2'-2 1/4" overhang

Purlins facing same direction

Failure Load: 188 plf Failure Mode: Lateral Torsional Buckling

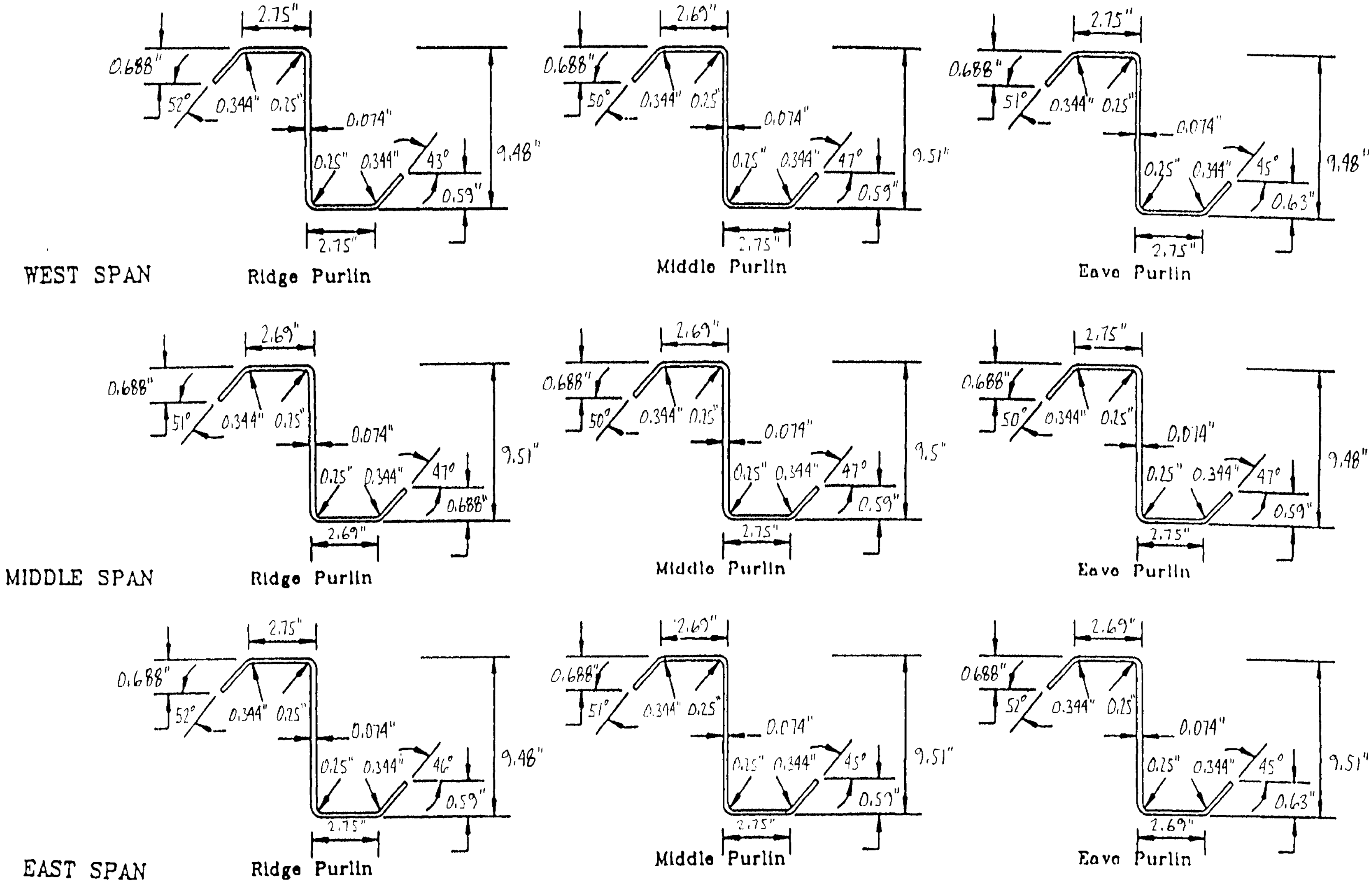
Predicted Failure Loads: (F_y = 62.29 ksi)

Constrained Bending:	M_n 177.1	in-kips	Load NA	plf
Base Test Method:	M(+) 50.5	in-kips	Load 222.8	plf
	M(-) 48.1	in-kips	Load 368.2	plf

Discussion:

- Load deflection curve was essentially linear.
- Pan type roofing panel with 2 piece clip.
- Failure was in ridge purlin of west span by lateral torsional buckling.
- It is believed that if brace had not failed, failure load would have been greater than 90% of predicted.

Note: one of 3rd point braces failed, this caused a failure at a lower load and allowed purlins to fail in a lateral torsional mode, due to larger unbraced length.

