Research Report

ANCHORAGE FORCES IN TWO PURLIN LINE STANDING SEAM Z-PURLIN SUPPORTED ROOF SYSTEMS

by

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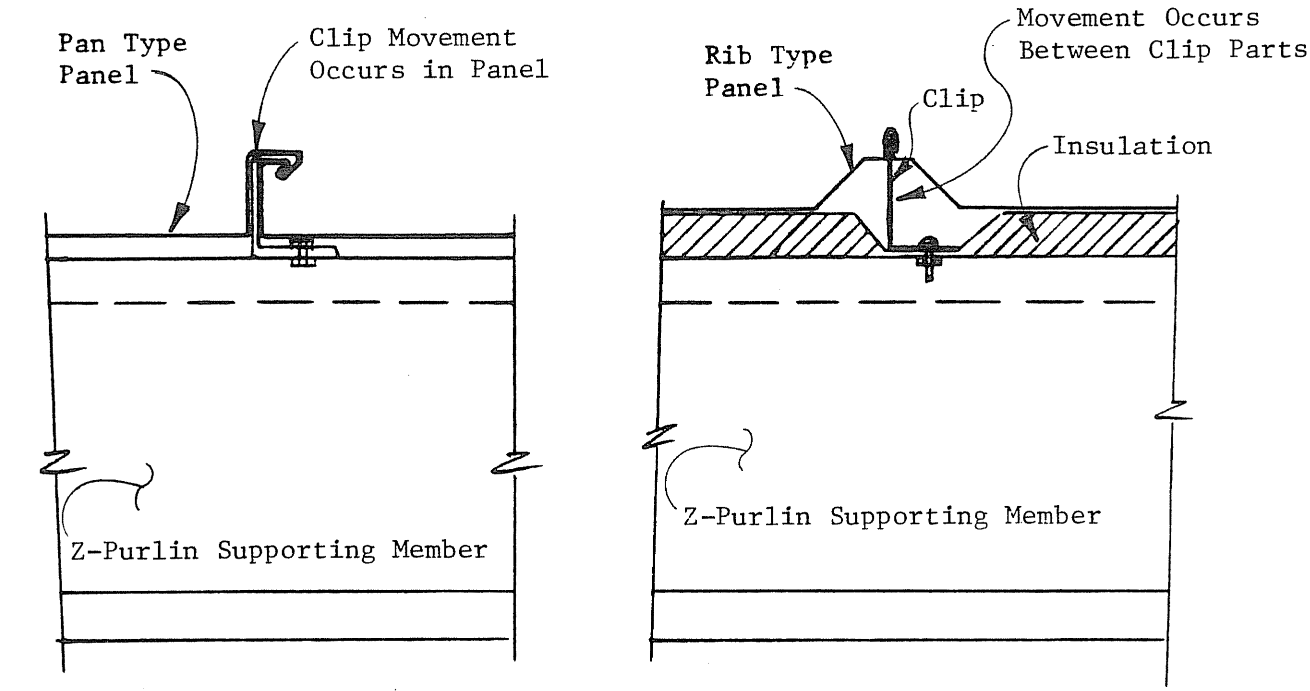
CHAPTER 1

INTRODUCTION

1.1 Scope of Research

A research program to experimentally study the behavior of Z-purlin supported standing seam roof systems is reported herein. The study was conducted at the Fears Structural Engineering Laboratory, University of Oklahoma, under the sponsorship of the Metal Building Manufacturers Association (MBMA). For the purposes of this report, a standing seam roof system is defined as a roof cladding composed of steel cold-formed sheets attached to supporting members with steel clips which permit longitudinal movement of the sheets with respect to the supporting members. Figure 1.1 shows details of typical standing seam roof systems with and without insulation systems. The principal advantage of a standing seam roof system is the elimination of penetrations through the panels. Typically, the only penetrations are near the eave where self-drilling or self-tapping fasteners are used to prevent the panels from sliding off of the roof or at sheet-to-sheet splice locations.

The primary purpose of the research was to verify current design equations for predicting anchorage forces in cold-formed Z-purlin supported roof systems. Although, not strictly required in the project, experimental failure loads were compared to predicted failure loads and computed assuming: (1) full lateral restraint, (2) constrained



a) Pan Type Panel Without Insulation   b) Rib Type Panel With Insulation

Figure 1.1 Typical Standing Seam Roof System Clip Details

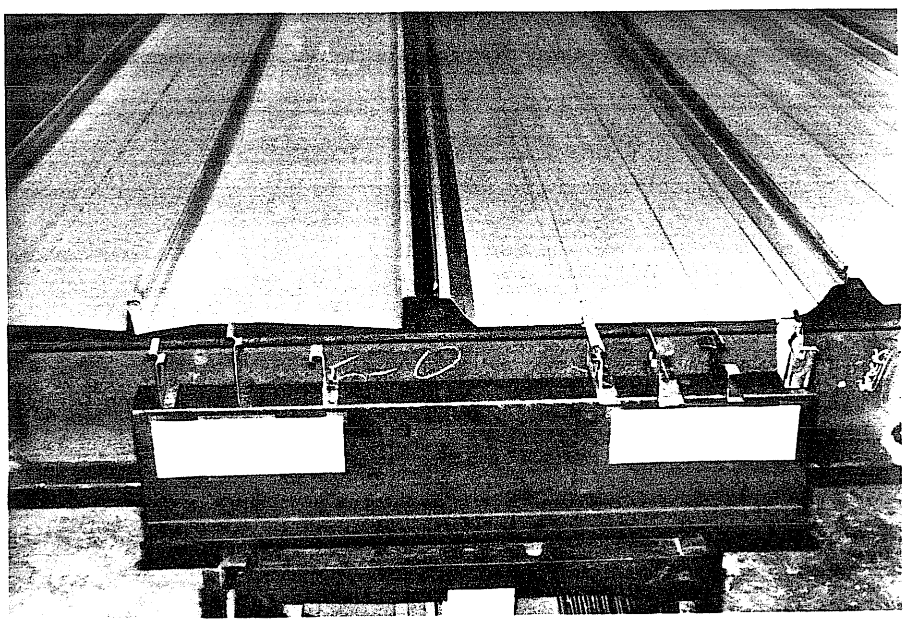
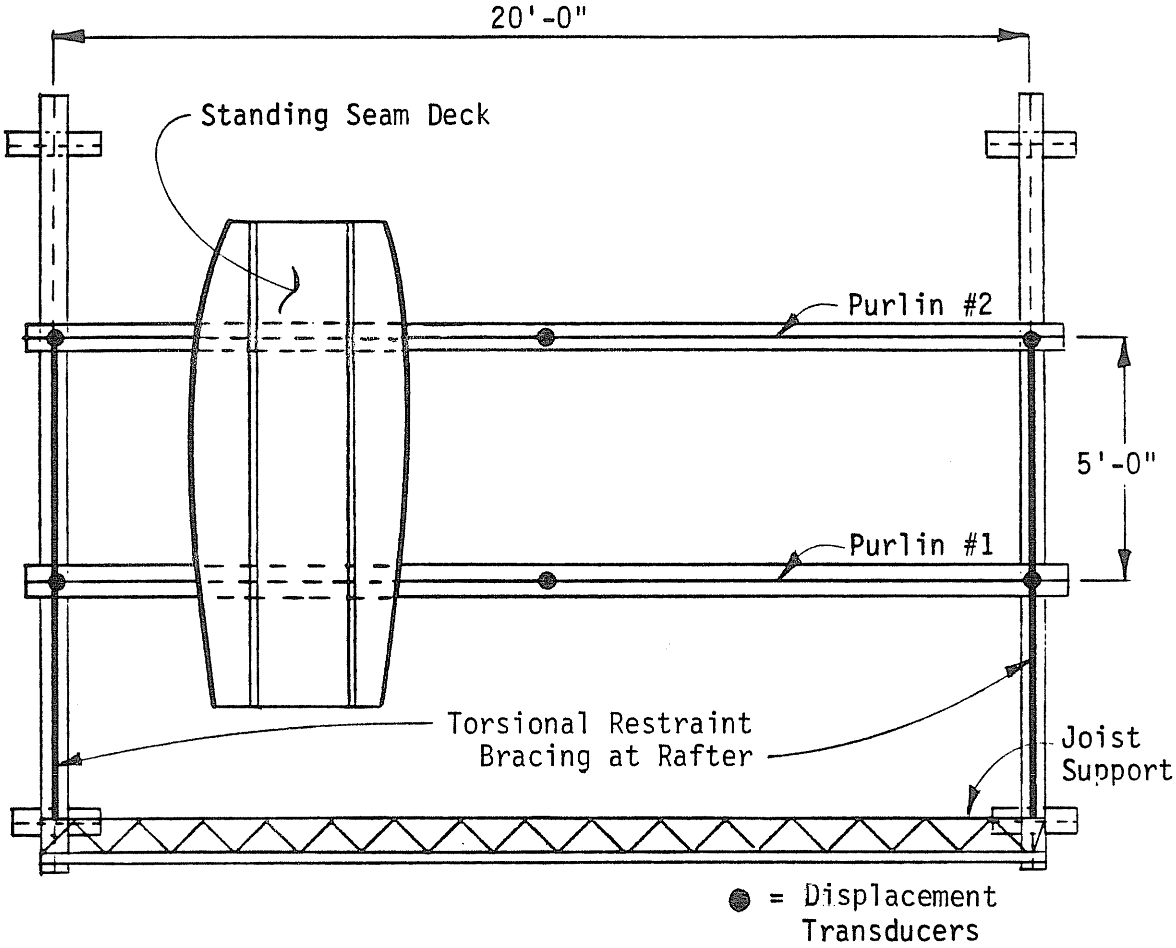
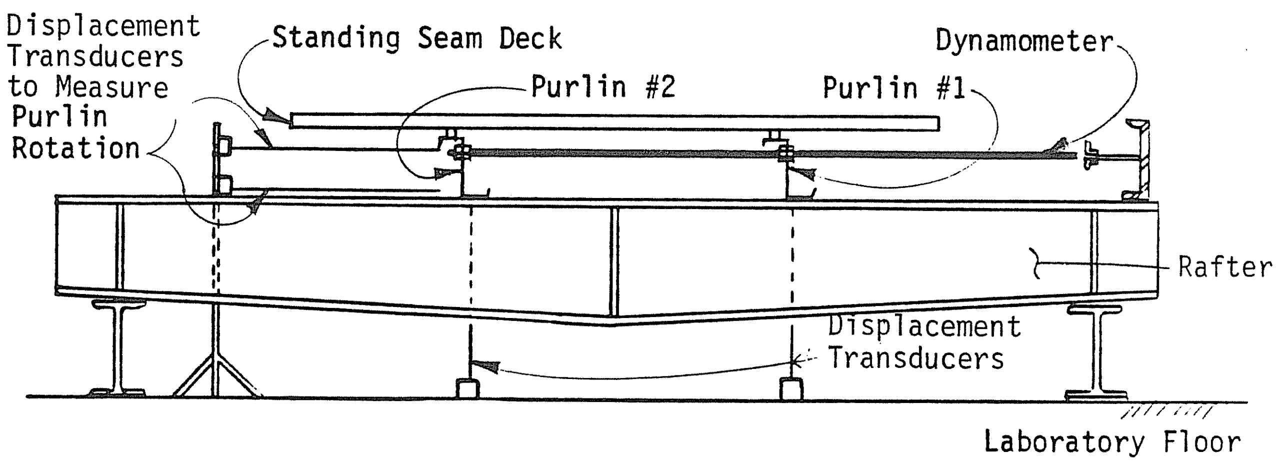


Figure 1.2 Photograph of Panel and Clip Types

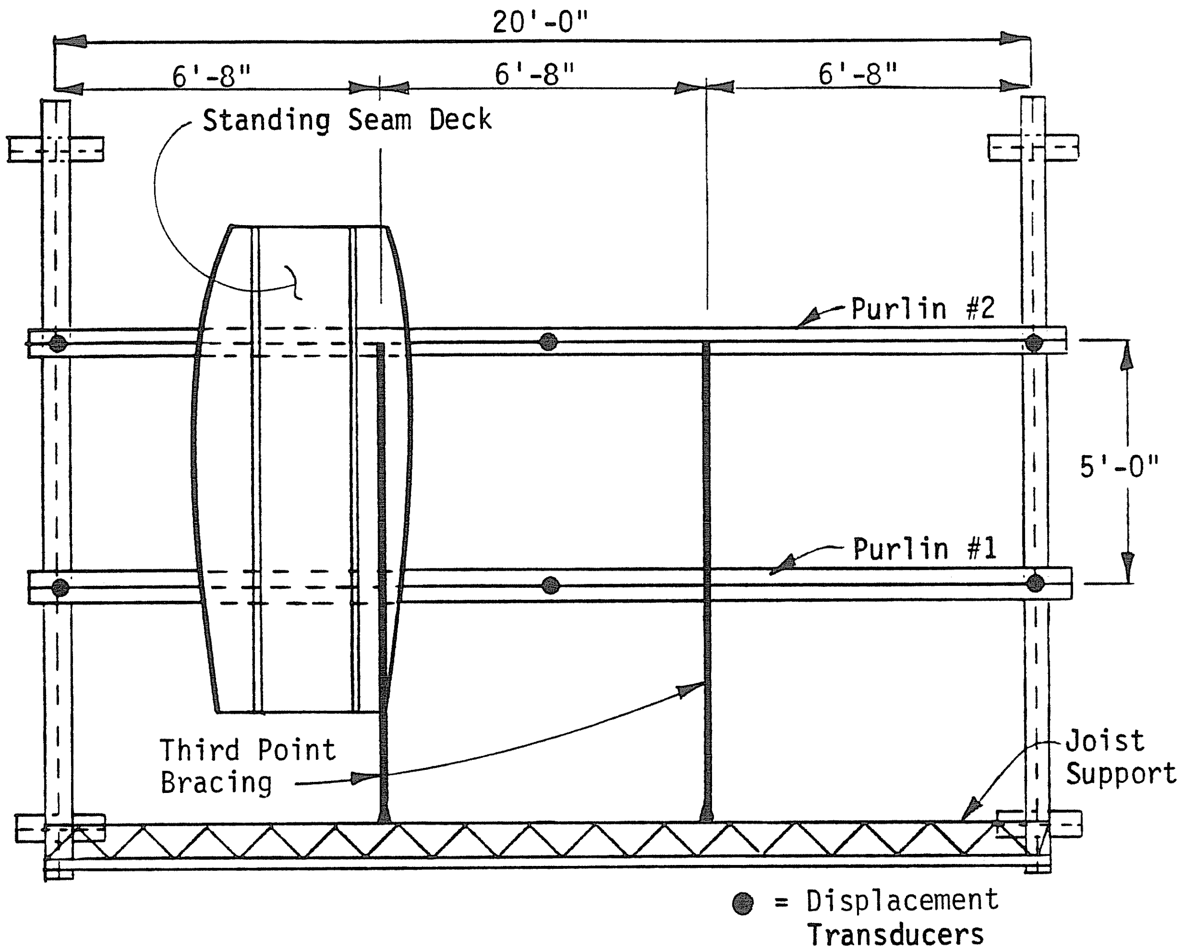


(a) Plan View

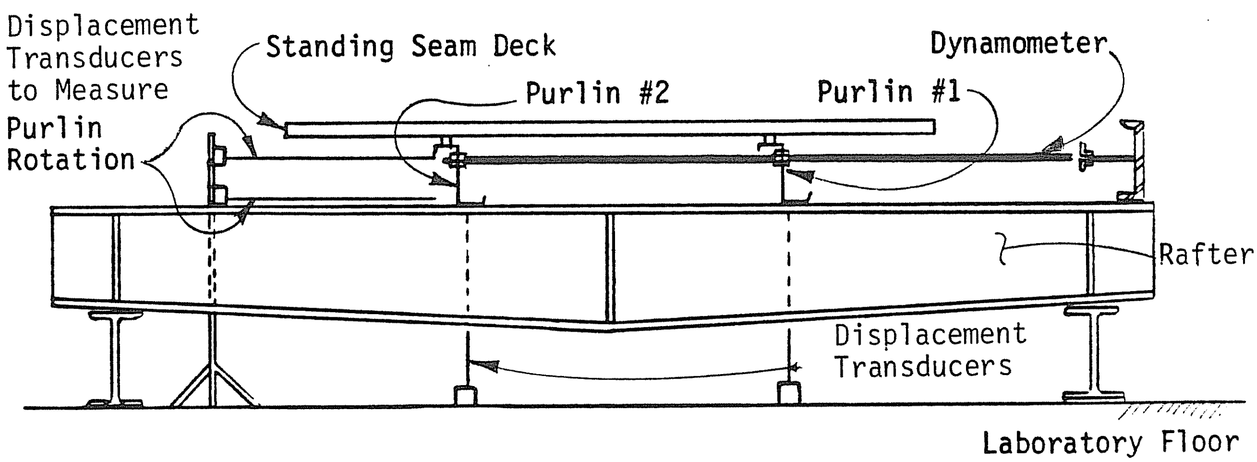


(b) Elevation

Figure 1.3 Simple Span Test Setup - Torsional Restraint

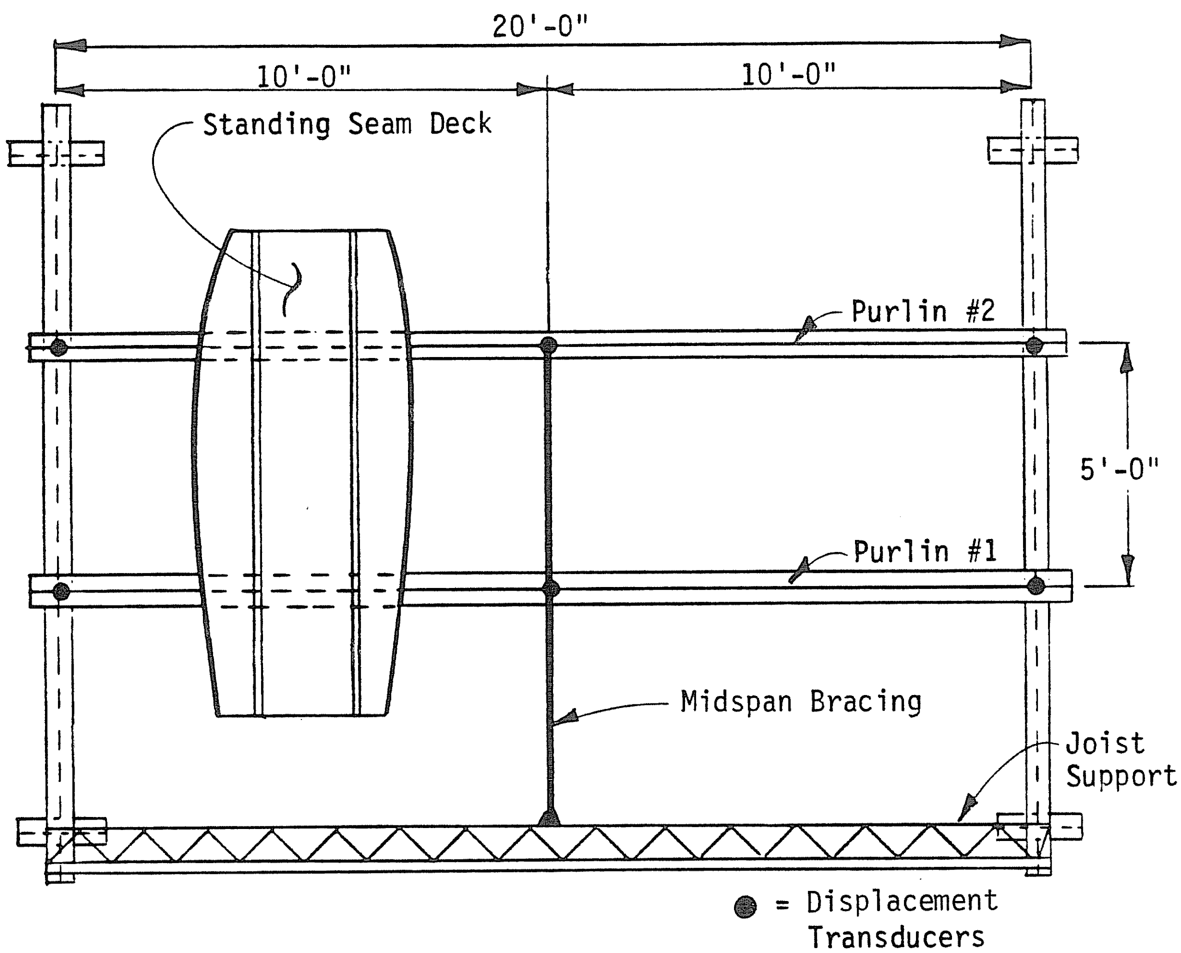


(a) Plan View

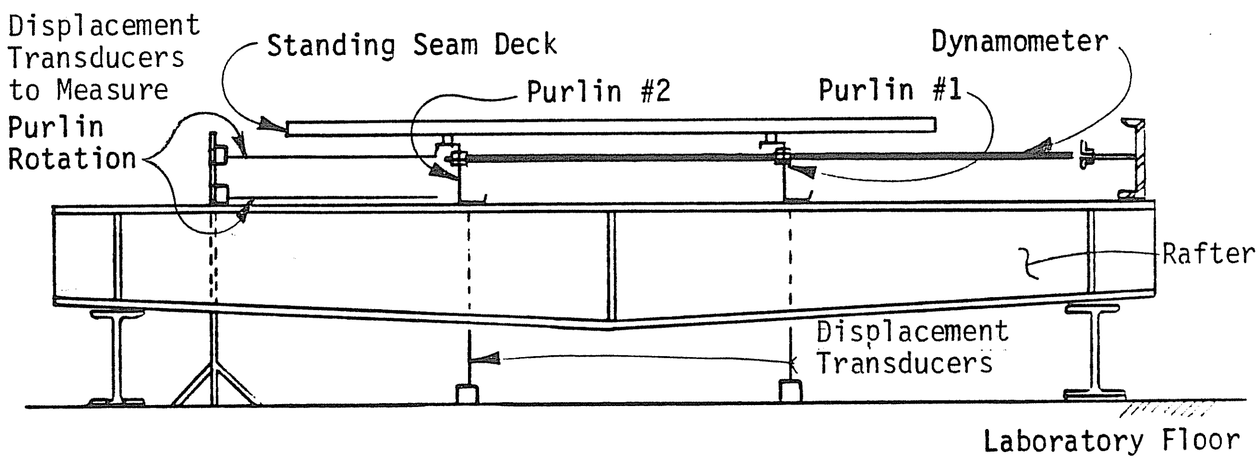


(b) Elevation

Figure 1.4 Simple Span Test Setup - Third Point Restraint

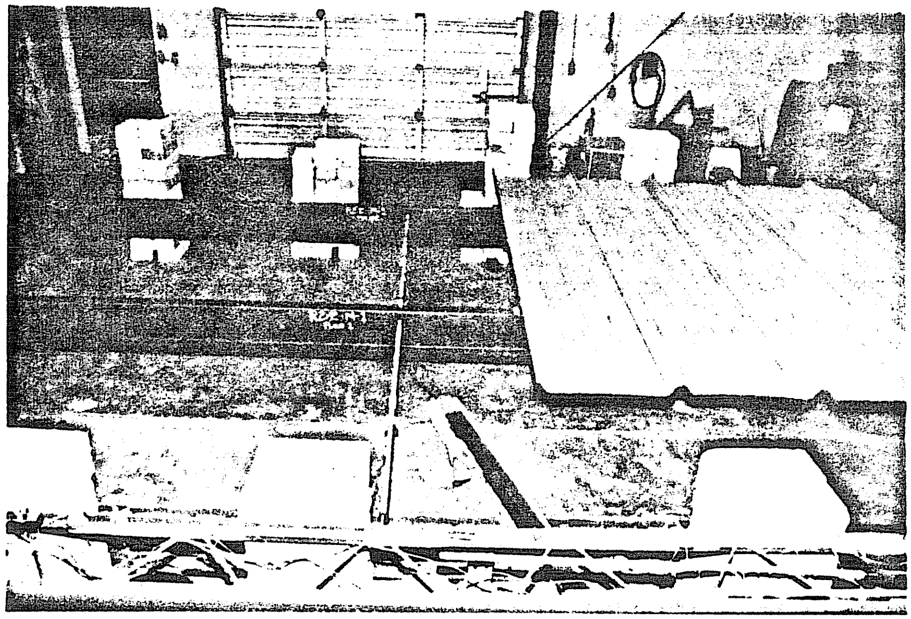


(a) Plan View

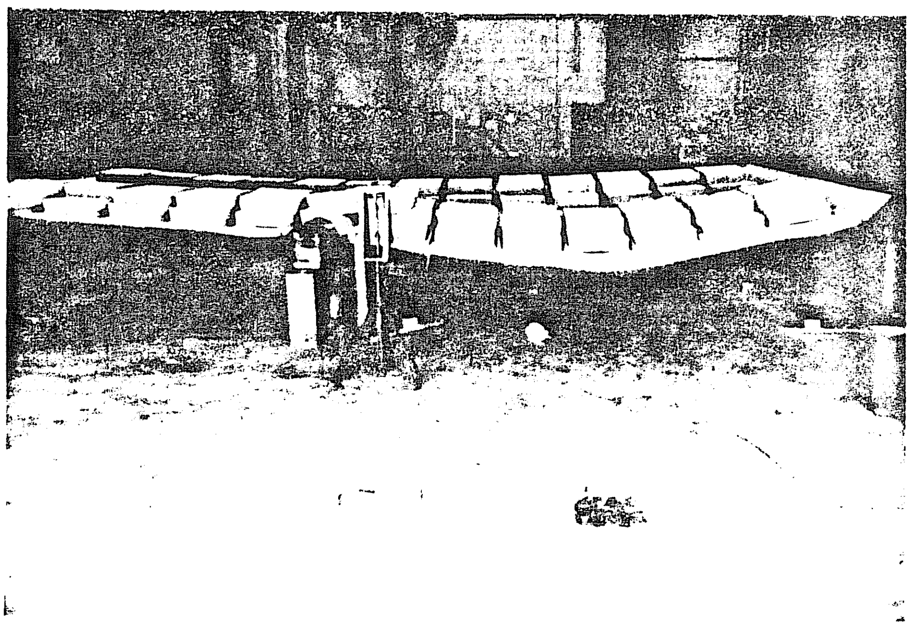


(b) Elevation

Figure 1.5 Simple Span Test Setup - Midspan Restraint



(a) Prior to Testing



(b) After Completion of Testing

Figure 1.6 Photographs of Single Span Test Setup

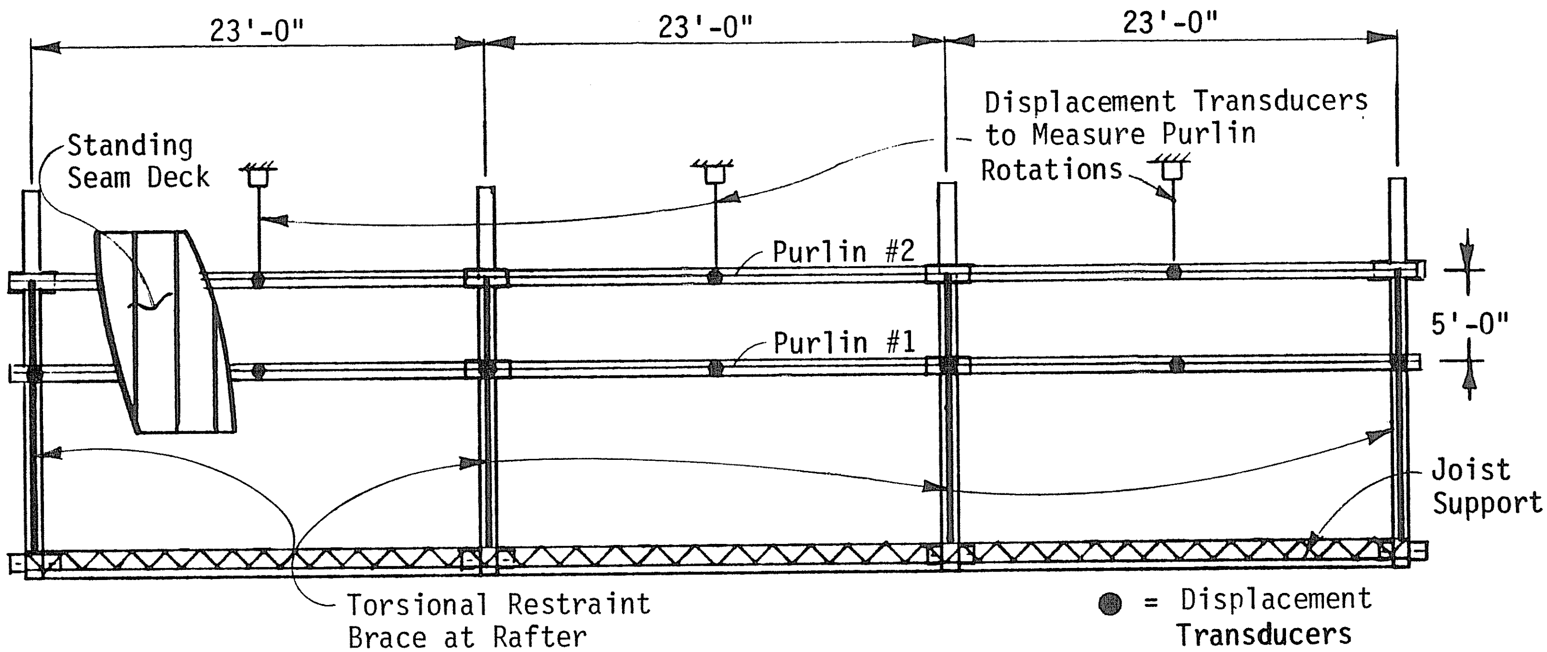


Figure 1.7 Continuous Span Test Setup - Torsional Restraint

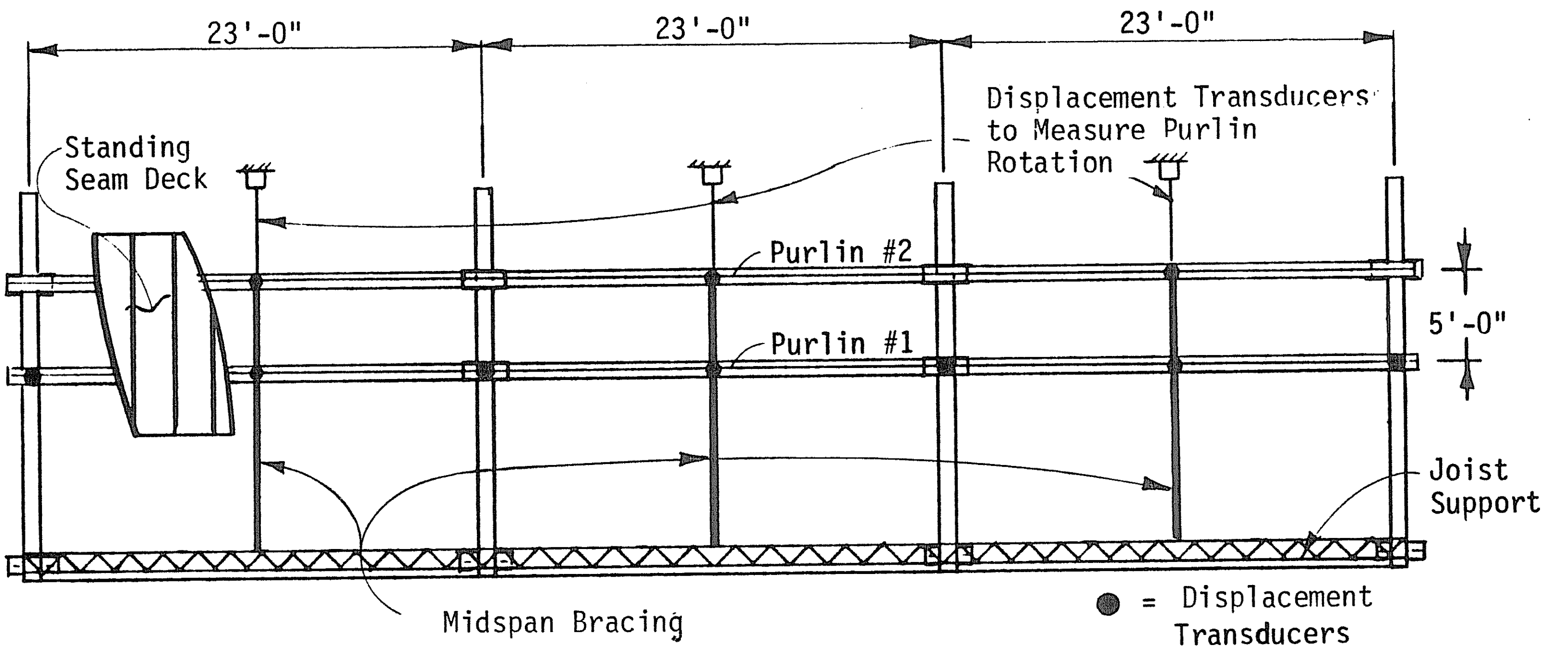


Figure 1.8 Continuous Span Test Setup - Midspan Restraint

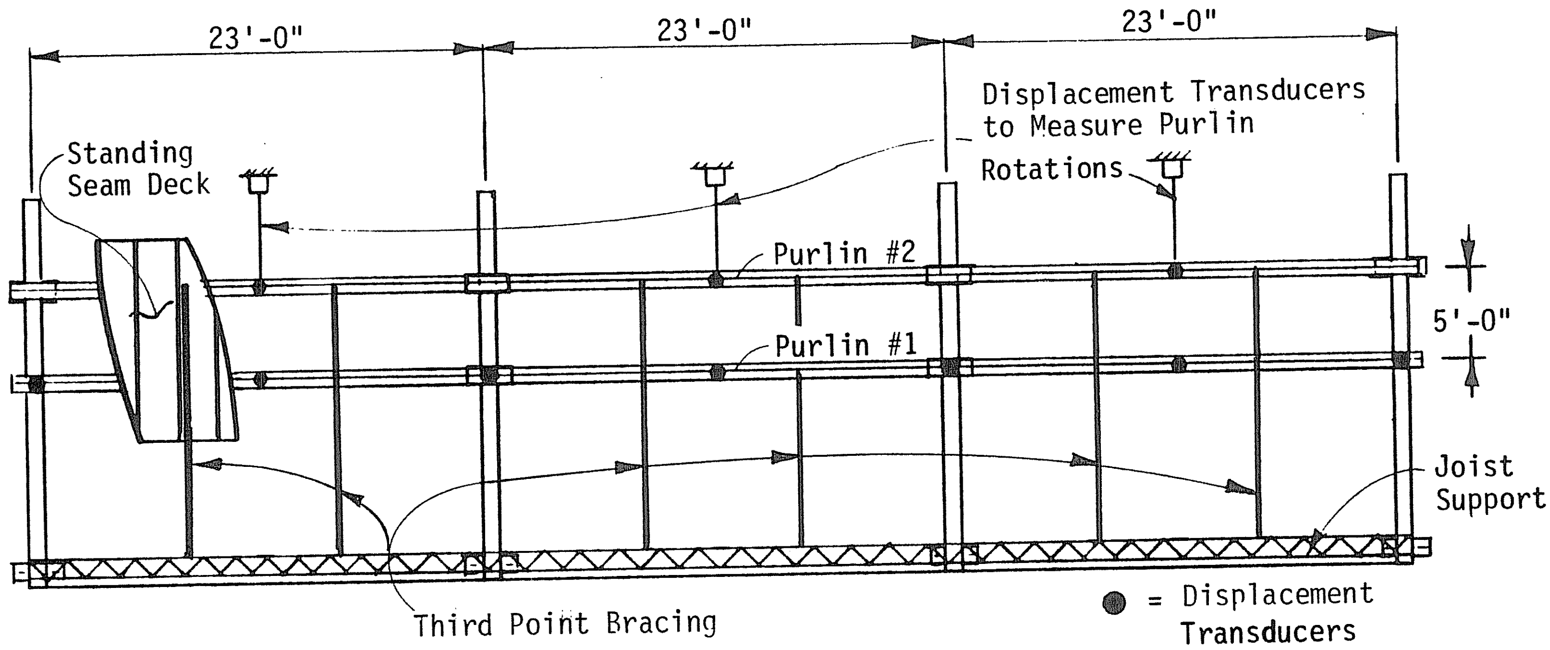


Figure 1.9 Continuous Span Test Setup - Midspan Restraint

bending and (3) 1986 AISI specification procedures. The predicted failure loads were then compared to experimental results.

To encompass as wide a variety of roof configurations as possible, several manufacturers' systems were tested. Three pan type, Figure 1.1(a) and three rib type, Figure 1.1(b), systems were used in the testing. The sliding clip configurations for each panel type are shown in the photograph in Figure 1.2. Clip heights were 3 in. and 4 in. and both two piece clips, where motion occurs within the clip parts, and one piece clips, where motion occurs between the panel and the clip, were used.

A total of twelve standing seam tests were conducted: six single span tests and six three-continuous span tests. In addition, one conventional (thru-fastener) single span test was conducted for comparison purposes. Span lengths were nominally 20 ft. for the single span tests and 23 ft. for the continuous span tests. In all tests, 8 in. deep Z-purlins, with top flanges facing in the same direction, were used. Three anchorage brace configurations were used, one with each of the two roof system types for each of the two span configurations. Table 1.1 gives the complete test matrix. Test designations are to be interpreted as follows: P1/2-R-1 indicates pan type panel #1 (P1), two purlin lines (/2), anchorage braces at rafters (-R), single span (-1) and R2/2-M-3 indicates rib type panel #2 (R2), two purlin lines (/2), anchorage braces at midspan (-M), three continuous spans (-3).

Three series of supplementary tests were also conducted. Results include comparison of predicted and measured anchorage forces, predicted and experimental failure loads, system restraint forces and diaphragm strengths.