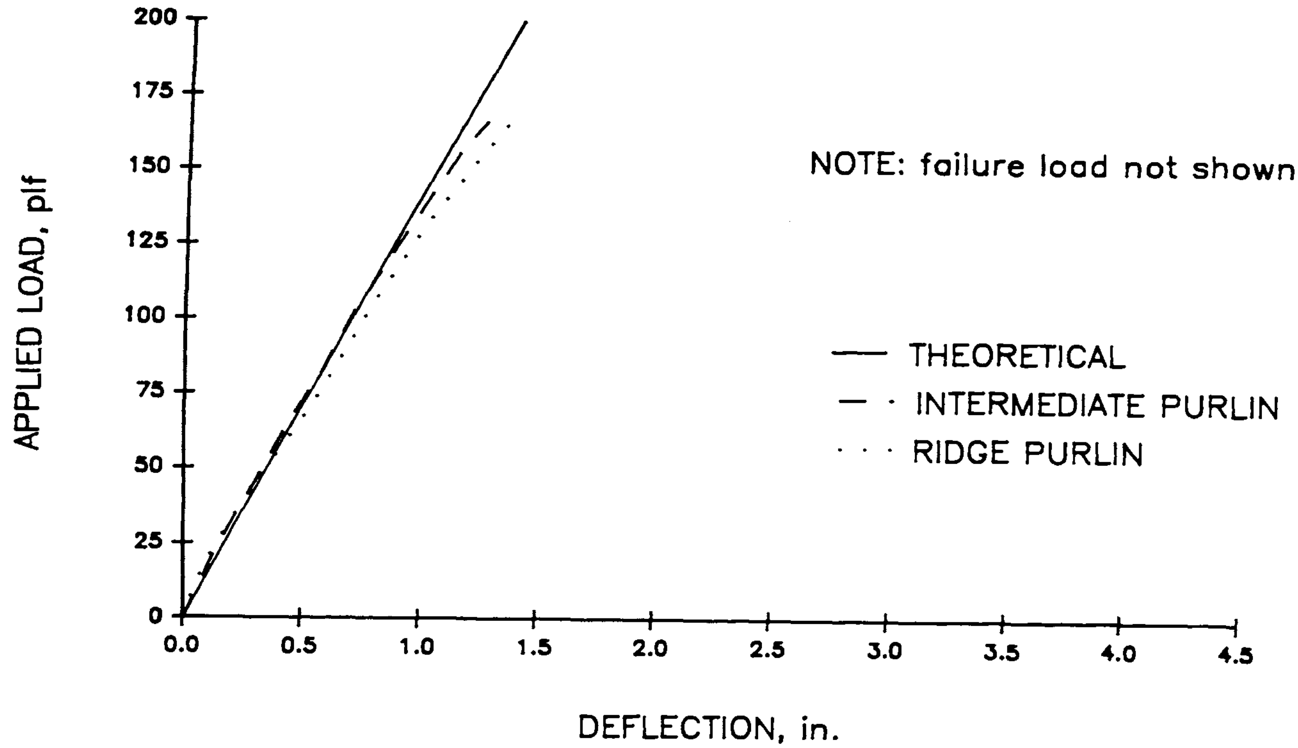

WEST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
MIDDLE SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin

TEST Z-T-P/S-3

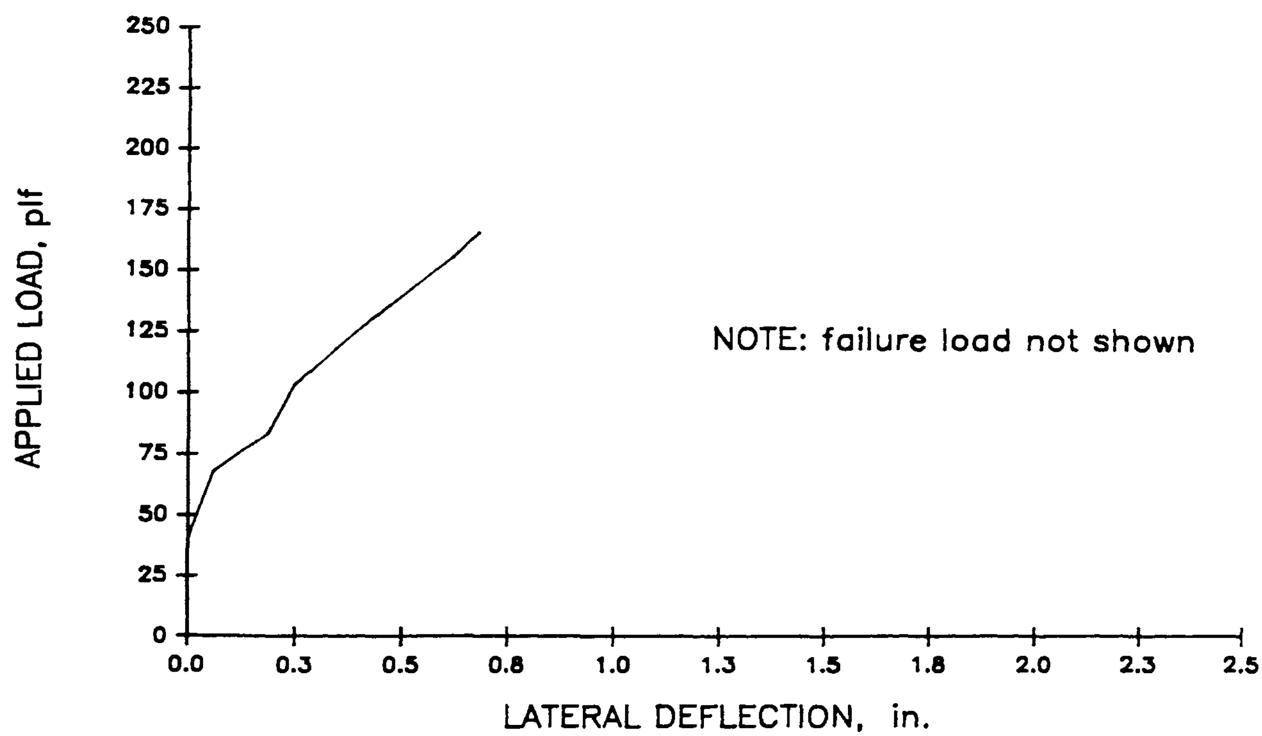
TEST Z-T-P/S-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

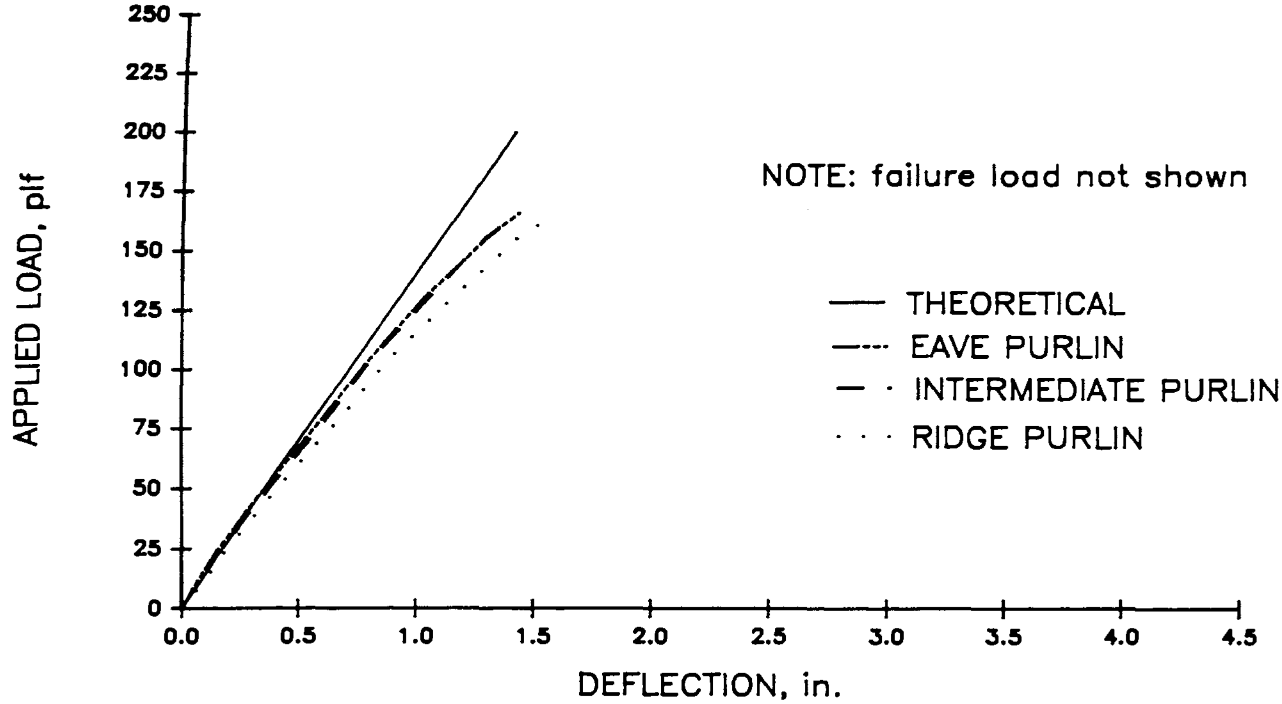
Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip									
Dimension (inches)	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688
Lip Angle (degree)	52.0	51.0	52.0	51.0	50.0	50.0	52.0	50.0	51.0
Flange Width (inches)	2.75	2.69	2.69	2.69	2.69	2.75	2.75	2.69	2.75
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BOTTOM									
Vertical Lip									
Dimension (inches)	0.59	0.59	0.63	0.688	0.59	0.59	0.59	0.59	0.63
Lip Angle (degree)	46.0	45.0	45.0	47.0	47.0	47.0	43.0	47.0	45.0
Flange Width (inches)	2.75	2.75	2.69	2.69	2.75	2.75	2.75	2.75	2.75
Radii (inches)									
Lip to Flange	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344	0.344
Flange to Web	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total Depth (inches)	9.48	9.51	9.51	9.51	9.50	9.48	9.48	9.51	9.48
Thickness (inches)	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
Gross Moment of Inertia (inches^4)	15.76	15.82	15.78	15.85	15.76	15.78	15.83	15.80	15.87
Material Yield Stress (ksi)	62.29	62.29	62.29	62.29	62.29	62.29	62.29	62.29	62.29
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	177.3	177.5	177.0	177.1	177.9	178.2	177.1	178.1	177.4