Table 1.1

Test Matrix

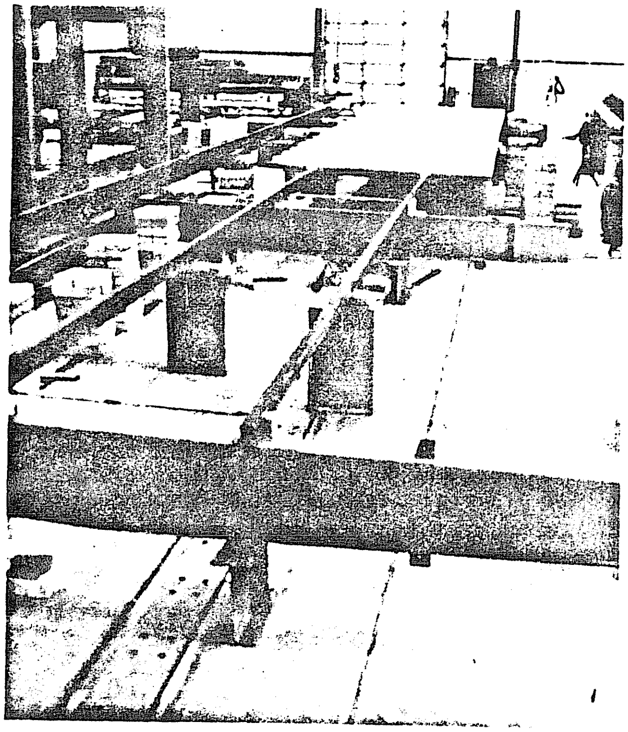
Test No.	Span(s) (ft.)	Panel Type	Clip Type	Bracing Configuration		
				Rafter Brace	Third Point Braces	Mid-Span Braces
P1/2-R-1	20.0	Pan	Two Piece	X		
P1/2-T-1	20.0	Pan	Two Piece		X	
P1/2-M-1	20.0	Pan	Two Piece			X
R2/2-R-1	20.0	Rib	Two Piece	X		
R2/2-T-1	20.0	Rib	Two Piece		X	
R2/2-M-1	20.0	Rib	Two Piece			X
P2/2-R-3	3 @ 23.0	Pan	Two Piece	X		
P2/2-T-3	3 @ 23.0	Pan	Two Piece		X	
P2/2-M-3	3 @ 23.0	Pan	Two Piece			X
R3/2-R-3	3 @ 23.0	Rib	Two Piece	X		
R3/2-T-3	3 @ 23.0	Rib	Two Piece		X	
R3/2-M-3	3 @ 23.0	Rib	Two Piece			X
CONV/2-R-1	20.0	Conv.	--	X		

1.2 Overview of the Testing Procedures

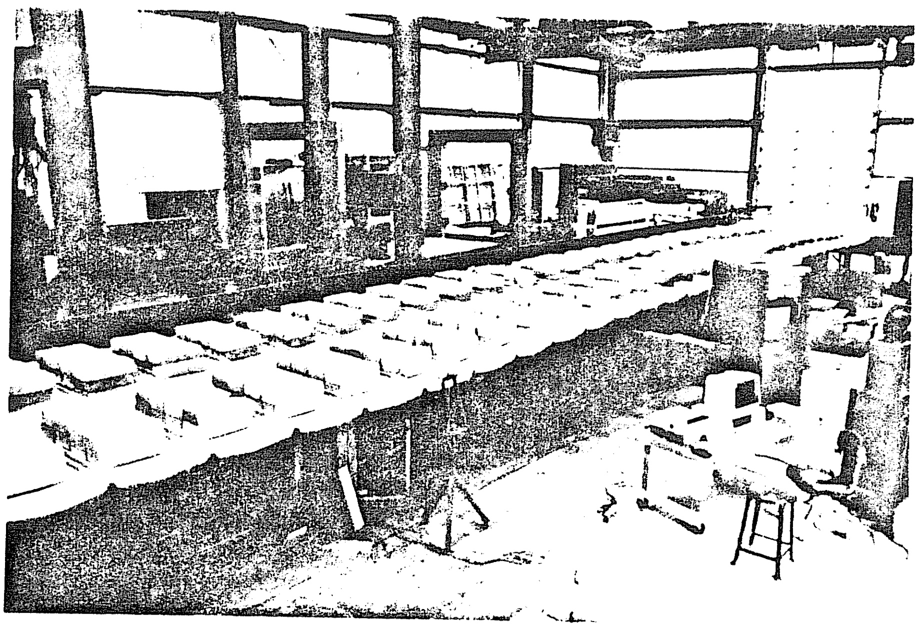
Details of the single span test setups are shown in Figures 1.3, 1.4 and 1.5. Photographs of the single span test setup are shown in Figure 1.6. For the torsional restraint anchorage configuration (Figure 1.3), anchorage braces are located at the rafters and provide a torsional simple support condition at the ends of the purlin. For the third point anchorage configuraton (Figure 1.4), anchorage braces are connected at the purlin span third points and restrain lateral movement at these locations. In the midspan restraint system (Figure 1.5), anchorage braces are connected to the purlins at midspan and restrain lateral movement at this location. The conventional roof system was tested using the torsional restraint anchorage configuration (Figure 1.3).

Details of the continuous span test setups are shown in Figures 1.7, 1.8, 1.9, which depict torsional restraint, third point restraint and midspan restraint, respectively. Photographs of the continuous span test setup are shown in Figure 1.10. The configurations are similar to the single span test setups.

Simulated live load was applied using concrete blocks. Vertical displacements were measured using displacement transducers located at the midspans of each purlin line. Anchorage forces were measured using calibrated dynamometers. Measurements were made at each anchorage location between purlin lines #1 and #2 and between purlin line #1 and the joist support. All data was taken and recorded using a microcomputer based data acquisition system with selected data being plotted at the time of testing.



a) Prior to Testing



b) After Completion of Testing

Figure 1.10 Photographs of Continuous Spans Test Setup

Several supplementary tests were conducted as part of the research program. A test setup was constructed to measure lateral restraint provided by the various panel/clip/insulation combinations under simulated live load. This setup is described in Section 2.3. A diaphragm test setup was constructed to determine the panel strength and stiffness of various test configurations. This test setup is also described in Section 2.3. Finally, coupon tests of Z-purlin material were conducted to determine yield stress, tensile strength and percent elongation.

Details of the testing and results are found in the following chapters. Complete data sets for each test are found in the appendices.

1.3 Review of Previous Research

Ghazanfari and Murray [1] conducted a study on the effect of parameter variation on anchorage forces in Z-purlin supported, conventional metal building roof systems. One of the parameters studied was the variation of lateral forces with an increasing panel shear stiffness. They found that the anchorage forces will increase from zero to a maximum as the panel shear stiffness is increased from zero to approximately 1500 lbs/in and then remain nearly constant as it is increased to infinity.

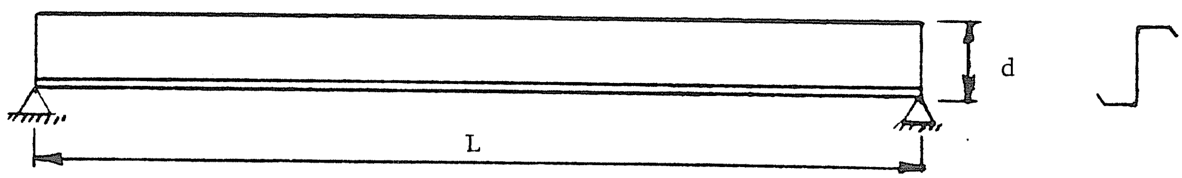
Curtis and Murray [2] reported the results of a series of tests that were conducted to study the accumulation of lateral forces when the number of purlin lines is increased. Tests were conducted using conventional roof systems supported by two, four, and six Z-purlin lines. It was found that the ratio of the anchorage forces-to-the-total applied vertical load decreases as much as 60% when the number of purlin lines is increased. The same conclusions were reported for tests conducted by Seshappa and Murray [3], who used cold-formed, quarter-scale Z-purlins to study the lateral restraint requirements for Z-purlin supported conventional roof systems. They conducted 28 quarter-scale tests, using single span and three-continuous span configurations with two to six purlin lines and different bracing configurations.

Elhouar and Murray [4] studied the anchorage requirements for thru fastener, corrugated steel panel, multiple purlin line, multiple span roof systems. A stiffness model was developed to predict the magnitude and distribution of the brace forces required to prevent lateral movement. They developed a hybrid space frame/space truss model to predict the external restraint forces. The stiffness method is used to obtain the results with the three main components being the purlin, panel and brace.

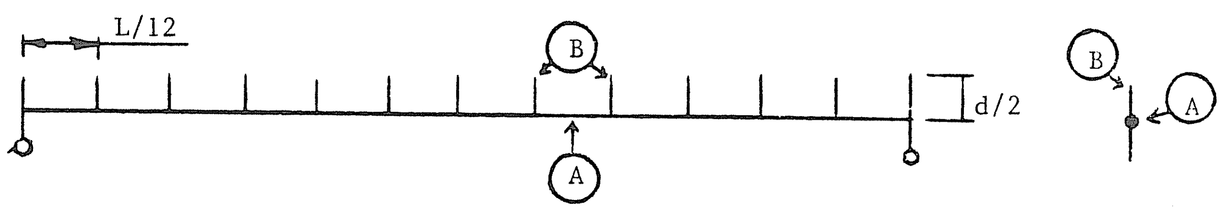
In their model, the purlin is divided into twelve space frame line elements, referred to as Type A elements as shown in Figure 1.11. The area and inertia properties are the same as the purlin cross section properties plus a torsional constraint which is 10.0 in^4 for full scale systems and 0.625 in^4 for quarter-scale systems. The Type B line elements shown in Figure 1.11 are to provide compatibility of displacements between the purlin and the panel rafter. The panel is represented by a plane truss as shown in Figure 1.12. For a known shear stiffness G', the deflection of a shear panel in the direction of the load P can be determined from [5]

$$\Delta = \frac{(PL)}{(4G'a)} \qquad (1.1)$$

where L and a are the dimensions of the panel. By applying the same load P to the truss shown in Figure 1.12(b), the



(a) Actual System



(b) Stiffness Model

Figure 1.11 Purlin Stiffness Model

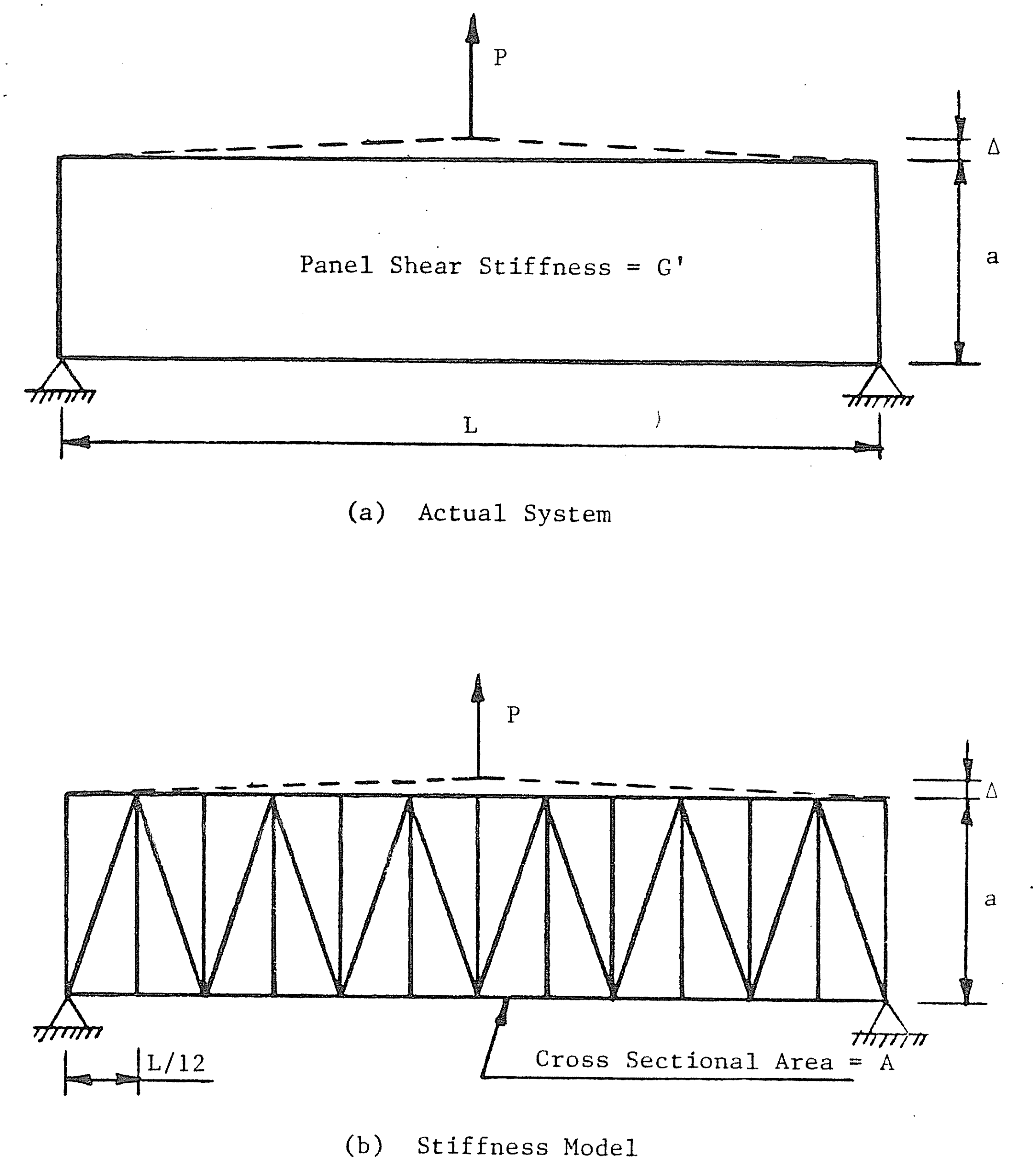


Figure 1.12 Panel Stiffness Model

area, A, of the truss members can be determined, and consequently, the truss will have the same stiffness G' when loaded at its midspan.

In an actual roof system, gravity loads are transmitted eccentrically to the purlins with respect to their shear center. To simplify the problem, Elhouar and Murray approximated this effect by using a triangular distribution. The system is then analyzed for a uniformly distributed vertical load, w, and a uniformly distributed torque, given by

$$M_x = w\ (b_f/3) \tag{1.2}$$

where b_f is the purlin flange width.

After experimental verification of the model and collecting sufficient analytical data, Elhouar and Murray performed a statistical regression analysis to develop a single expression for each of the three anchorage configurations, written in terms of the purlin cross section dimensions, number of purlin lines, number of spans and span length, to determine the anchorage force requirements. Three lateral restraint configurations were considered; (1) torsional restraint at the rafters; (2) third point restraints in each span, and midspan restraint in each span. The results of this work form Section D3.2.1 of the 1986 AISI Specification [6].

To the writers' knowledge, no research has been previously conducted on anchorage forces for Z-purlin supported, standing seam roof systems. Consequently, the model developed by Elhouar and Murray, which will be referred to herein as the Elhouar Model, will be used to predict anchorage forces for the Z-purlin supported, standing seam roof systems tested.

CHAPTER II

TEST DETAILS

2.1 Test Components.

Z-Purlins. The Z-purlins used for this test were supplied by MBMA. All Z-purlins dimensions shown in Figure 2.1 were carefully measured prior to testing. The measured dimensions are found in Appendix A for the simple span tests and in Appendix B for the continuous span tests.

Panels, Clips and Fasteners. All standing roof system components were also supplied by MBMA. The standing seam panels were categorized as pan or rib (Figure 1.1). The panel widths varied from 16 in. to 24 in.; panel thickness was nominally 24 gage.

Two types of clips were supplied: one piece clips and two piece floating panel clips. In systems using one piece clips, motion occurs between the panel seam and the clips. When two piece clips are used, motion occurs between the clip parts. Both clip designs allowed for expansion and/or contraction from a center point. Two clip heights were used: 3 in. and 4 in. ?

Each clip was attached to the supporting Z-purlins by standard 1/4 in. diameter machine bolts so that the test

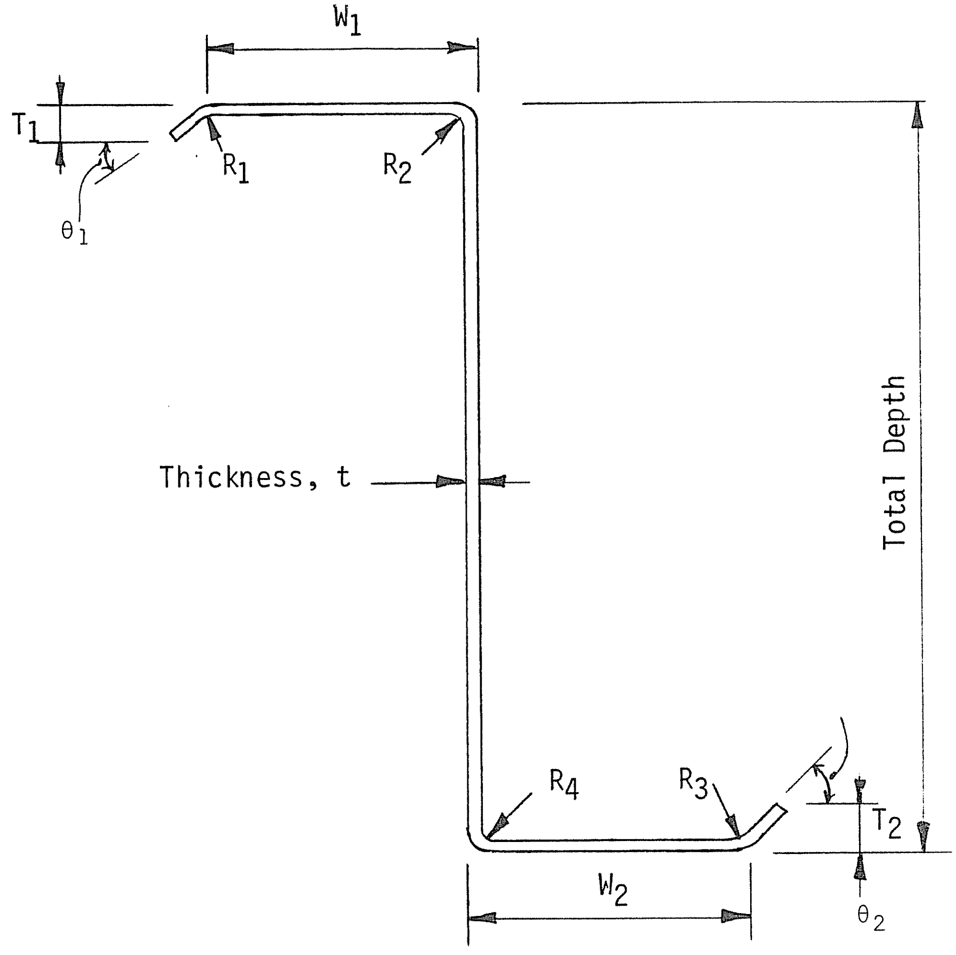


Figure 2.1 Purlin Cross-Section and Geometric Parameter

setup could be easily disassembled upon completion of testing.

2.2 Anchorage Force Tests Test Setups.

Test Setup. General details of the anchorage force test setups are shown in Figures 1.4 through 1.10. The purlins were attached to the supporting rafter sections using 1/2 in. diameter machine bolts through the bottom flanges of the purlins and the top flanges of the rafters. Two 1/2 in diameter rollers were inserted between the rafter sections and the column supports to allow the rafter sections to rotate.

For all tests, the anchorage braces (calibrated dynamometers) was placed 2 1/4 in. from the top flange of the Z-purlin as shown in Figure 2.2. In the three span test setups, the purlins were lapped 24 in. over the interior rafters and fastened together using the bolt pattern shown in Figure 2.3. Four 1/2 in. machine bolts were used to connect the overlapping purlin webs.

Instrumentation. Instrumentation consisted of calibrated dynamometers, strain gages, dial gages, and linear displacement transducers. The calibrated dynamometers were typical intermediate or torsional anchorage (restraint) braces with a full strain gage bridge installed at approximately the brace midlength. The braces were then calibrated using a universal testing machine. Calibrated dynamometer locations are shown in Figures 1.3 through 1.5 and 1.7 through 1.9 for the single and continuous span tests, respectively.