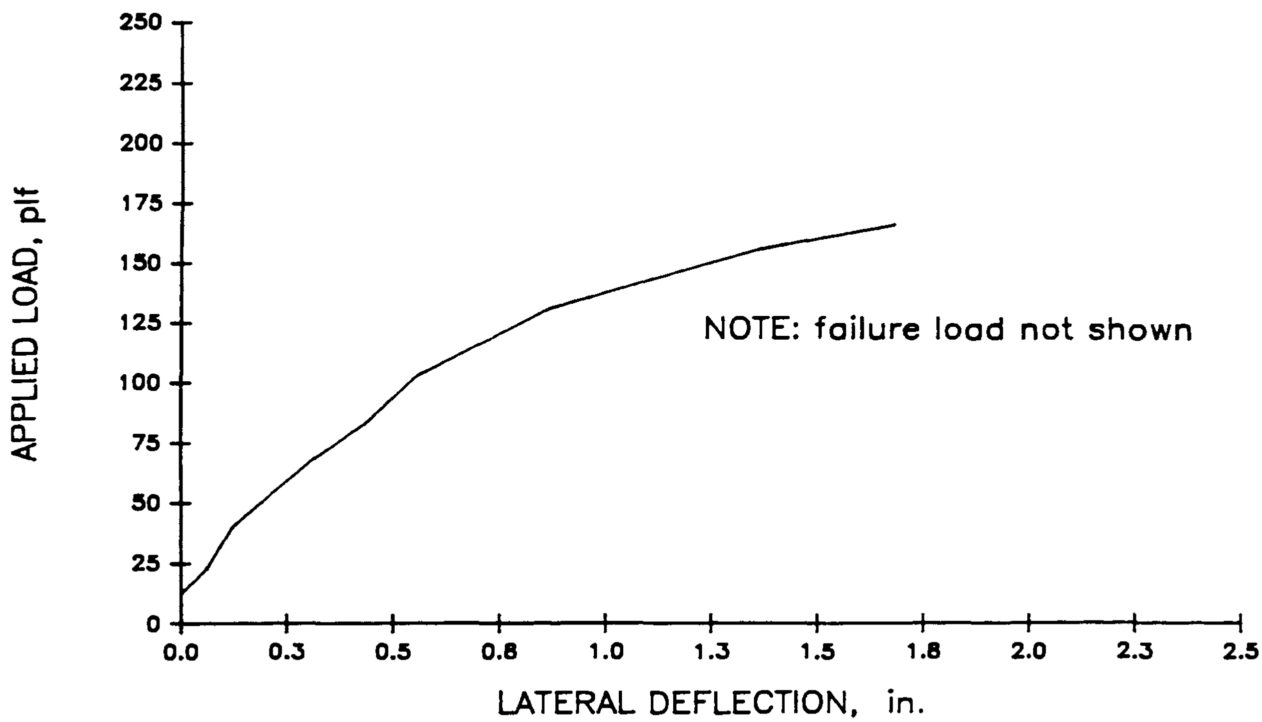
LOAD VS. DEFLECTION, TEST Z-T-P/S-3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION,, TEST Z-T-P/S-3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z–T–P/S–3, WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–P/S–3, WEST SPAN

Z-T-R/S-1
Test Summary

Test Date: May 11, 1989

Purpose: Single Span Base Test

Span(s): 1 @ 25'-0"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.075"	--	0.075"
Sweep	negligible	--	negligible

Parameters: Gravity Loading, 3rd point bracing

Two Purlin Lines, 5'-0" O.C. 1'-0" overhang

Purlins facing same direction

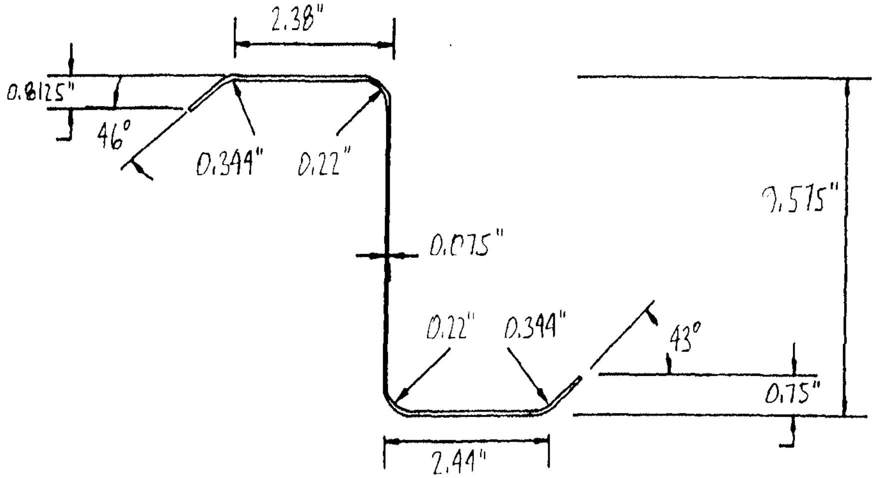
Failure Load: 126 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 63.51 ksi)

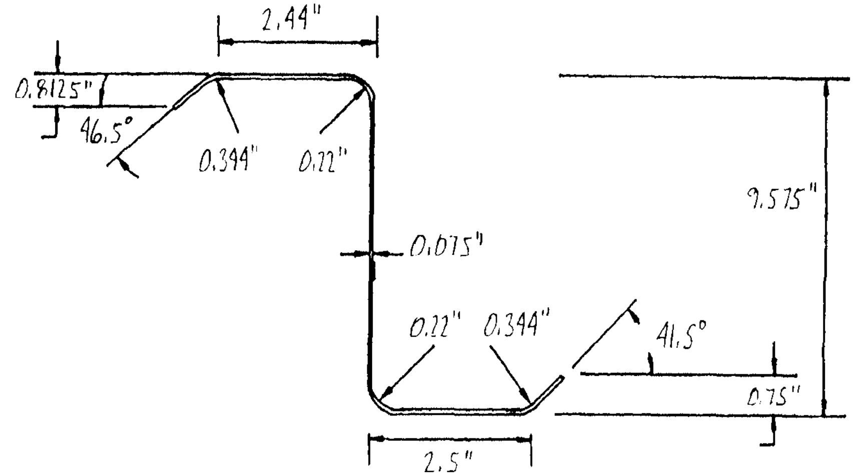
Constrained Bending:	M_n	198.9	in-kips	Load	212.2	plf
Base Test Method:	M(+)	NA	in-kips	Load	NA	plf
	M(-)	NA	in-kips	Load	NA	plf

Discussion:

- Rib type roof panels with 2-piece clip.
- Load deflection curve was essentially linear.
- Lateral deflection was less than 1/2 inch.
- Failure bending moment was 66% of max. theoretical capacity.
- Failure was in the eave purlin by local buckling.