Linear displacement transducers were used to measure both vertical and horizontal displacements of the purlins.

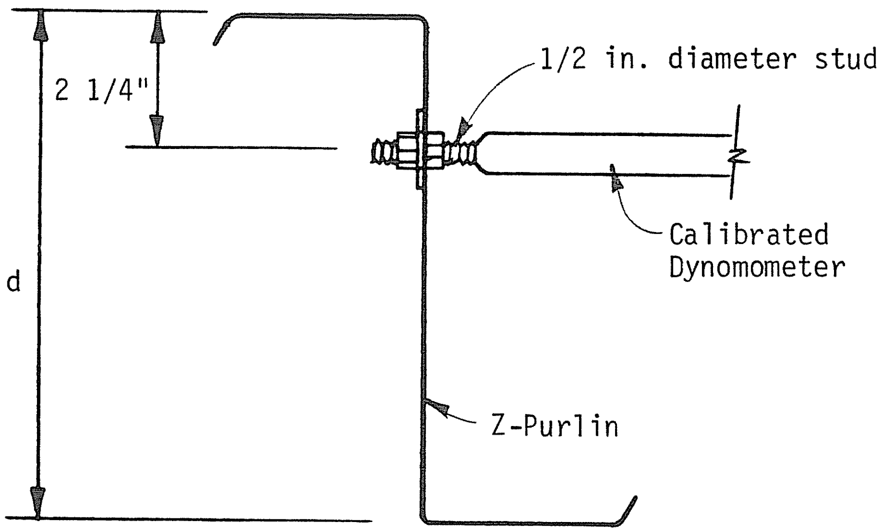


Figure 2.2 Detail of Bracing-to-Purlin Connection

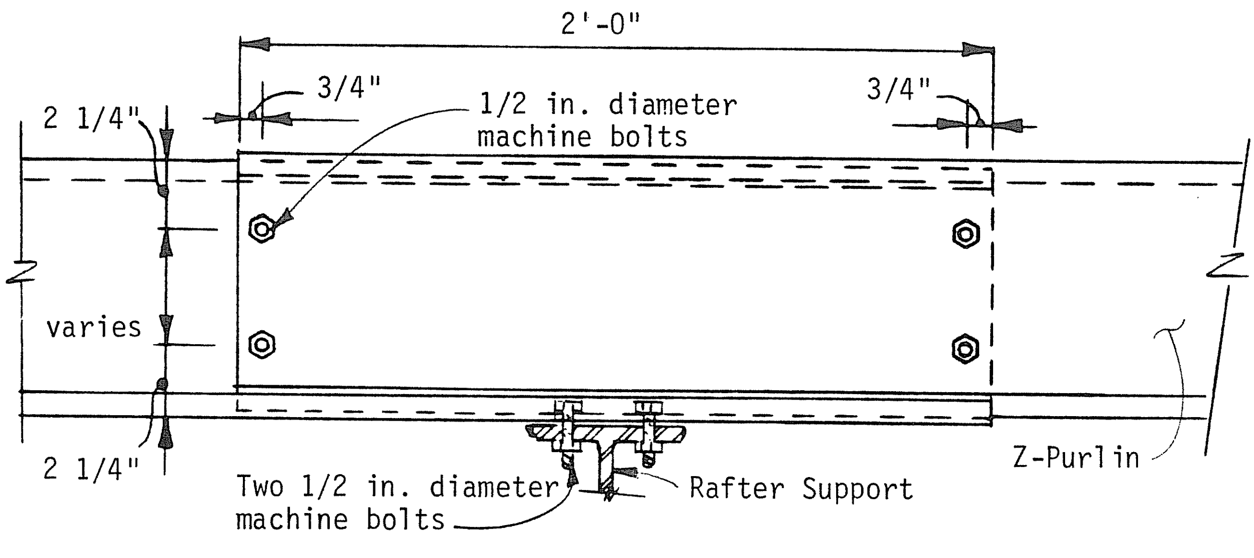


Figure 2.3 Details of Interior Purlin Connection
Used in Continuous Span Tests

The vertical displacements of the rafters supporting the purlins were measured, averaged and subtracted from the centerline purlin deflection to obtain the true vertical purlin deflection. Horizontal displacements at the midspans of the second purlin line were measured as shown in Figure 2.4. Two displacement transducers were used to measure the lateral displacement of points near the top and bottom flanges of the purlin. The displacement transducers were mounted on a plate that could be positioned vertically so that the measurement wires remained horizontal when the loaded purlin deflected downward. The average measurement of the two displacement transducers was recorded as the midspan lateral displacement of the test setup. The distance between the two measurements divided by their vertical spacing was recorded as the midspan purlin rotation. Horizontal displacements at the midspan of the reaction joists were also monitored so that true horizontal displacements could be obtained.

Gravity load was measured by the number of concrete blocks (solid, 4 in. by 8 in. by 16 in.) placed on the test purlins. A number of randomly selected blocks were weighed prior to testing; their weight was found to be 33±0.1 pounds each.

All data for each test was read, processed, printed and plotted using a computer based data acquisition system.

Testing Procedure. At the beginning of each test, a uniform load of approximately 10% of the estimated failure load was applied to the roof system. Readings were taken and plotted to check the behavior of the roof system and the operation of the data acquisition system. Following this initial loading, zero readings were recorded for all dynamometers, strain gages and displacement transducers.

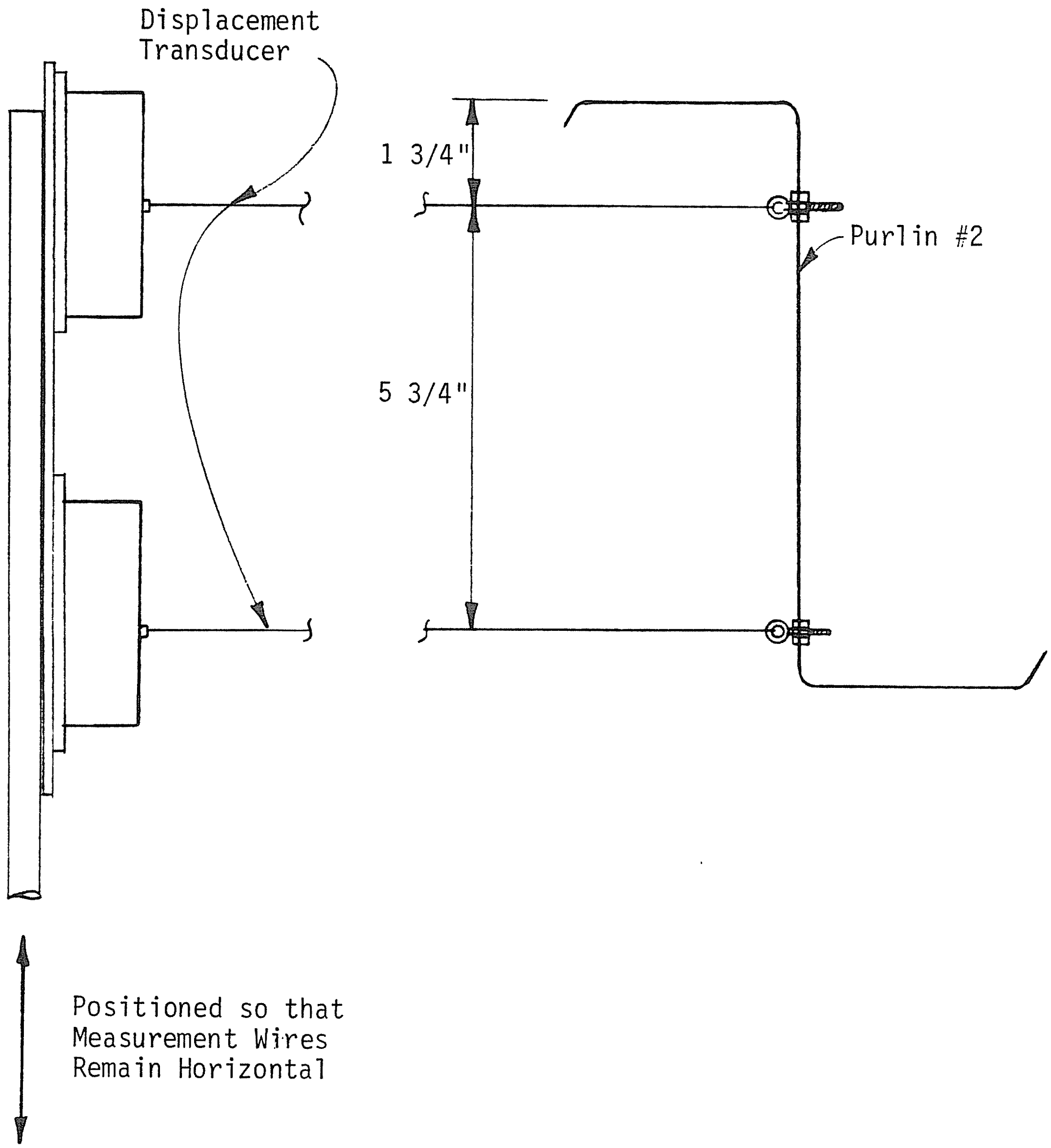


Figure 2.4 Instrumentation for Measurement of Purlin Lateral Displacements

The system was then loaded in approximately 12 plf increments until near the failure load when the loading increment was reduced to approximately 4 plf. The system was loaded until failure occurred and the failure mode and other observations were recorded for each test.

2.3 Supplementary Tests.

Coupon Tests. Table 2.1 lists the measured material properties obtained from eight coupon tests. The coupon material was removed from undamaged areas of randomly selected purlins upon completion of testing. The average yield stress was 56.6 ksi. This value was used in all theoretical calculations.

System Restraint Tests. To determine the capability of the various panel-to-purlin connection clips and of panel "hugging" or "drape" to provide lateral restraint to a purlin flange, a special test fixture and procedure was used. The fixture consisted of two short sections of 8 in. deep joists connected to a support frame, four connection clips, three panels 10 ft. long, an air bag, a containment box, an air compressor, a load cell, a double action hydraulic cylinder, an electric hydraulic pump, two displacement transducers and a high-speed computer based data acquisition system. The setup details are shown in Figure 2.5. Figure 2.6 is a photograph of the setup.

To assemble a test setup, standing seam roof system clips were first bolted (to permit reuse) to the purlins and insulation (if used) and panels installed using standard procedures. The assembly was then turned over and placed on the air bag in the containment box. The hydraulic ram was then connected to the support frame using a linkage containing calibrated load cells.

Table 2.1

Purlin Material Tensile Coupon Test Results

Test No.	Thickness (in.)	Width (in.)	Yield Stress (ksi)	Tensile Stress (ksi)	Elongation (%)
1	0.069	0.494	57.1	78.5	N.A.
2	0.072	0.506	61.7	76.8	N.A.
3	0.072	0.503	55.6	78.1	N.A.
4	0.072	0.508	56.3	78.7	27.5
5	0.069	0.462	57.4	78.7	22.6
6	0.072	0.461	55.5	76.8	24.1
7	0.072	0.462	55.9	78.5	24.3
8	0.072	0.464	53.6	76.9	26.0
Avg.			56.6	77.9	24.9

N.A. = Not Available

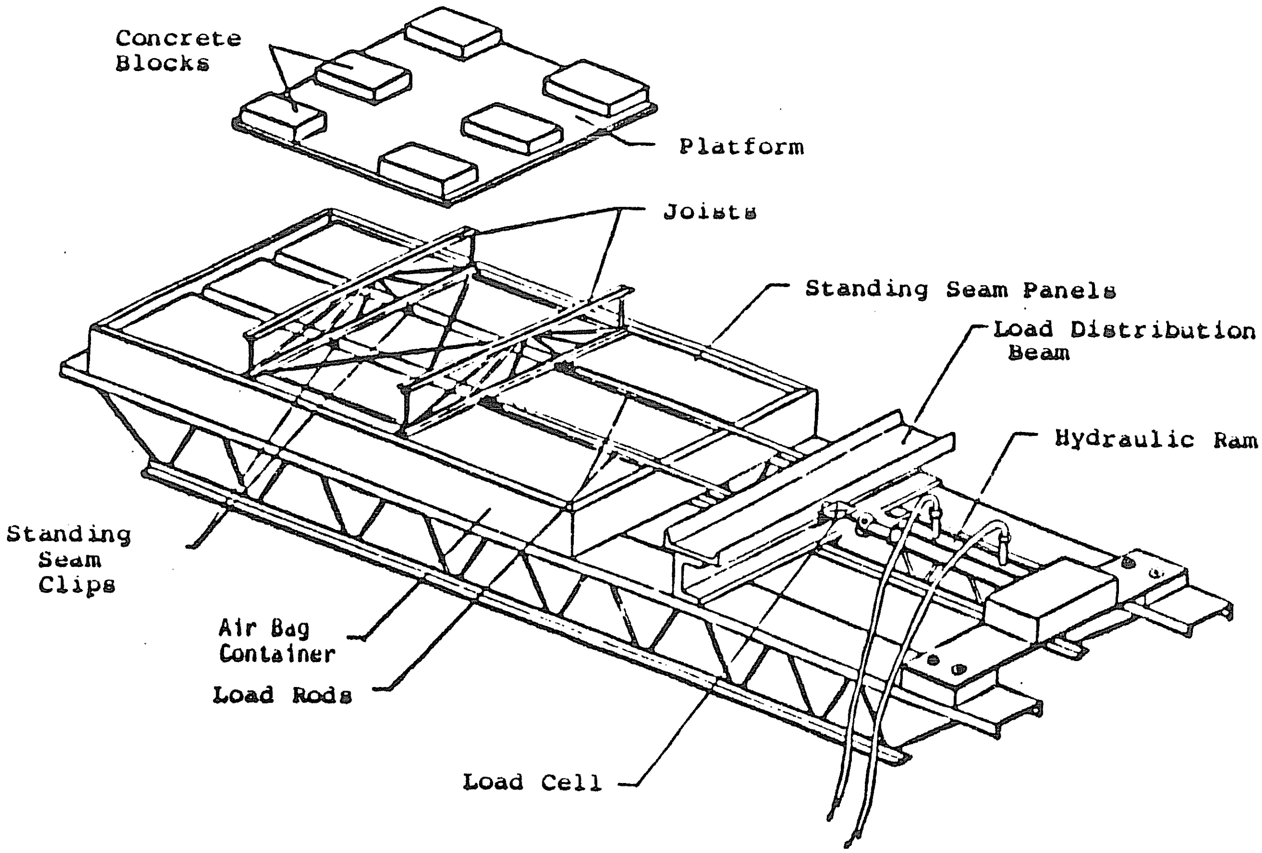


Figure 2.5 System Restraint Test Setup

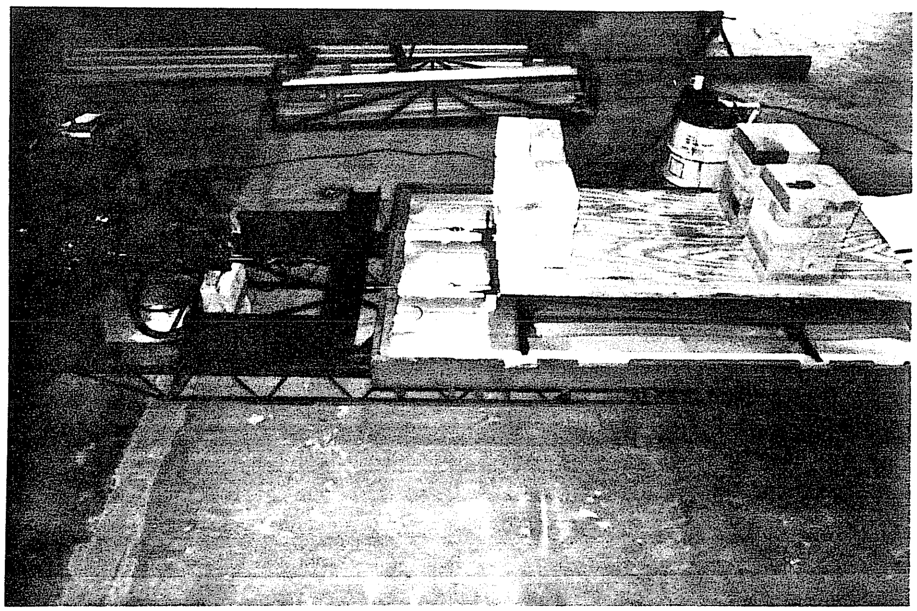


Figure 2.6 Photograph of System Restraint Test Setup

To perform a test, concrete blocks were first placed on the support frame. Air was then pumped into the air bag until the supported frame was free of the containment box and the weight of the blocks was balanced by the pressure in the air bag. Using the hydraulic ram, force was applied transverse to the panel until the support frame moved relative to the panel. The displacement transducers were used to measure the motion of the support frame relative to the panel. The load cell was used to measure the applied force. The force and displacements were measured and plotted in real time using the data acquisition system. The data acquisition system for this series of tests consisted of a 16 channel high-speed A/D converter, a 64 bit micro-processor and a high-speed plotter.

Results from these tests are discussed in Section 3.2.1.

Diaphragm Tests. The test setup used for the diaphragm tests is shown in Figure 2.7. Figure 2.8 is a photograph of the test setup. The setup consists of an exterior reaction frame constructed of built-up H-shaped sections and an interior panel support frame constructed of hot-rolled C-sections. All connections in the exterior frame are moment resistant and all connections in the interior frame are pinned. Both frames are in the same horizontal plane. The interior frame is supported on large casters which permit relatively free movement on the laboratory floor.