Ridge Purlin



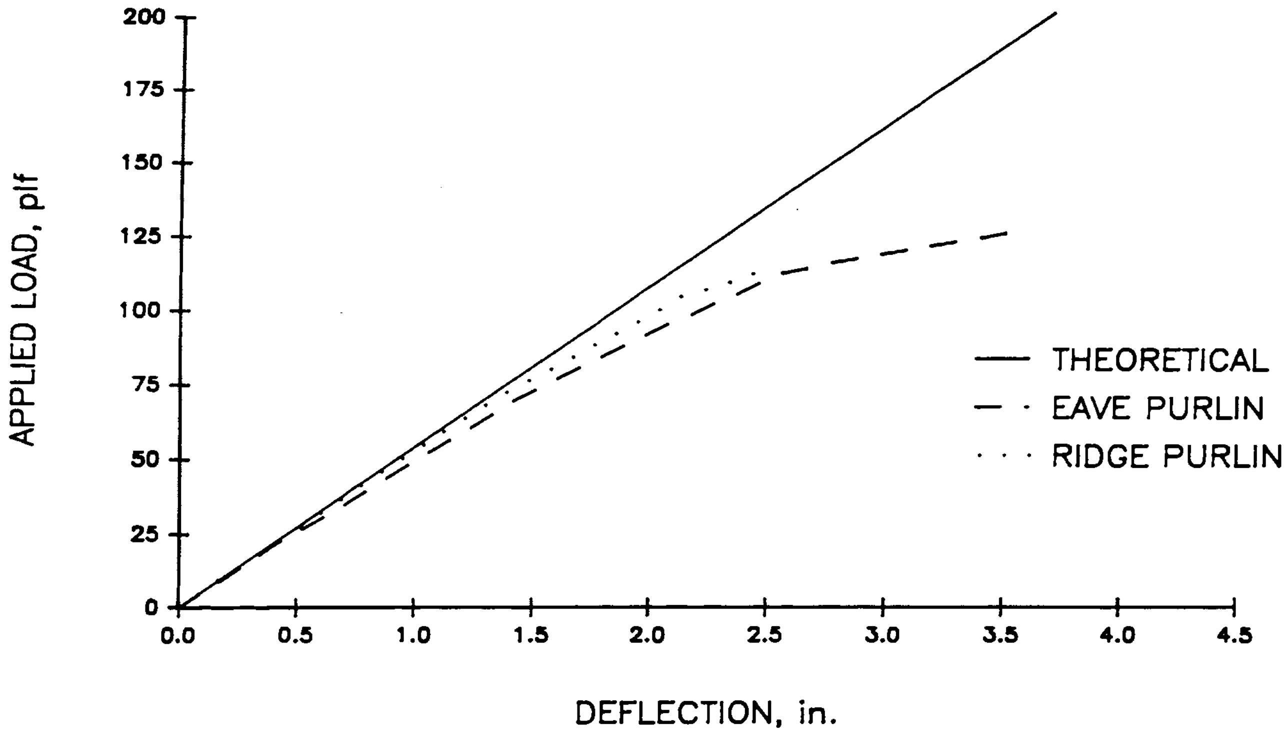
Eave Purlin

BASE TEST

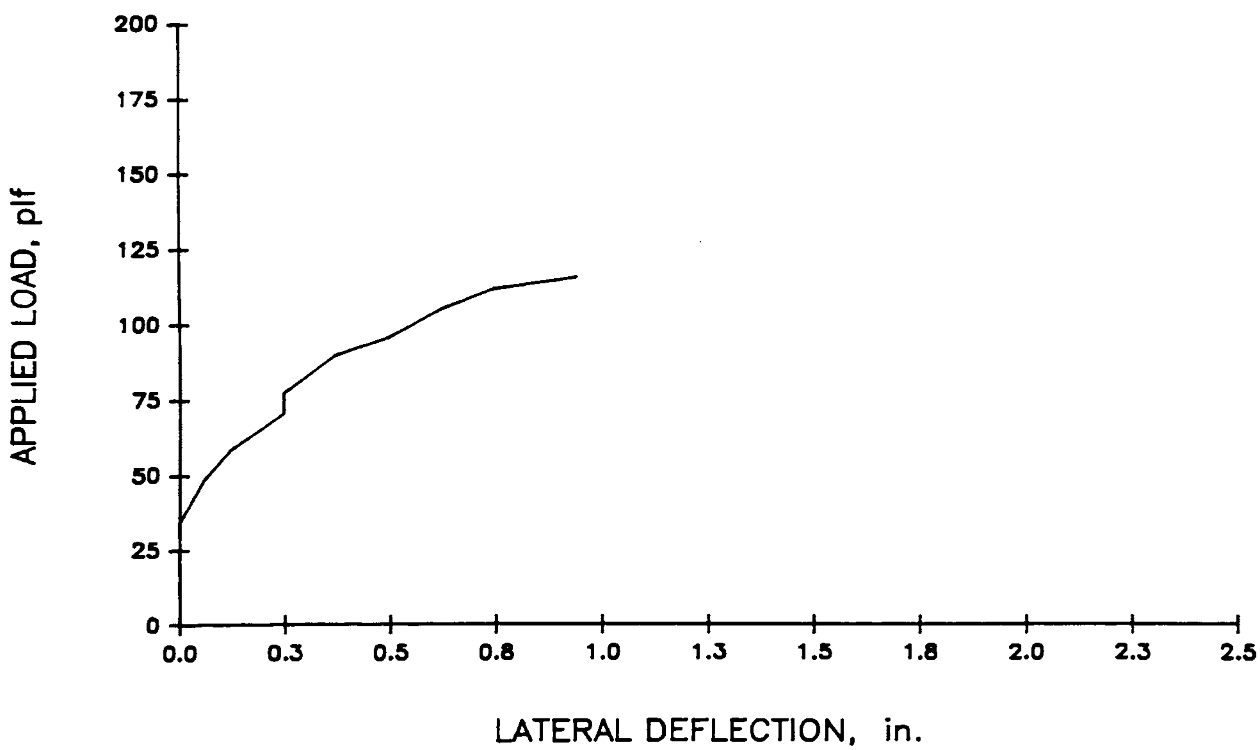
TEST Z-T-R/S-1

TEST Z-T-R/S-1
MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

Parameter	Single Span	
	Ridge	Eave
TOP		
Vertical Lip		
Dimension (inches)	0.8125	0.8125
Lip Angle (degree)	46.0	46.5
Flange Width (inches)	2.38	2.44
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.22	0.22
BOTTOM		
Vertical Lip		
Dimension (inches)	0.75	0.75
Lip Angle (degree)	43.0	41.5
Flange Width (inches)	2.44	2.50
Radii (inches)		
Lip to Flange	0.344	0.344
Flange to Web	0.22	0.22
Total Depth (inches)	9.575	9.575
Thickness (inches)	0.075	0.075
Gross Moment of Inertia ($inches^4$)	15.96	16.19
Material Yield Stress (ksi)	63.51	63.51
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	119.9	198.9



LOAD VS. DEFLECTION, TEST Z–T–R/S–1



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–R/S–1

Z-T-R/S-3
Test Summary

Test Date: June 8, 1989

Purpose: Confirming Multi-Span Test

Span(s): 3 @ 23'-6"

Measured Dimensions:

	Eave	Intermediate	Ridge
Thickness	0.075"	0.075"	0.075"
	0.075"	0.075"	0.075"
	0.075"	0.075"	0.075"
Sweep	negligible	negligible	negligible
	negligible	negligible	negligible
	negligible	negligible	negligible

Parameters: Gravity Loading, 3rd point bracing

Three Purlin Lines, 5'-0" O.C. 2'-2 1/4" overhang

Purlins facing same direction

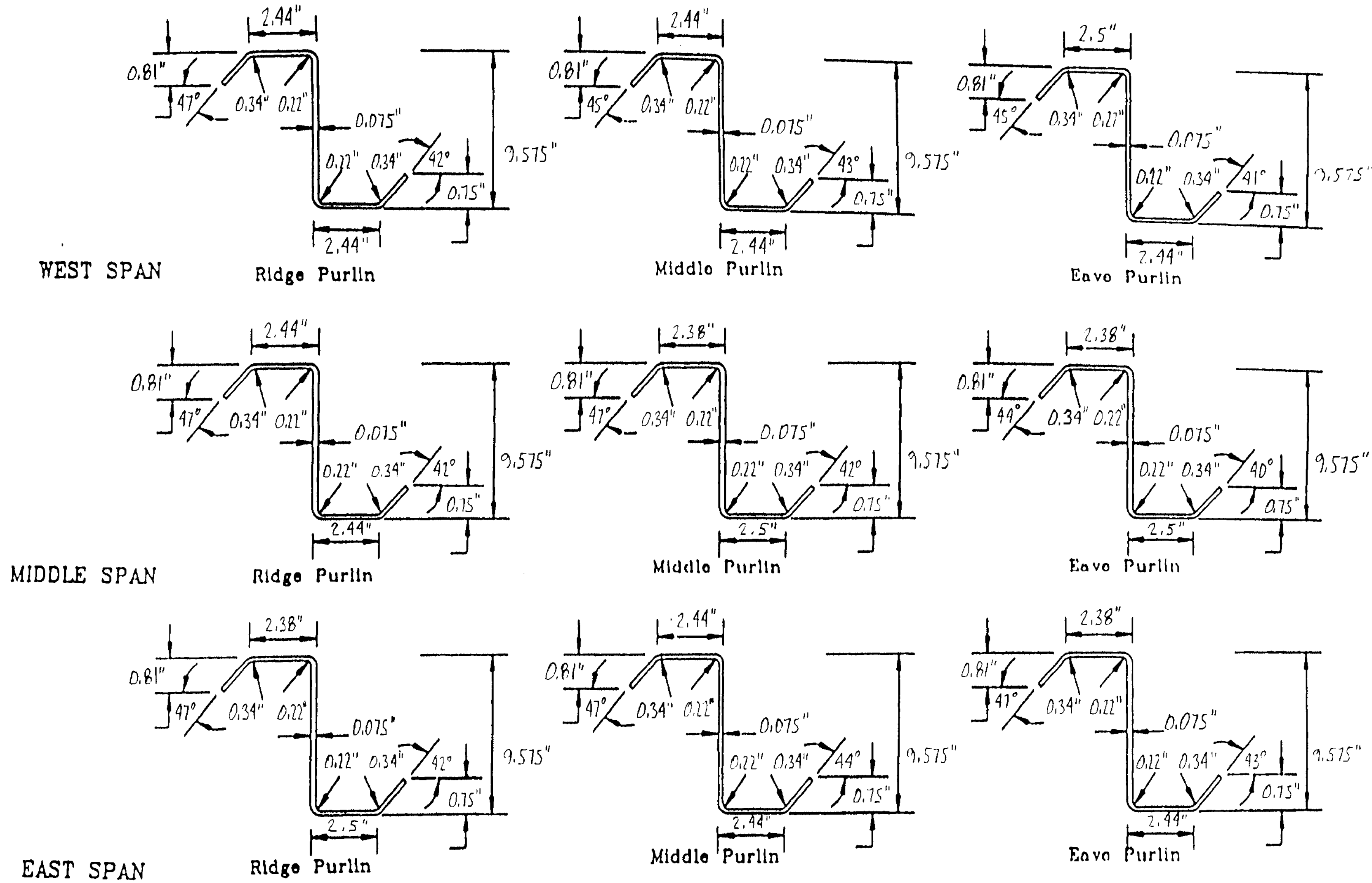
Failure Load: 238 plf Failure Mode: Local Buckling