The test assemblies were approximately square with one Z-Purlin at the panel mid-depth. Standard sliding seam roof system clips were used to attach the panels to the Z-purlin. The perimeter edges of the assembly were bolted to the interior support frame with 1/4 in. diameter machine bolts, 6 in. on center. The tests were conducted without

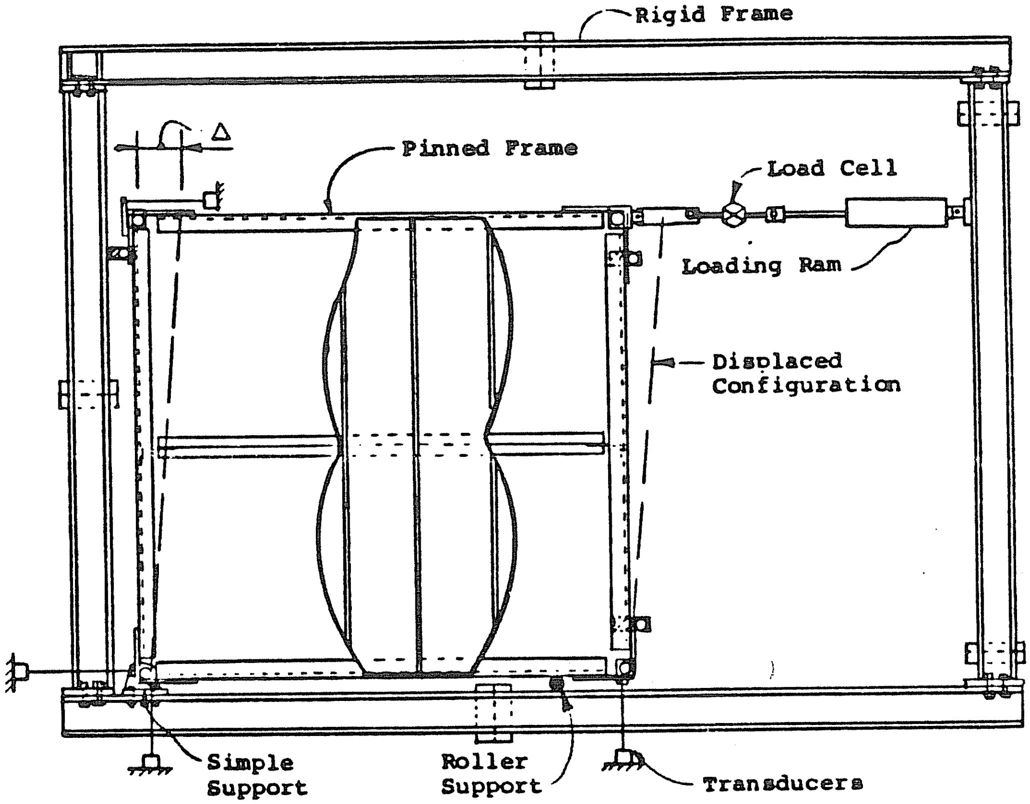


Figure 2.7   Diaphragm Test Set-up

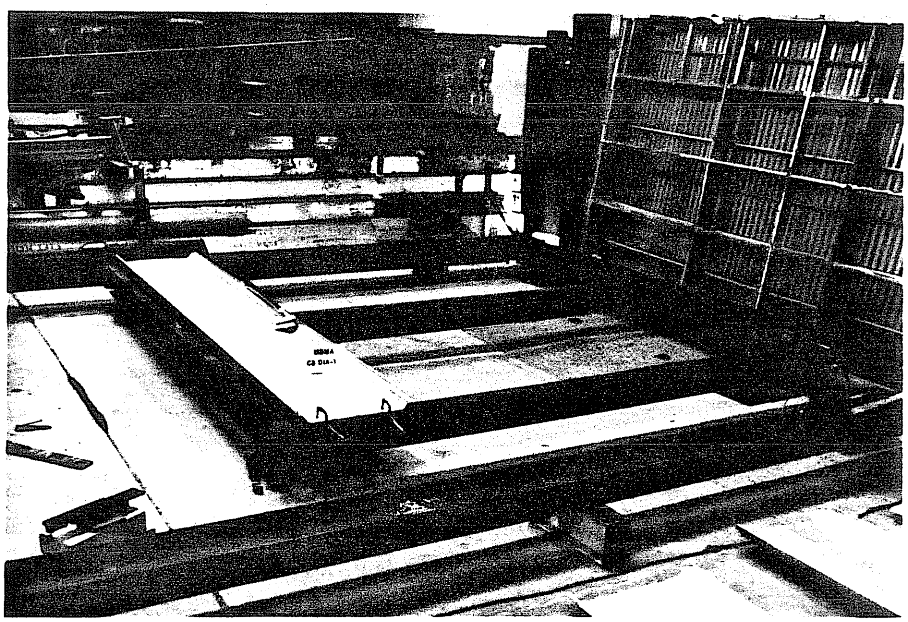


Figure 2.8 Photograph of Diaphragm Test Set-up

insulation between the panels and supporting purlin and frame.

To conduct a test, load was applied using a 35 kip capacity, dual action, hydraulic ram and electric pump. The load was monitored with a calibrated 10 kip capacity load cell and associated instrumentation. The loading procedure consisted of a preload and a final load applied in increments.

Displacement of the interior frame was measured, in the direction of the applied load both at the top and bottom of the interior frame. The measured deflections were averaged to eliminate torsional effects. Displacements of the exterior reaction frame were measured at support locations (Figure 2.7). All readings were recorded, using a micro-computer based data acquisition system, and corrections were made to measured horizontal displacements to account for movement of the supporting frame.

CHAPTER III

TEST RESULTS

3.1 Anchorage Force Tests

3.1.1 General

Test results consist of load versus anchorage force, load versus vertical deflection and load versus purlin rotation data, along with experimental failure loads. Load vs. deflection data includes plots of simulated live load vs. vertical deflection and live load vs. purlin rotation at the midspan of each purlin.

The Elhouar Stiffness Model described in Section 1.3 was used to determine the magnitude and distribution of the required anchorage forces for the Z-purlin supported roof systems. The computer software package STRUDL (Structural Design Language), available on the IBM 3081 computer at the University of Oklahoma, was used to perform the analyses.

In the analyses, the panel is represented by a plane truss. The shear stiffness of the standing seam roof diaphragm, G', was assumed to be 1000 lb/in. By applying a load P to the truss as shown in Figure 1.12, and assuming an area, A, for all truss members, the deflection of the plane truss can be calculated. Assuming the system is linear elastic, the area of the truss members can then be adjusted to produce the same deflection as the standing seam diaphragm with an assumed G' of 1000 lbs/in. The area of the truss members was calculated to be 0.0118 $in.^2$ and 0.0113 $in.^2$ for the single span and continuous span test setups, respectively.

The vertical deflection plots also include theoretical deflection as computed assuming constrained bending. For the single span test series:

$$\Delta_c = \frac{5wL^4}{384\ EI} \tag{3.2}$$

where Δ_c = midspan deflection, I = the moment of inertia of the purlin with respect to the horizontal axis, w = uniform load, L = span, and E = modulus of elasticity. In the continuous span test series, theoretical deflections were computed using a stiffness analysis with twice the moment of inertia and twice the cross-sectional area for the 24 in. long lapped moment connection.

Results for the single span and continuous span test series are found in Appendices A and B, respectively. A data package for each test is provided and includes a summary sheet, purlin measurements, failure load analyses results, load versus anchorage force plots and load versus purlin movement plots.

3.1.2 Single Span Test Series

These tests were conducted to determine the magnitude of anchorage forces in two purlin line, cold-formed Z-purlin supported, standing seam roof systems. Six tests were conducted to failure of the roof systems. Three bracing configurations, midspan restraint, third point restraint and bracing at the rafter, were used with pan and rib type decks. In addition, one test using a conventional, thru fastener roof system with rafter bracing was conducted. The data summaries for each of the seven tests are found in Appendix A. Excellent correlation was found between brace force predictions from the Elhouar Stiffness Model and experimental data (see figures in Appendix A.).

Plots of load versus vertical deflection and load versus purlin rotation are also found in Appendix A. Vertical deflections were generally 10-20% greater than predicted for systems with third point and midspan bracing. For the rafter bracing configurations, vertical deflections were non-linear and much greater than predicted.

Ultimate failure loads were computed assuming (1) full lateral constraint, (2) constrained bending and (3) the 1986 AISI Specification procedures for cross-section strength apply. The results shown in Table 3.1 were calculated using a yield stress of 56.6 ksi (average of the eight coupon test results) and have the AISI factor of safety removed.

Excellent agreement between predicted and experimental failure was found for the test conducted using the conventional, thru fastener roof system. For all of the standing seam system tests, the predicted failure load was substantially greater than, 128% to 348%, the experimental results.

3.1.3 <u>Continuous Span Test Series</u>

Applied load versus brace force plots for the three-continuous span test setups are found in Appendix B. A total of six tests were performed, three with rib type panels and three with pan type panels. Good to excellent

Table 3.1

Summary of Failure Load Results

Test No.	Experimental Failure Load (plf)	Failure Mode	Predicted Failure Load (plf)	Predicted Ld. / Exp. Load
P1/2-R-1	59.5	Lateral Buckling	207.2	3.48
P1/2-T-1	141.0	Local Buckling	216.4	1.53
P1/2-M-1	138.3	Local Buckling	210.8	1.52
R2/2-R-1	85.8	Local Buckling	198.9	2.32
R2/2-T-1	155.1	Local Buckling	204.9	1.32
R2/2-M-1	160.1	Local Buckling	205.6	1.28
P2/2-R-3	99.5	Lateral Buckling	233.3	2.34
P2/2-T-3	207.1	Local Buckling	281.2	1.36
P2/2-M-3	154.0	Local Buckling	248.5	1.61
R3/2-R-3	85.1	Local Buckling	252.6	2.97
R3/2-T-3	175.5	Local Buckling	253.7	1.45
R3/2-M-3	137.7	*Local Buckling @ 7-0" from support	249.4	1.81
CONV/2-R-1	198.0	Local Buckling	202.5	1.02

Note: *Not Typical Failure Mode

correlation was found between brace force predictions and experimental data using the Elhouar Model (see figures in Appendix B.)

Ultimate failure loads were computed using the same assumptions as described in Section 3.1.2. Standard stiffness analyses were used to determine the magnitude and location of maximum moments. Results shown in Table 3.1 are based on the average measured yield stress of 56.6 ksi. Agreement between analytical and experimental results is again poor. Predicted failure loads are 136% to 297% greater than the experimental failure loads.

3.2 Results of Supplementary Tests

3.2.1 System Restraint Tests

Using the setup described in Section 2.5, 245 system restraint tests were performed. Thirty tests were performed with insulation, eighty-four with insulation and thermal blocks, and one hundred thirty one with no insulation. For system C2, tests were conducted using both hand seamed and machined seamed panels. Table 3.2 summarizes the test results showing the average effective coefficient of friction at each load level along with the corresponding standard deviation. The effective coefficient of friction is defined as

$$CF = \frac{\text{Lateral force required to produce slip per clip}}{\text{Normal force per clip}} \qquad (3.1)$$

From Table 3.2, the largest coefficient of friction were recorded for test configurations using pan type panels and one piece clips, with one exception--Test No. 12 which

Table 3.2
Summary of System Restraint Test Results

Test No.	Test Designation	System Parameters: Panel Type (t,in.)	Clip Type	Insulation	Thermal Blocks	Test Data: Normal Loading (lbs/clip)	No. of Tests	Effective Coeff. of Friction	Standard Deviation
1	C1 w/o-M.S.	Rib (0.029)	2 piece	none	none	116.0	4	0.4498	0.0176
						200.0	4	0.3890	0.0142
						300.0	4	0.3748	0.0037
						400.0	4	0.3345	0.0067
2	C2 w/o-H.S.	Pan (0.025)	1 piece short	none	none	99.0	4	1.1952	0.1152
						165.0	9	0.8131	0.1722
						264.0	10	0.5722	0.0971
						330.0	10	0.4830	0.0757
						495.0	6	0.3837	0.0500
3	C2 w/o-M.S.	Pan (0.025)	1 piece short	none	none	99.0	4	0.5673	0.0720
						165.0	4	0.4379	0.0600
						264.0	4	0.3570	0.0152
						330.0	4	0.3404	0.0129
						429.0	4	0.3206	0.0115
4	C2-I-M.S.	Pan (0.025)	2 piece short	3" Insulation	none	148.5	6	1.6927	0.2230
						247.5	6	1.2491	0.1529
						363.0	4	1.0355	0.0228
						379.5	2	0.8129	0.0267
						459.0	6	0.8057	0.0824
5	C2-I-M.S.	Pan (0.025)	1 piece short	3" Insution	none	99.0	4	1.0713	0.1398
						165.0	4	0.6951	0.0486
						264.0	4	0.4913	0.0146
						330.0	4	0.4351	0.0144
						429.0	4	0.3956	0.0128
6	C2L-I-H.S.	Pan (0.029)	1 piece long	3" Insulation	Thermal Blocks	148.5	6	1.2548	0.1484
						247.5	6	0.8980	0.0400
						363.0	6	0.7625	0.0431
						495.0	6	0.6870	0.0505
7	C2L-I-M.S.	Pan (0.025)	1 piece long	3" Insulation	Thermal Blocks	99.0	4	0.8093	0.0619
						165.0	4	0.6566	0.0655
						264.0	4	0.5450	0.0429
						330.0	4	0.5174	0.0321
						429.0	4	0.4823	0.0234

Table 3.2
Summary of System Restraint Test Results, Continued

Test No.	Test Designation	System Parameters				Test Data			
		Panel Type (t,in.)	Clip Type	Insulation	Thermal Blocks	Normal Loading (lbs/clip)	No. of Tests	Effective Coeff. of Friction	Standard Deviation
8	C3 w/o-M.S.	Rib (0.025)	2 piece	none	none	181.5 297.0 445.5 594.0	4 4 4 4	1.1658 0.8355 0.6842 0.6116	0.0437 0.0357 0.0242 0.0224
9	C3-I-M.S.	Rib (0.025)	2 piece	3" Insulation	Thermal Blocks	181.5 297.0 445.5 594.0	4 4 4 4	1.1168 0.7513 0.6195 0.5503	0.2055 0.1028 0.0385 0.0343
10	C4 w/o	Pan (0.025)	2 piece	none	none	132.0 231.0 330.0 462.0	4 4 4 Clip	0.9633 0.7299 0.5837 Failure	0.0391 0.0880 0.0500 ------
11	C4-I-M.S.	Pan (0.025)	2 piece	3" Insulation	none	132.0 231.0 330.0	2 2 2	0.8413 0.5127 0.6180	0.0373 0.0239 0.0433
12	C6-I-M.S.	Rib (0.025)	2 piece	3" Insulation	Thermal Blocks	165.0 297.0 445.5 594.0	6 6 6 6	0.5012 0.4054 0.3844 0.3872	0.0218 0.0564 0.0522 0.0368

Notes: w/o = without insulation between panels and joist
I = with insulation between panels and joist
H.S. = hand seamed panels
M.S. = machine seamed panels

consisted of rib type panels and two piece clips. The two lowest coefficients of friction were from tests using rib type panels and two piece clips. For all tests, the effective coefficient of friction decreased with increasing normal loading.

For configuration C2 (pan type panels with one piece clips), the coefficient of friction was lower when the panels were machine seamed and, for the same seaming method, when the tests were conducted without insulation (see Figure 3.1). For systems C3 (rib type panels with two piece clips) and C4 (pan type panels with two piece clips), the coefficient of friction decreased when insulation was placed between the panels and the joist frame, as shown in Figures 3.2 and 3.3.

3.2.2 Diaphragm Tests

Table 3.3 shows the strength and stiffness results for the 18 diaphragm tests. Six combinations of panel and clip types were used in the tests. The tests were conducted without insulation in place and with all four edges bolted and with all four edges bolted to the interior support frame at 6 in. on center (see Figure 2.7 for details).

The two largest average stiffness values were recorded for configurations using rib type panels and two piece clips (Test Designations C3 and C6). The lowest average stiffness value was recorded for a pan type panel and one piece clip configuration (Test Designation C2). Except for configuration C2, the measured stiffness values are greater than 1000 lb/in., which was used in the Elhouar Stiffness Model to obtain brace force predictions for the anchorage force tests (Section 3.1.1). However, it is noted that the system components used in the diaphragm test series are not necessarily the same as used in the anchorage force tests.

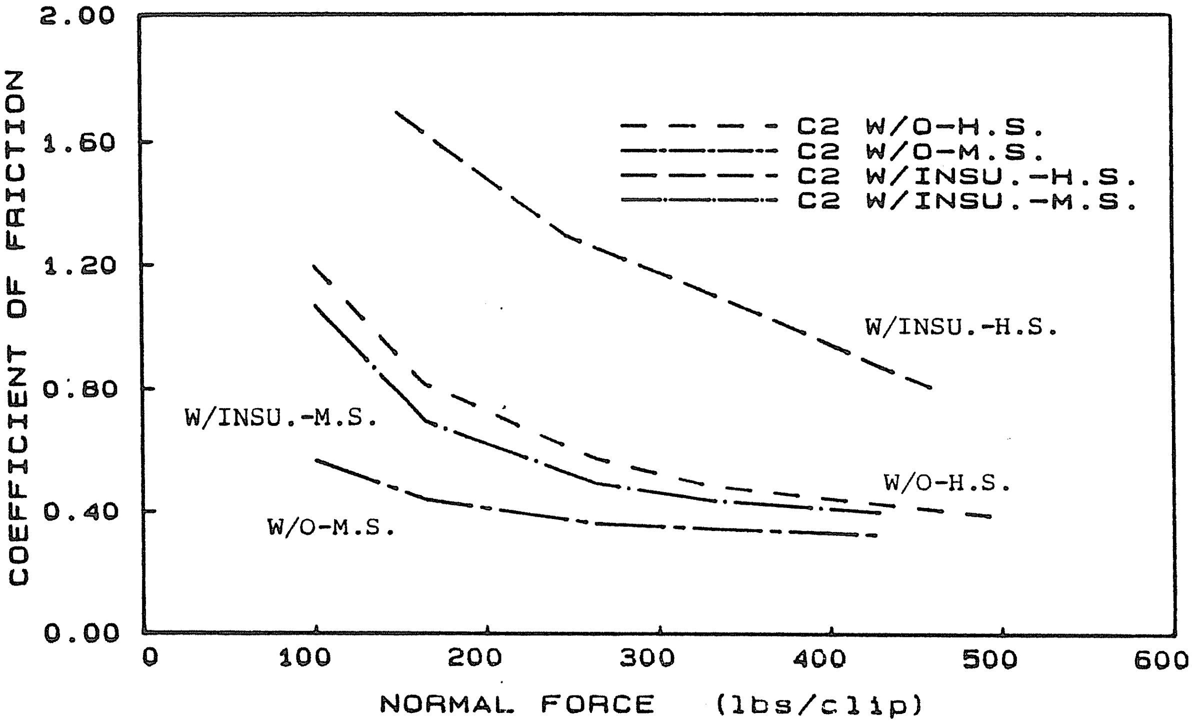


Figure 3.1 Coefficient of Friction versus Normal Force for Configuration C2.

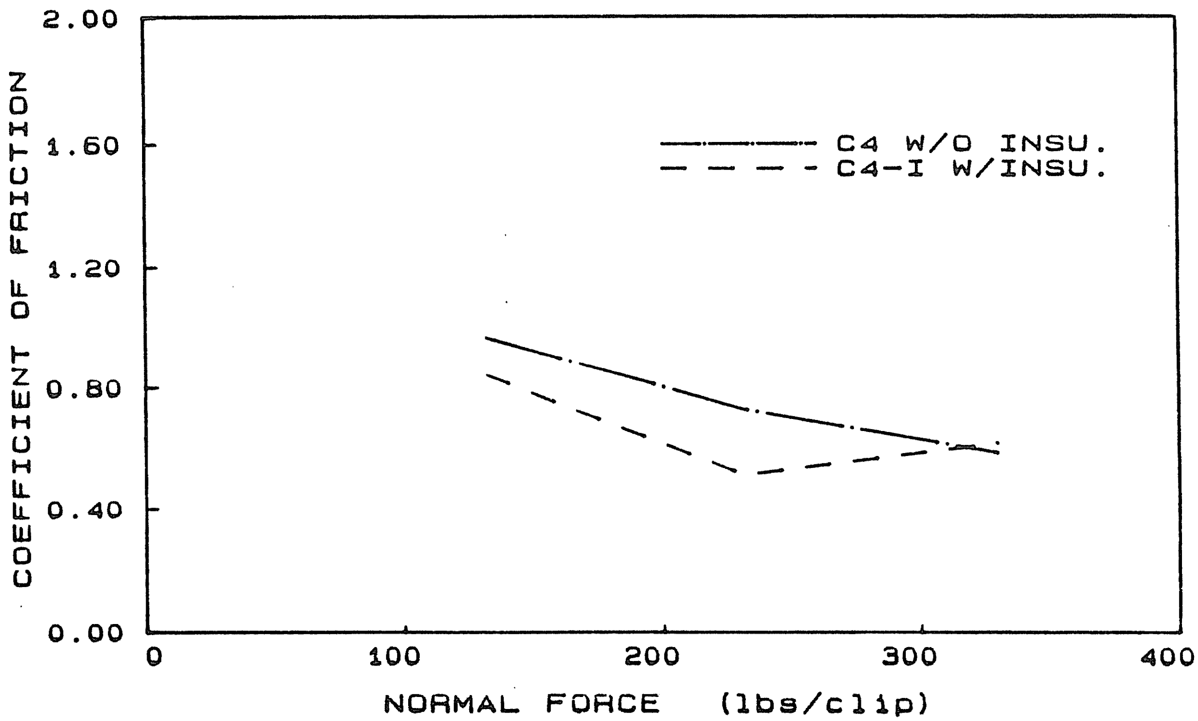


Figure 3.2 Coefficient of Friction versus Normal Force for Configuration C3.