Predicted Failure Loads: (F_y = 62.57 ksi)

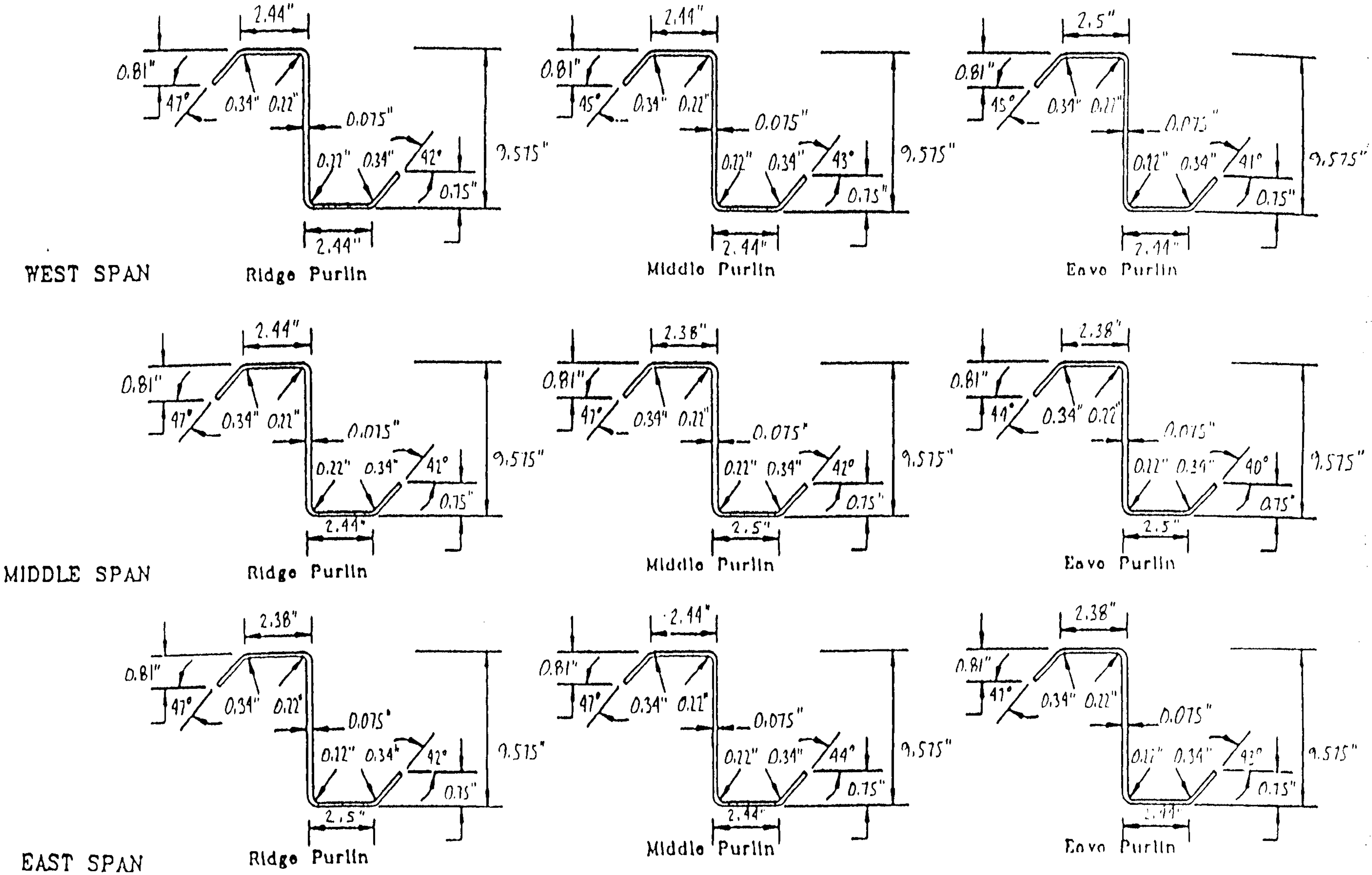
Constrained Bending:	M_n	196.8	in-kips	Load	NA	plf
Base Test Method:	M(+)	50.7	in-kips	Load	232.9	plf
	M(-)	46.2	in-kips	Load	426.0	plf

Discussion:

- Rib type roofing panels with 2 piece clip.
- Load deflection curves essentially linear.
- Failure was in the west span, in the ridge and intermediate purlins, located at point of max. positive moment. Failure mode was local buckling of the (top) compression flange.
- Indications of buckling in the negative moment zone were also present. The (bottom) compression flange on either side of intermediate rafter closest to bay containing failed purlins (west), showed signs of buckling.
- East bay's lateral movement was (north) towards the eave angle. This continues until deck reached the chamber wall. At approximately 85% of capacity, lateral movement measured in the normal direction towards the ridge purlin.


WEST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
MIDDLE SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin

TEST Z-T-R/S-3

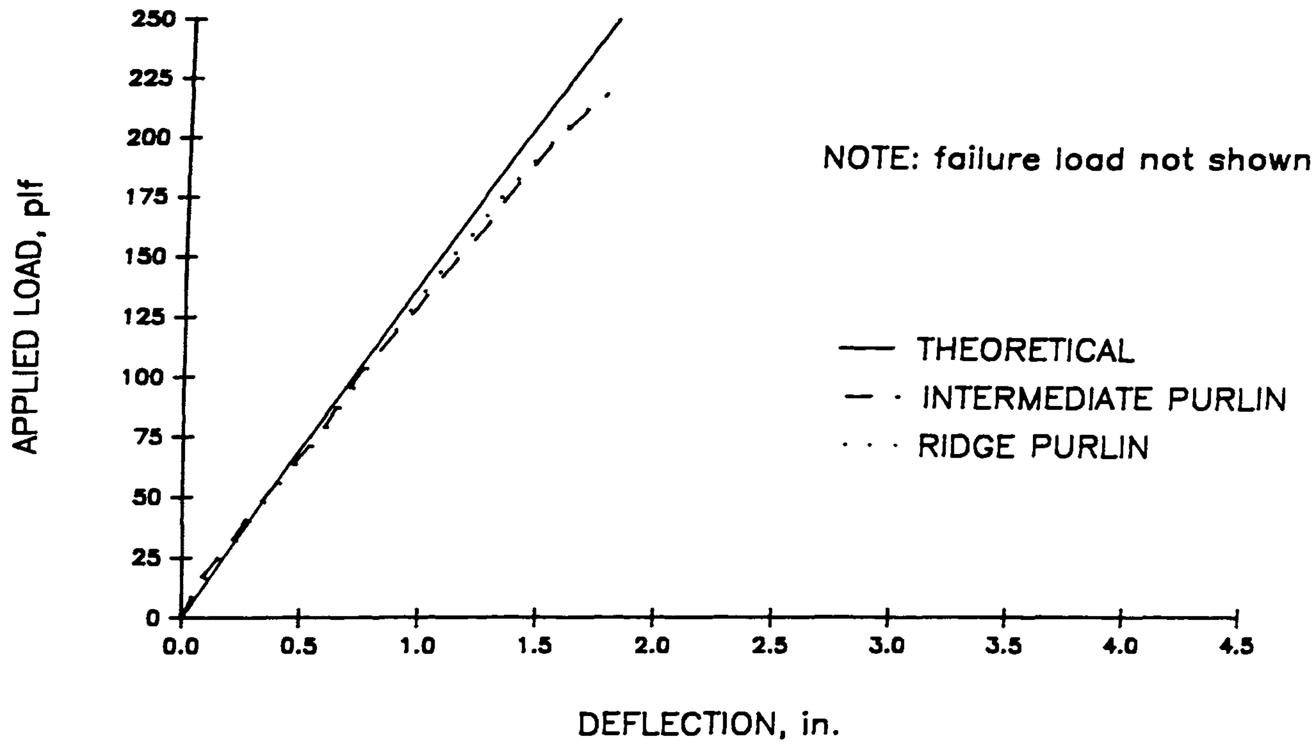

WEST SPAN
MIDDLE SPAN
EAST SPAN
Ridge Purlin
Middle Purlin
Eave Purlin
9.575"
0.075"
0.81"
0.34"
0.22"
0.75"