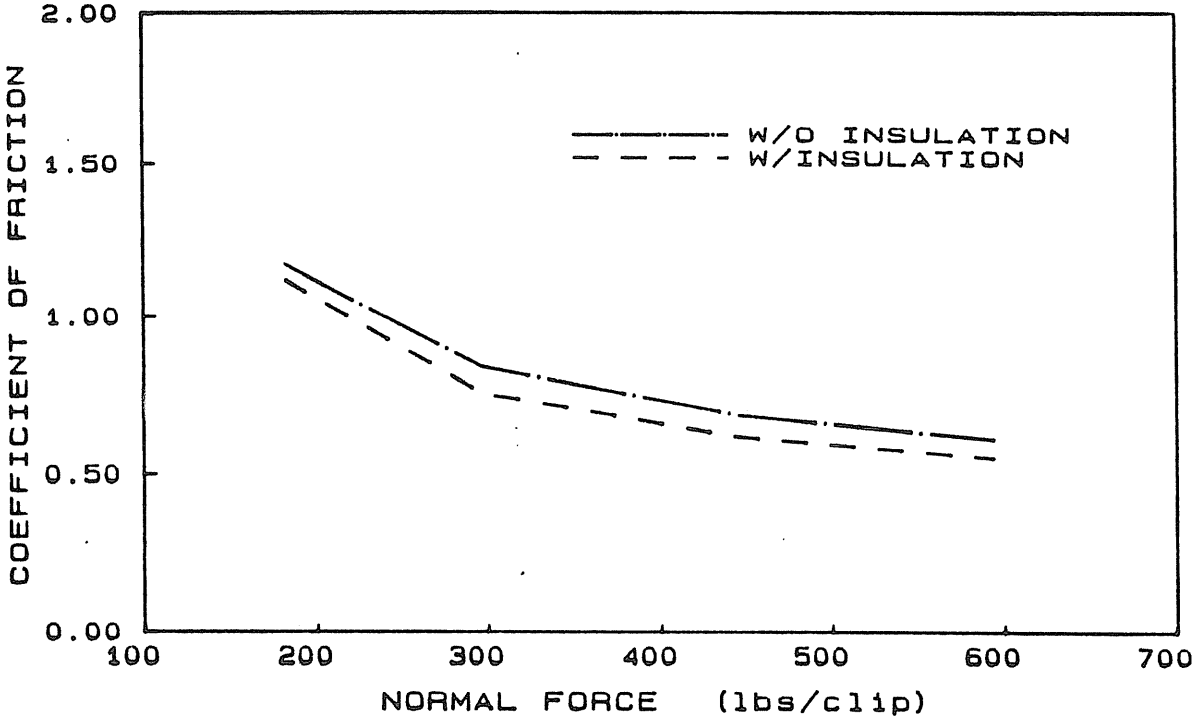


Figure 3.3 Coefficient of Friction versus Normal Force for Configuration C4.

Table 3.3

Diaphragm Test Results

Test Designation	Panel Type (Thickness)	Panel Width (in)	Clip Type	Strength (lb/ft)	Stiffness (lb/in)
C1	Rib (0.029 in)	(24 in)	2 piece	143.2 145.8 139.4	2155.4 2117.6 2030.9
C2	Pan (0.025 in)	(20 in)	1 piece	100.7 103.6 103.1	959.6 799.8 792.7
C3	Rib (0.025 in)	(24 in)	2 piece	136.3 139.8 128.5	2234.8 2691.3 2520.1
C4	Pan (0.025 in)	(18 in)	2 piece	93.6 95.3 93.7	2184.5 2267.0 2295.5
C5	Rib (0.025 in)	(24 in)	2 piece	134.5 138.0 137.6	2205.4 2218.5 2751.5
C6	Rib (0.025 in)	(24 in)	2 piece	161.0 164.6 160.7	3114.0 3955.1 3528.1

Based on the experimental test results, it appears that the type of seam affects the shear stiffness (G') of the deck. Configurations using single "lock" seams with lapped panels (Test Designations C1, C3, C4 and C5) had an average shear stiffness of 2306 16/in. Similar configurations but without lapped panels (Test Designation C2) had an average shear stiffness of 851 16/in. The average shear stiffness for the configuration using double "lock" seams (Test Designation C6) was 3532 16/in.

CHAPTER IV

SUMMARY AND RECOMMENDATIONS

Seven simple span and six three-continuous span, two purlin line, gravity loaded, Z-purlin supported, standing seam systems were tested to investigate anchorage requirements for various restraint systems. All tests were loaded to failure to study the effects of restraint configurations on the ultimate strength of the systems. In addition, two series of supplementary tests were conducted.

The following observations are made as a result of this test program:

1. Good to excellent correlation was found between brace force predictions using the Elhouar Stiffness Model and experimental data for the two purlin line systems tested. With confirmation of multiple purlin line systems, the current AISI anchorage force provisions for conventional metal building roof systems may be adequate for the standing seam roof systems; however, their use is not recommended without the necessary confirming tests.

2. The experimental failure loads were 30-75% of predicted failure loads calculated assuming full lateral restraint, constrained bending and using the 1986 AISI Specification provisions for determining cross-section strength. Obviously, the standing seam roof system setups that were tested do not provide full lateral restraint to the purlins. Further study is recommended.

3. Vertical deflections for the midspan and third point bracing configurations were found to be 10-20% greater than predicted using the constrained bending assumption. For the rafter bracing configuration, vertical deflections are non-linear and much greater than predicted.

4. Results of the system restraint supplementary tests show that the addition of insulation results in a slight decrease in the effective restraint of roof system configurations using two piece clips; there was a moderate increase in the coefficient of friction with the addition of insulation in systems using one piece clips.

5. Results of the diaphragm supplementary tests show that the type of panel seam and method of seaming affect the diaphragm shear stiffness (G') of the deck. Except for configurations using single "lock" seams with lapped panels, the measured diaphragm stiffnesses exceeded the minimum value required by current AISI anchorage force provisions.

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APPENDIX A
SINGLE SPAN TEST SUMMARIES

STANDING SEAM ROOF SYSTEMS SINGLE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: CONV/2-R-1 Test Date: 7-15-86

Span: 20 ft. Deck Type: Conventional Deck

Restraint Configuration: X Supports

________ Midspan

________ Third Pts.

Purlin Data: Thickness .072 in. Moment of Inertia 10.10 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 1/2"

Purlin #2 1/2"

Predictions: Failure Load 202.5 plf (1986 AISI)

235.6 plf (1980 AISI)

Brace Force @ 100 plf 356.8 lbs/brace

Vertical Deflection @ 100 plf 1.23 in.

Restraint: Braces at rafters between Purlins #1 and #2.

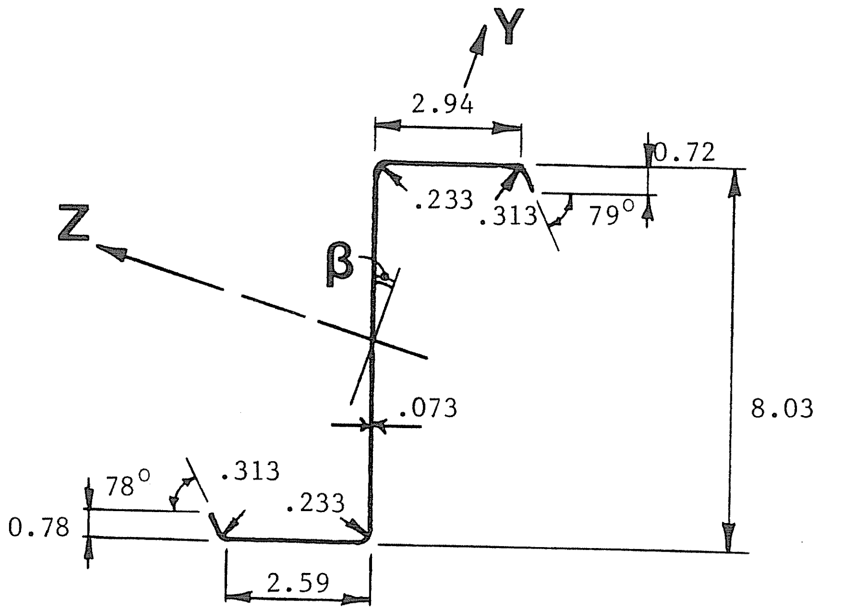
Experimental Failure Load: 198.0 plf

Failure Mode: Local buckling of compression flange on Purlin #1 at midspan.

Discussion:

- North lateral brace failed when deck collapsed.
- Purlin rotation at failure = 0.086 radians.
- Good correlation between theoretical and experimental predictions for both brace force and deflections.
- Experimental failure load was 97.8% of 1986 AISI/contrained bending/full lateral restraint predictions.

Purlin #1



Properties: Span (ft) = 20.0

Area (in^2) = 1.0767

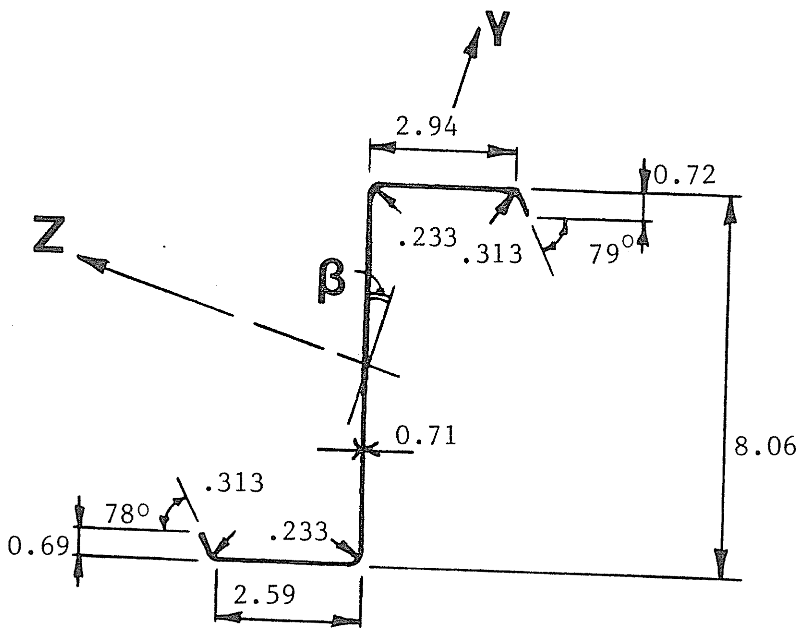
β(deg) = 18.3501

$I_x(in^4)$ = .0019

$I_y(in^4)$ = 0.7940

$I_z(in^4)$ = 11.8437

Purlin #2



Properties: Span (ft) = 20.0

Area (in^2) = 1.0404

β(deg) = 17.9234

$I_x(in^4)$ = 0.0018

$I_y(in^4)$ = 0.7481

$I_z(in^4)$ = 11.4548

Figure A.1 Measured Purlin Dimensions and Calculated Properties, Test CONV/2-R-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7500	0.7810
Lip angles	(degrees) :	79.0000	78.0000
Flange widths	(inches) :	2.9380	2.5940
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0310
Purlin thickness	(inches) :	0.0730

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3142
Gross moment of inertia	(in^4) :	10.32

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7843	inches
Effective moment of inertia	:	9.32	in^4
Allowable flexural capacity	:	75.52	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2206	inches	
Effective moment of inertia	:	10.21	in^4	
Allowable stress at flange	:	33.96	ksi	controls
Allowable stress at web	:	31.71	ksi	(at flange : 34.37 ksi)
Allowable flexural capacity	:	87.68	kip-in	

Figure A.2 Strength Calculations, Test CONV/2-R-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.6875
Lip angles	(degrees) :		79.0000	78.0000
Flange widths	(inches) :		2.9375	2.5938
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0710		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3174
Gross moment of inertia	(in^4) :	10.03

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7344	inches
Effective moment of inertia	:	9.01	in^4
Allowable flexural capacity	:	72.75	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.1863	inches		
Effective moment of inertia	:	9.89	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.40	ksi	(at flange : 34.01 ksi)	
Allowable flexural capacity	:	84.65	kip-in		

Figure A.2 Strength Calculations, Test CONV/2-R-1

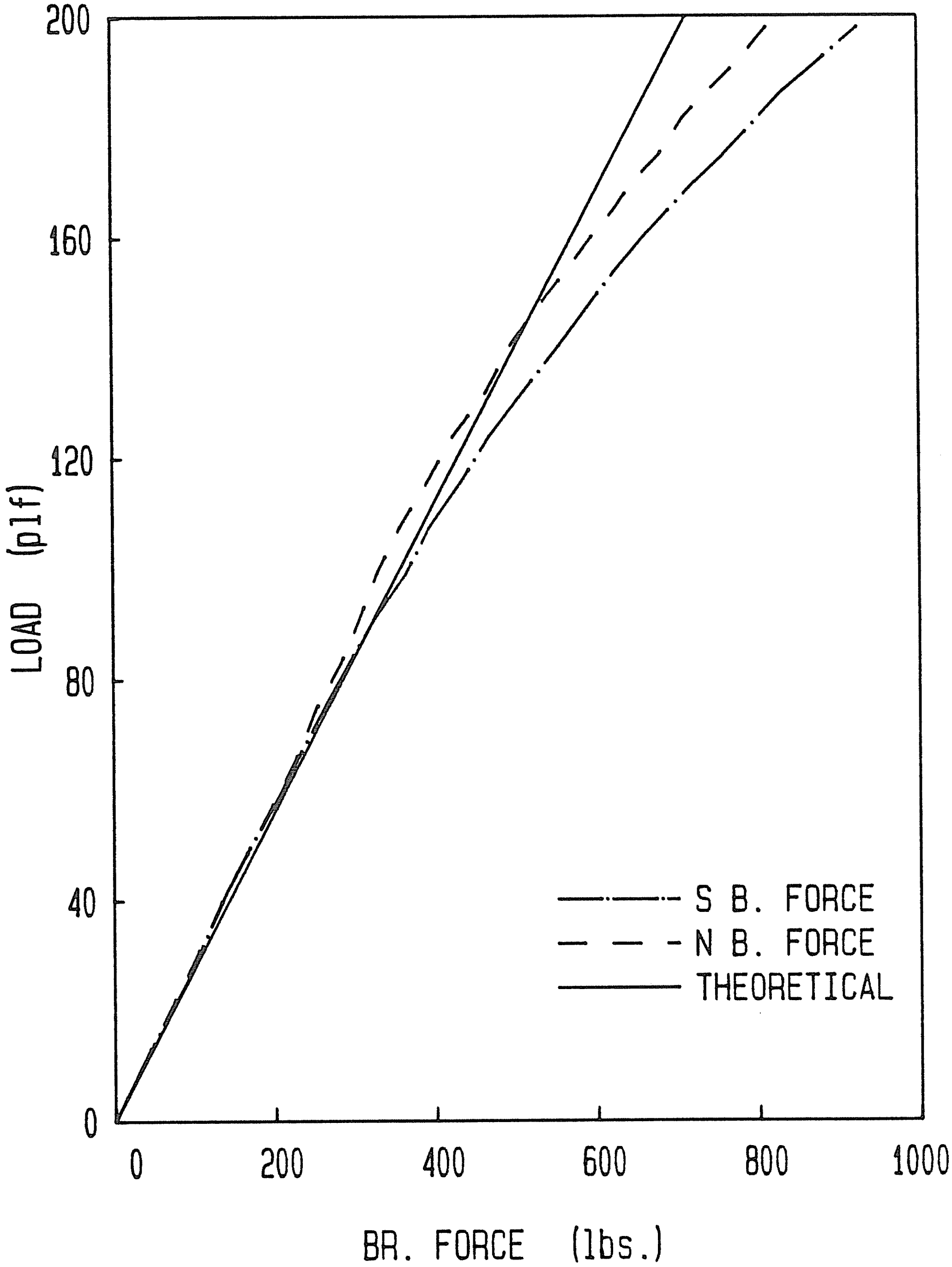
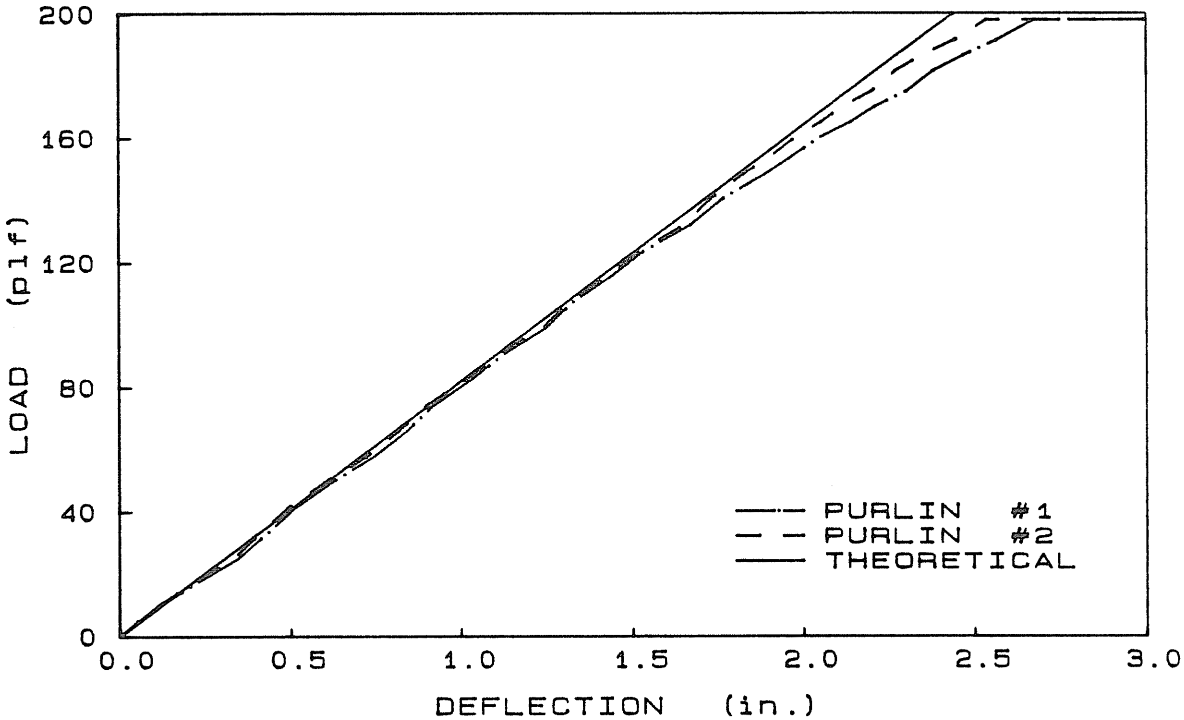
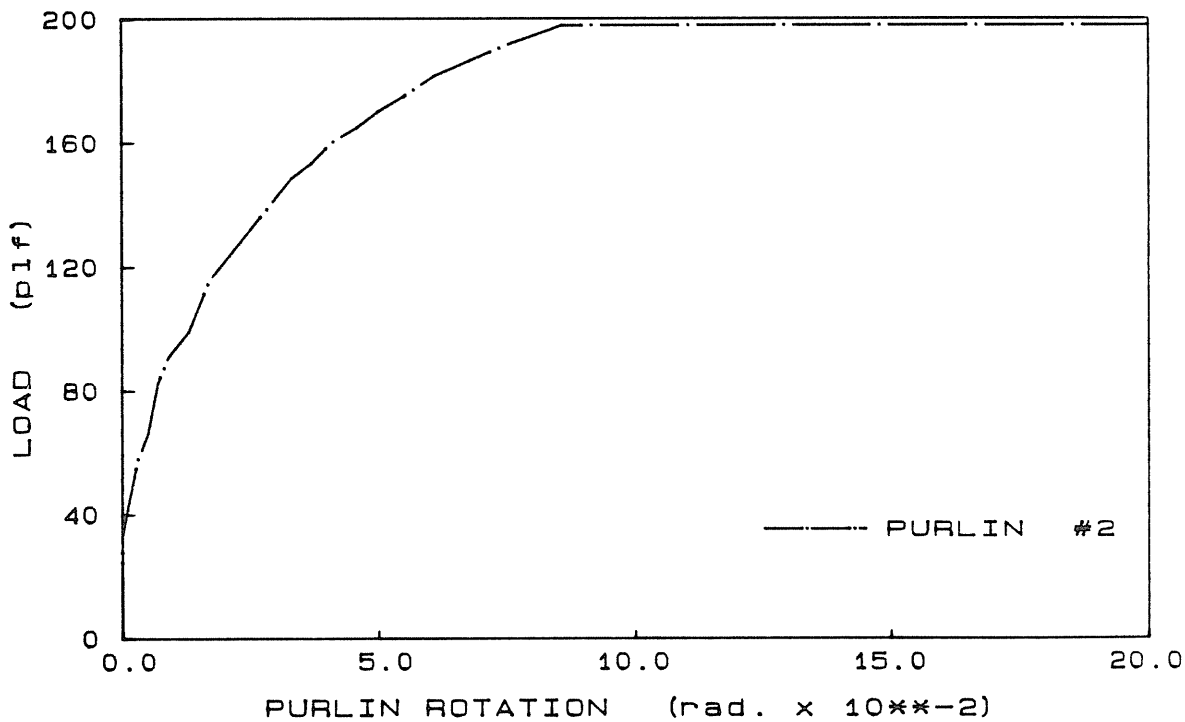


Figure A.3 Load vs. External Brace Forces, Test CONV/2-R-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.4 Load vs. Purlin Movement, Test CONV/2-R-1

STANDING SEAM ROOF SYSTEMS SINGLE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: R2/2-R-1 Test Date: 7-18-86

Span: 20 ft. Deck Type: Rib

Restraint Configuration: X Supports

________ Midspan

________ Third Pts.

Purlin Data: Thickness 0.069 in. Moment of Inertia 9.71 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 1/2"

Purlin #2 5/8"

Predictions: Failure Load 198.9 plf (1986 AISI)

228.1 plf (1980 AISI)

Brace Force @ 100 plf 359.7 lbs/brace

Vertical Deflection @ 100 plf 1.28 in.

Restraint: Bracing between purlins at third points

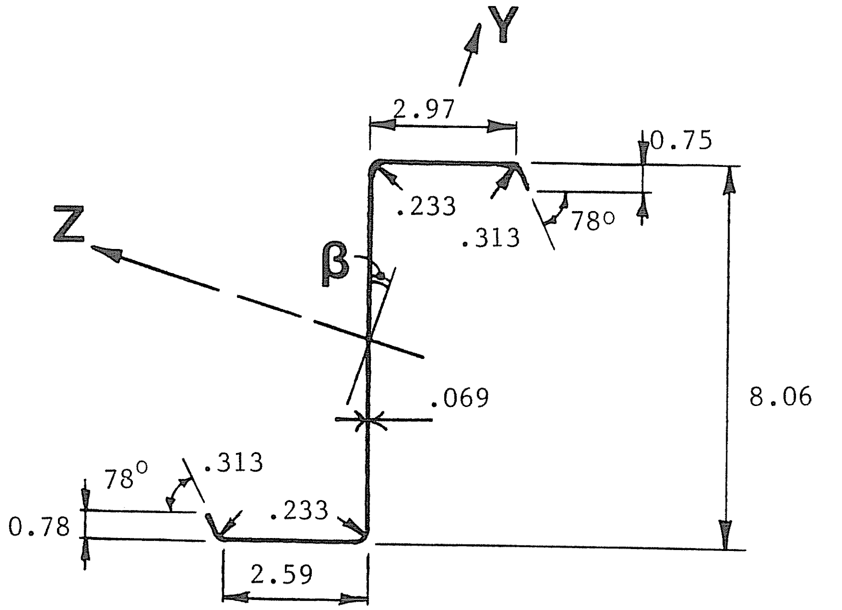
Experimental Failure Load: 85.8 plf

Failure Mode: Local buckling of compression flange

Discussion:

- Purlin rotation at failure = 0.313 radians
- Maximum clip movement = 0.40 inches
- Good correlation with brace force predictions
- Poor correlation with deflection predictions
- Experimental failure load was 43.1% of 1986 AISI/constrained bending/full lateral restraint predictions

Purlin #1



Properties: Span (ft) = 20.0

Area (in^2) = 1.0225

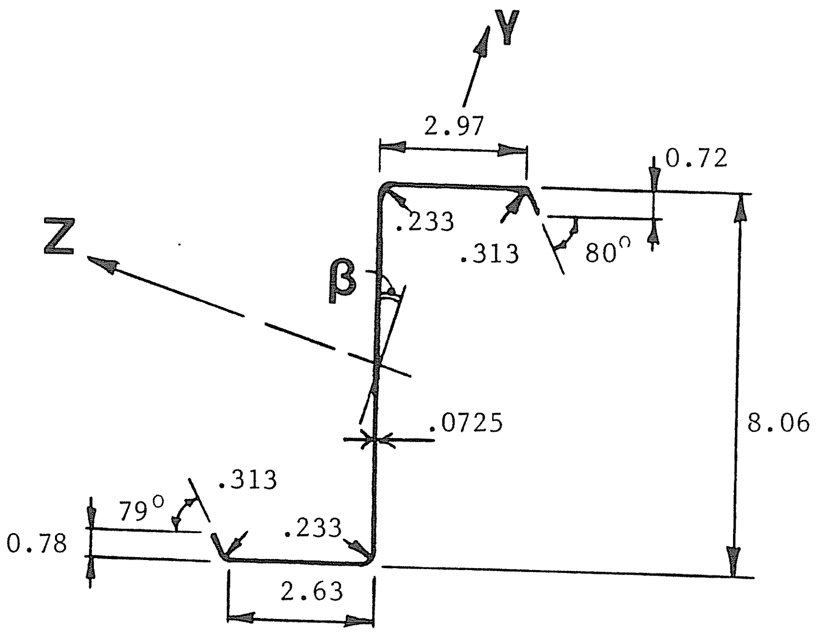
β(deg) = 18.3960

I_x (in^4) = 0.0016

I_y (in^4) = 0.7645

I_z (in^4) = 11.3487

Purlin #2



Properties: Span (ft) = 20.0

Area (in^2) = 1.0730

β(deg) = 18.3410

I_x (in^4) = .0019

I_y (in^4) = 0.7964

I_z (in^4) = 11.9071

Figure A.5 Measured Purlin Dimensions and Calculated Properties, Test R2/2-R-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.7813
Lip angles	(degrees) :		78.0000	78.0000
Flange widths	(inches) :		2.9688	2.5938
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0690		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3579
Gross moment of inertia	(in^4) :	9.91

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7528	inches
Effective moment of inertia	:	8.87	in^4
Allowable flexural capacity	:	71.46	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.1695	inches	
Effective moment of inertia	:	9.71	in^4	
Allowable stress at flange	:	33.96	ksi	
Allowable stress at web	:	31.12	ksi	(at flange : 33.67 ksi) controls
Allowable flexural capacity	:	81.96	kip-in	

Figure A.6 Strength Calculations, Test R2/2-R-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7188	0.7813
Lip angles	(degrees) :	80.0000	79.0000
Flange widths	(inches) :	2.9688	2.6250
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0725

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3402
Gross moment of inertia	(in^4) :	10.37

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7499	inches
Effective moment of inertia	: 9.31	in^4
Allowable flexural capacity	: 74.78	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2222	inches		
Effective moment of inertia	: 10.24	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.61	ksi	(at flange : 34.23 ksi)	
Allowable flexural capacity	: 87.25	kip-in		

Figure A.6 Strength Calculations, Test R2/2-R-1

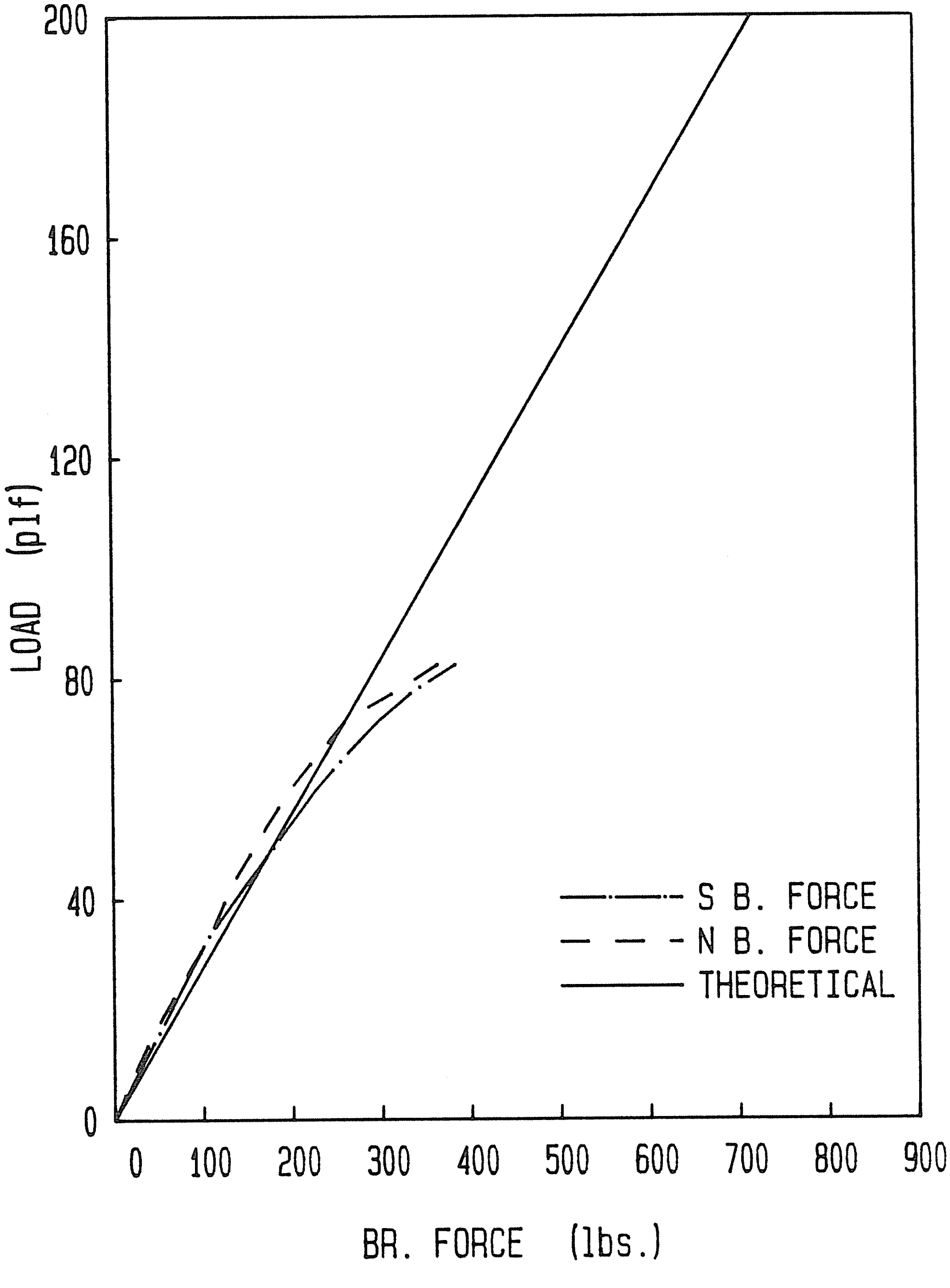
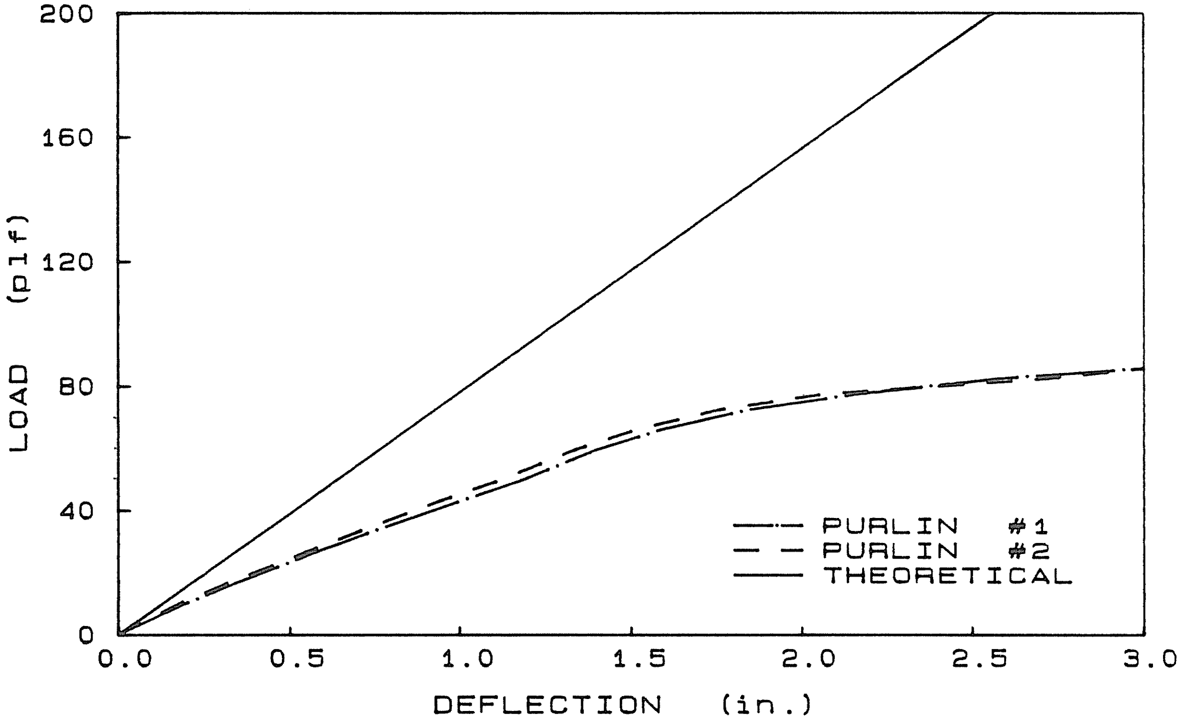
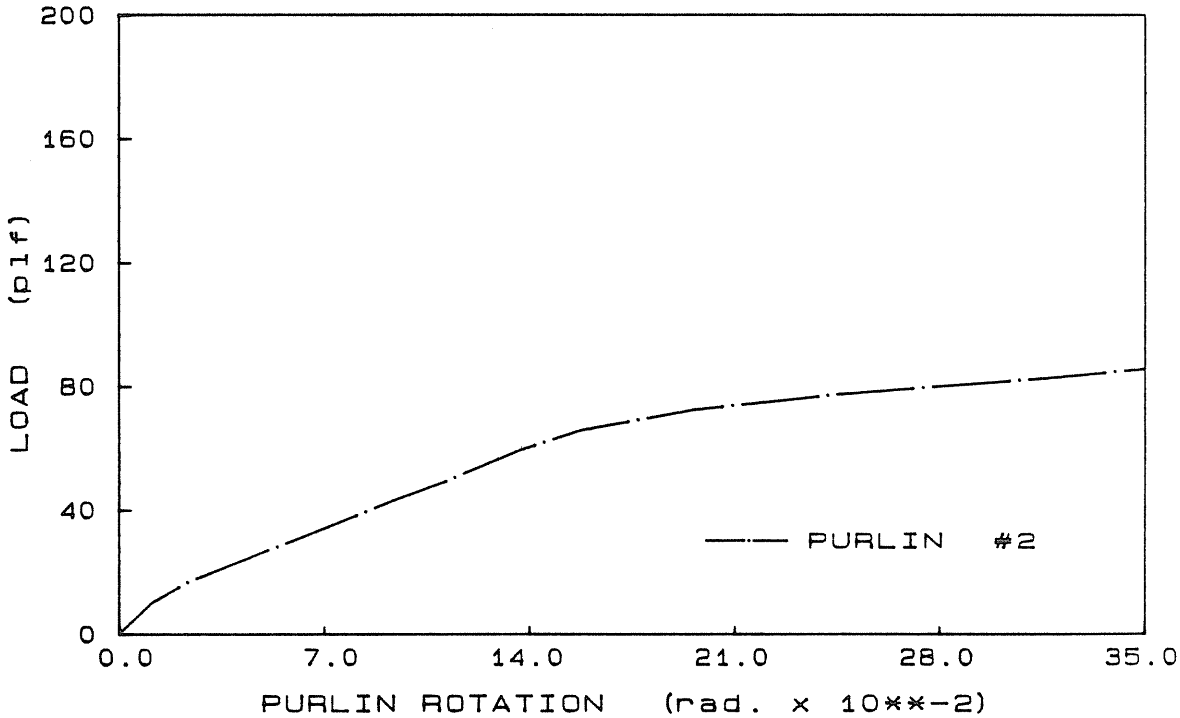


Figure A.7 Load vs. External Brace Forces, Test R2/2-R-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.8 Load vs. Purlin Movement, Test R2/2-R-1

STANDING SEAM ROOF SYSTEMS SINGLE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: P1/2-R-1 Test Date: 7-1-86

Span: 20 ft. Deck Type: Pan

Restraint Configuration: X Supports

______ Midspan

______ Third Pts.

Purlin Data: Thickness .072 in. Moment of Inertia 10.41 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 3/4"

Purlin #2 3/4"

Predictions: Failure Load 207.2 plf (1986 AISI)

238.3 plf (1980 AISI)

Brace Force @ 100 plf 334.3 lbs/brace

Vertical Deflection @ 100 plf 1.19 in.

Restraint: Bracing between Purlins #1 and #2 at rafters.