TEST Z-T-R/S-3

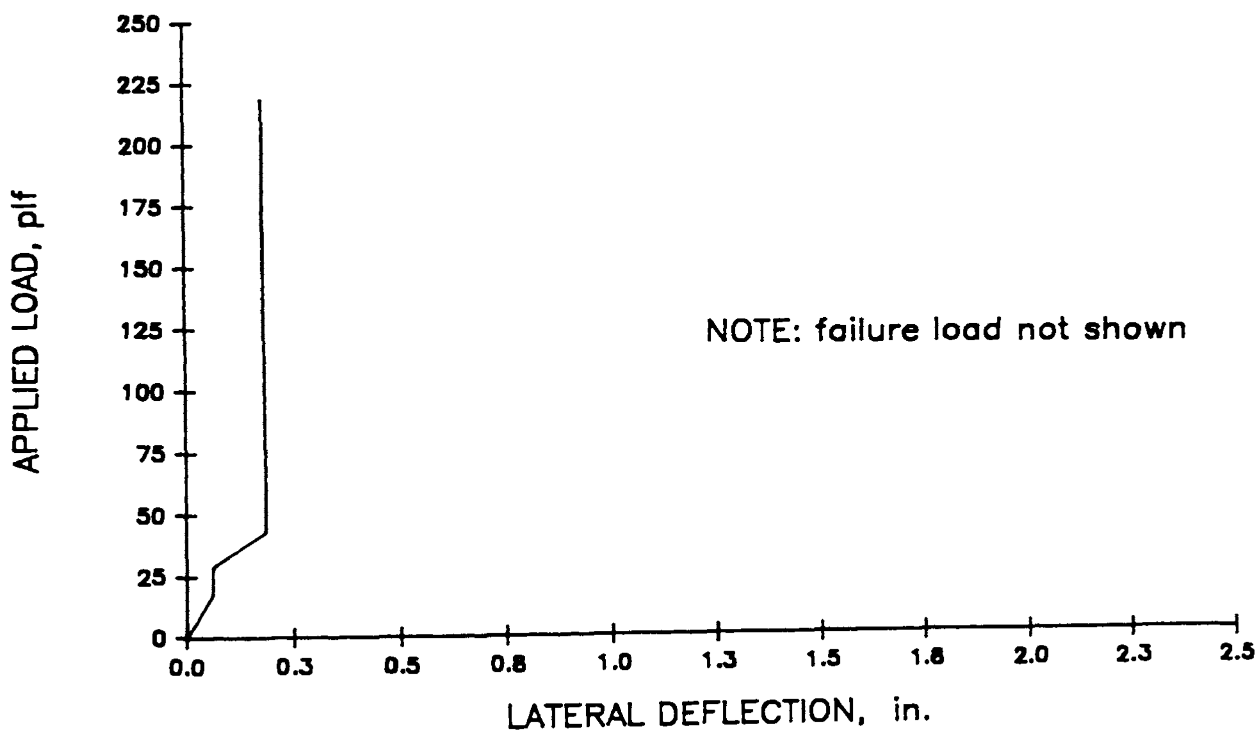
TEST Z-T-R/S-3

MEASURED GEOMETRY OF PURLIN CROSS-SECTIONS

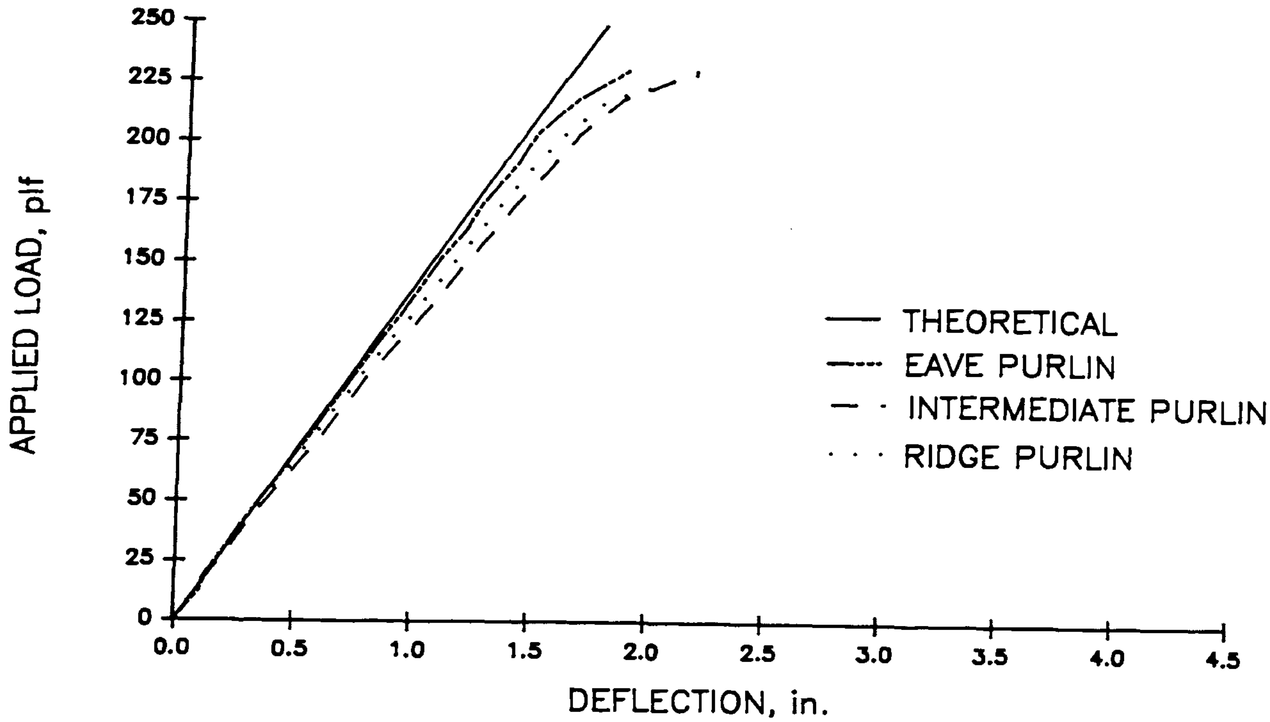
Parameter	East Bay			Center Bay			West Bay		
	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave	Ridge	Intermediate	Eave
TOP									
Vertical Lip Dimension (inches)	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Lip Angle (degree)	47.0	47.0	47.0	47.0	47.0	44.0	47.0	45.0	45.0
Flange Width (inches)	2.38	2.44	2.38	2.44	2.38	2.38	2.44	2.44	2.50
Radii (inches)									
Lip to Flange	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Flange to Web	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
BOTTOM									
Vertical Lip Dimension (inches)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Lip Angle (degree)	42.0	44.0	43.0	42.0	42.0	40.0	42.0	43.0	41.0
Flange Width (inches)	2.50	2.44	2.44	2.44	2.50	2.50	2.44	2.44	2.44
Radii (inches)									
Lip to Flange	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Flange to Web	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total Depth (inches)	9.575	9.575	9.575	9.575	9.575	9.575	9.575	9.575	9.575
Thickness (inches)	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Gross Moment of Inertia ($inches^4$)	16.06	16.00	15.92	16.06	16.06	16.21	16.06	16.08	16.25
Material Yield Stress (ksi)	62.57	62.57	62.57	62.57	62.57	62.57	62.57	62.57	62.57
1986 AISI Allowable flexural capacity x 1.67 (kip-inch)	198.3	196.5	197.6	196.8	198.3	197.7	196.8	197.7	195.5



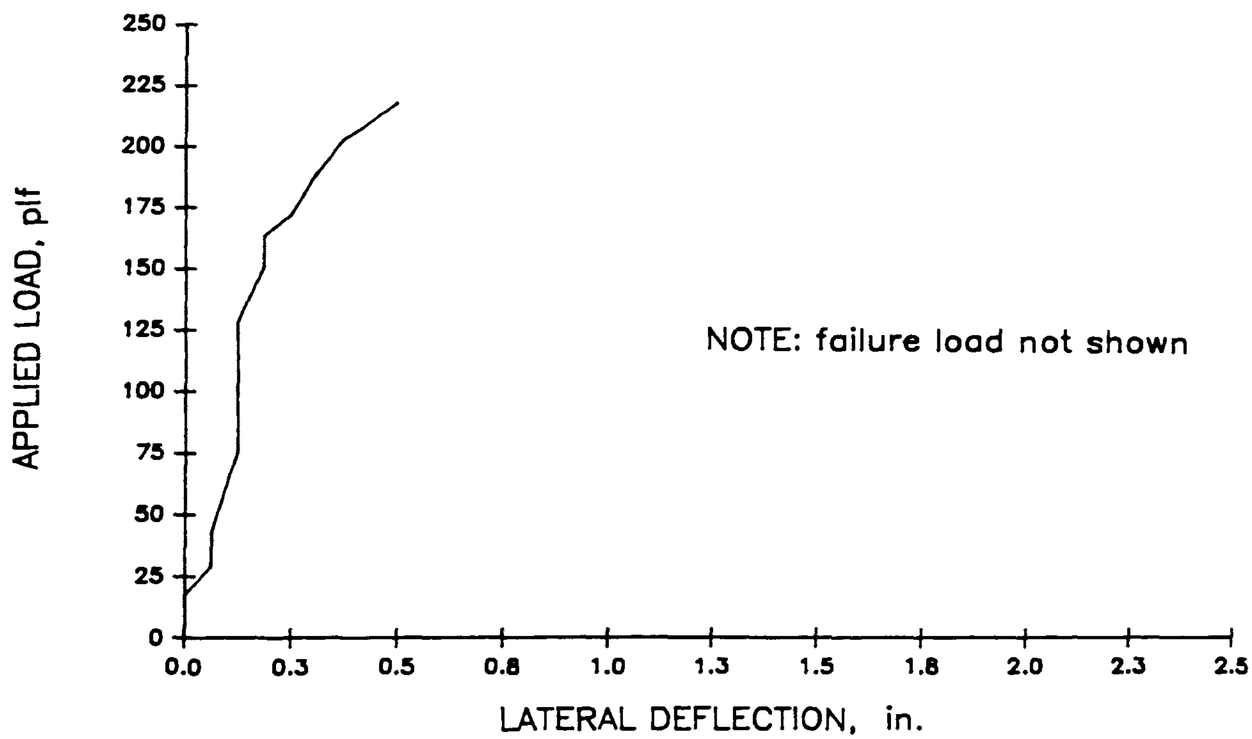
LOAD VS. DEFLECTION, TEST Z–T–R/S–3, EAST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z–T–R/S–3, EAST SPAN



LOAD VS. DEFLECTION, TEST Z-T-R/S-3, WEST SPAN



LOAD VS. LATERAL PANEL DEFLECTION, TEST Z-T-R/S-3, WEST SPAN