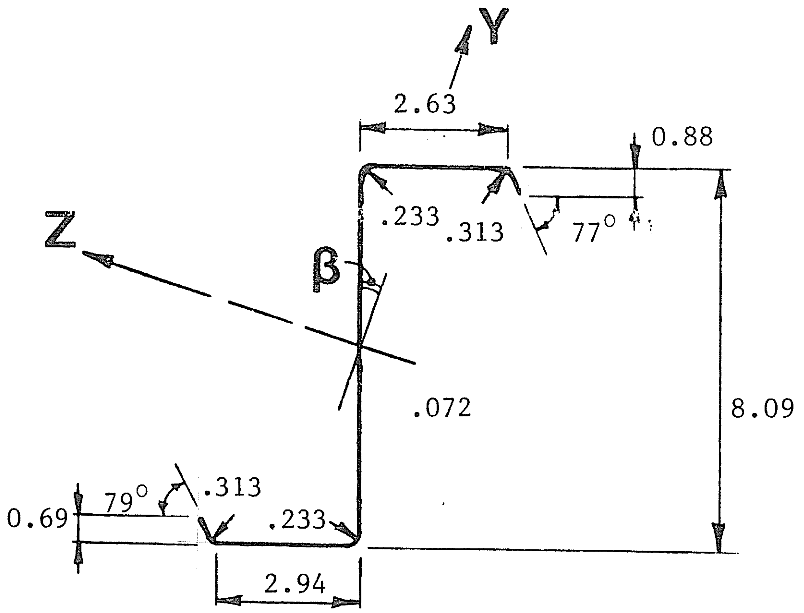
Experimental Failure Load: 59.5 plf

Failure Mode: Compression failures of clips producing small dynamic loads; buckling of purlin.

Discussion:

- Purlin #2 rotation @ 54.5 plf = 0.086 rad.
- Horizontal deflection of Purlin #2 = 0.928 in.
- Poor correlation between theoretical and experimental predictions for both brace force and deflections.
- Experimental failure load was 28.2% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1

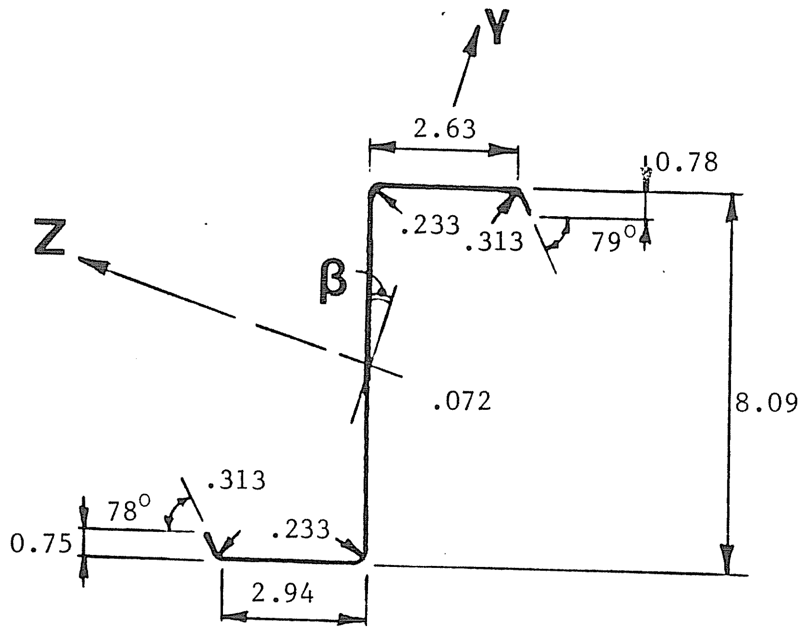


Properties: Span (ft) = 20.0 $I_x(in^4)$ = .0019

Area (in^2) = 1.0735 $I_y(in^4)$ = .8061

β (deg) = 18.3015 $I_z(in^4)$ = 11.9984

Purlin #2



Properties: Span (ft) = 20.0 $I_x(in^4)$ = .0019

Area (in^2) = 1.0712 $I_y(in^4)$ = 0.8022

β(deg) = 18.2392 $I_z(in^4)$ = 11.9573

Figure A.9 Measured Purlin Dimensions and Calculated Properties, Test P1/2-R-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8750	0.6880
Lip angles	(degrees) :		77.0000	79.0000
Flange widths	(inches) :		2.6250	2.9380
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0940		
Purlin thickness	(inches) :	0.0720		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0142
Gross moment of inertia	(in^4) :	10.44

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7092	inches
Effective moment of inertia	: 9.75	in^4
Allowable flexural capacity	: 77.65	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0142	inches	
Effective moment of inertia	: 10.44	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.50	ksi	(at flange : 34.04 ksi)
Allowable flexural capacity	: 86.85	kip-in	

Figure A.10 Strength Calculations, Test P1/2-R-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

				TOP	BOTTOM
Vertical lip dimensions	(inches)	:		0.7810	0.7500
Lip angles	(degrees)	:		79.0000	78.0000
Flange widths	(inches)	:		2.6250	2.9380
Radii	(inches)				
Lip to flange		:		0.3125	0.3125
Flange to web		:		0.2330	0.2330
Total purlin depth	(inches)	:	8.0940		
Purlin thickness	(inches)	:	0.0720		

MATERIAL PROPERTIES

Material yield stress	(ksi)	:	56.6
Modulus of elasticity	(ksi)	:	29500.0

GENERAL

Flat width of compression flange	(inches)	:	2.0030
Gross moment of inertia	(in^4)	:	10.41

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.6137	inches
Effective moment of inertia	:	9.54	in^4
Allowable flexural capacity	:	74.46	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	:	2.0030	inches		
Effective moment of inertia	:	10.41	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.50	ksi	(at flange : 34.01 ksi)	
Allowable flexural capacity	:	85.61	kip-in		

Figure A.10 Strength Calculations, Test P1/2-R-1

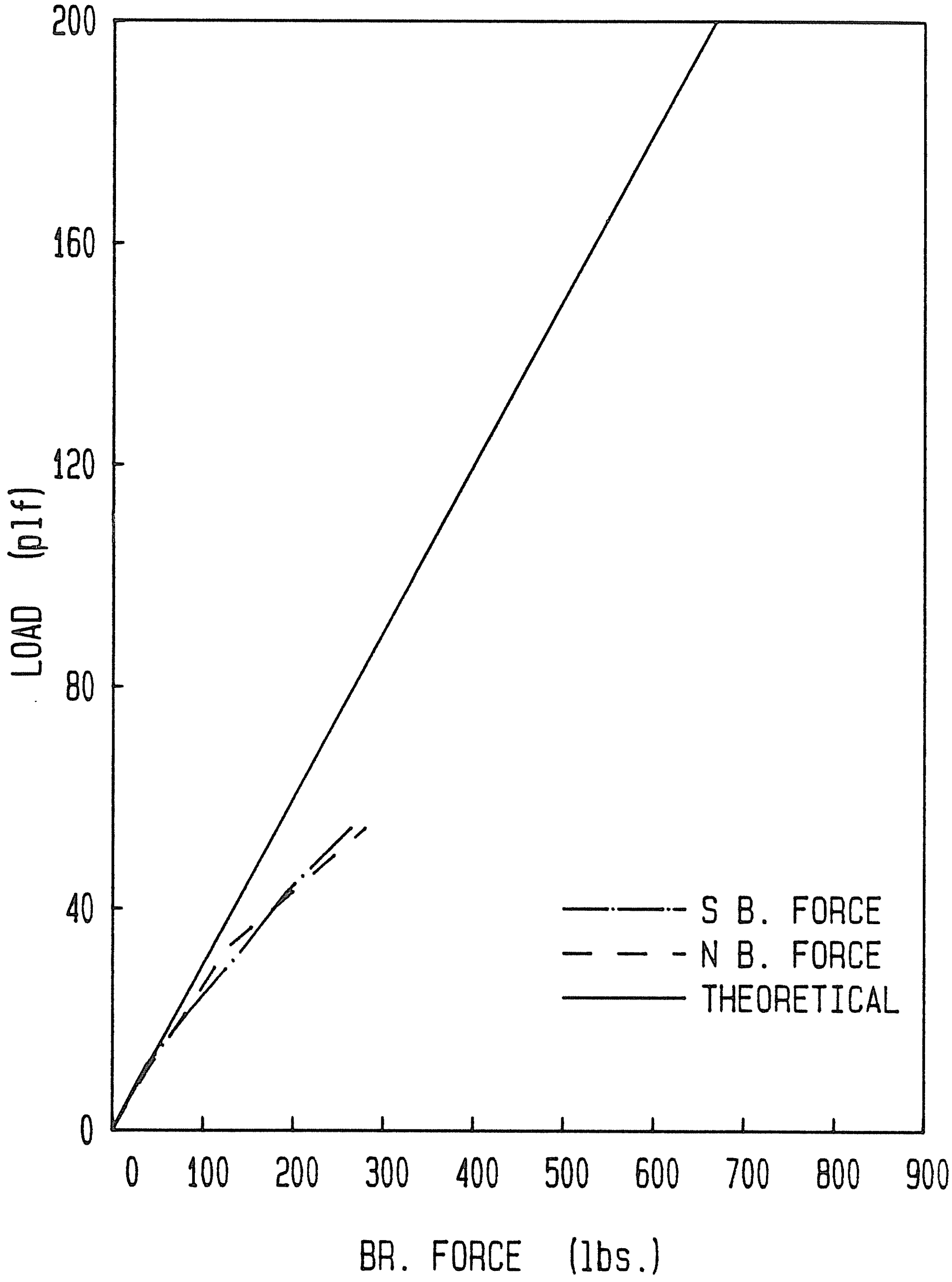
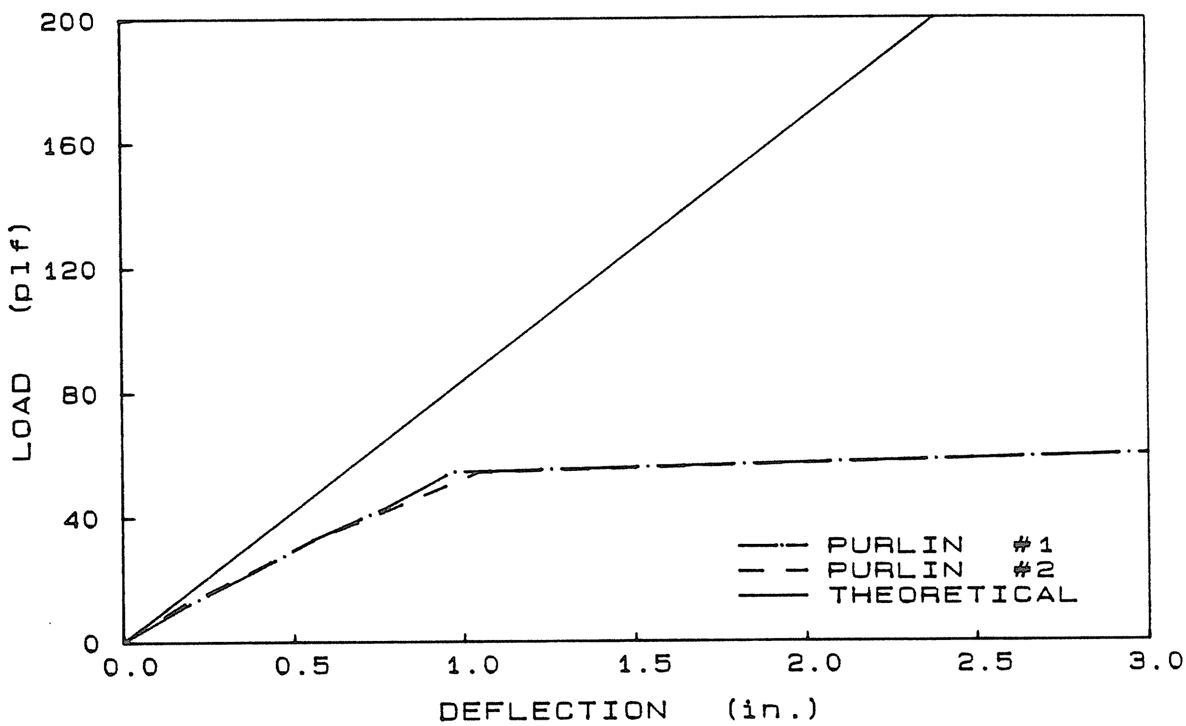
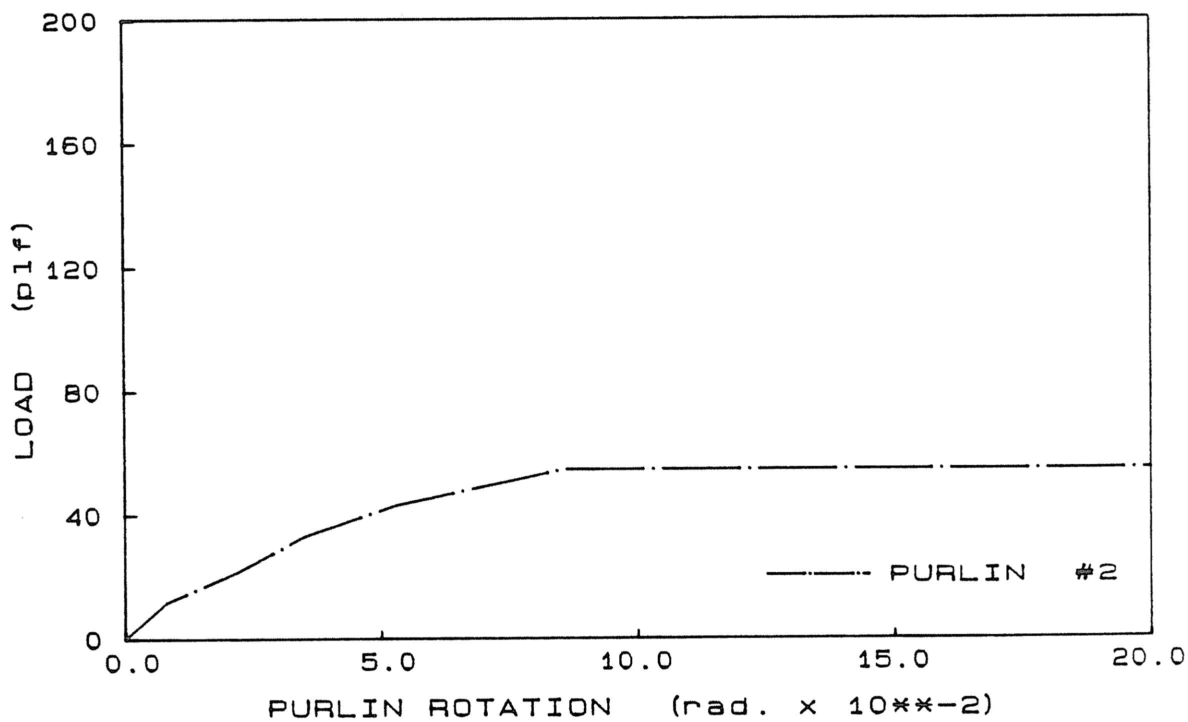


Figure A.11 Load vs. External Brace Forces, Test P1/2-R-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.12 Load vs. Purlin Movement, Test P1/2-R-1

STANDING SEAM ROOF SYSTEMS SINGLE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: R2/2-T-1 Test Date: 7-21-86

Span: 20.0 ft. Deck Type: Rib

Restraint Configuration: ________ Supports

________ Midspan

X Third Pts.

Purlin Data: Thickness .072 in. Moment of Inertia 10.17 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 1/4 in.

Purlin #2 1/4 in.

Predictions: Failure Load 204.9 plf (1986 AISI)

239.6 plf (1980 AISI)

Brace Force @ 100 plf 385.1 lbs/brace

Vertical Deflection @ 100 plf 1.22 in.

Restraint: Brace between purlins #1 and #2 at midspan

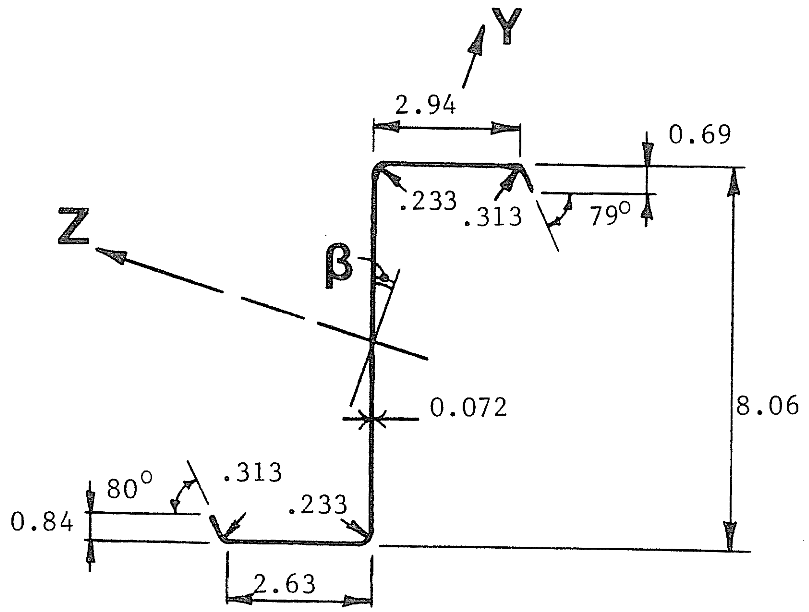
Experimental Failure Load: 155.1 plf

Failure Mode: Local buckling of the compression flange at midspan of Purlin #2.

Discussion:

- Purlin rotation at failure = 0.186 radians.
- Good correlation between theoretical and experimental prediction for both brace force and deflections.
- Little clip moment in the center of purlins to a maximum of 0.15 inches at ends.
- Experimental failure load was 75.7% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1



Properties: Span (ft) = 20.0

Area (in^2) = 1.0657

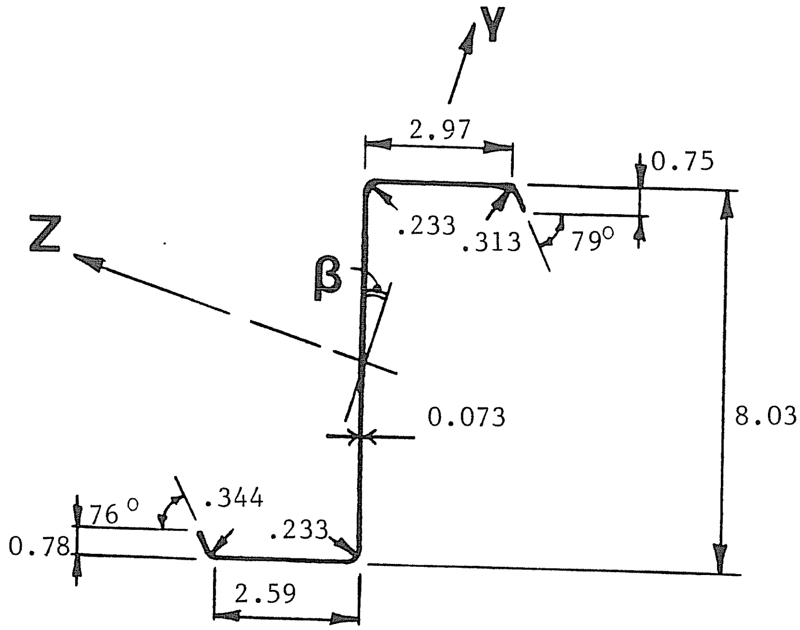
β(deg) = 18.2899

I_x (in^4) = 0.0019

I_y (in^4) = 0.7863

I_z (in^4) = 11.8114

Purlin #2



Properties: Span (ft) = 20.0

Area (in^2) = 1.0789

β(deg) = 18.5396

I_x (in^4) = 0.0019

I_y (in^4) = 0.8079

I_z (in^4) = 11.9048

Figure A.13 Measured Purlin Dimensions and Calculated Properties, Test R2/2-T-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.6875	0.8438
Lip angles	(degrees) :	79.0000	80.0000
Flange widths	(inches) :	2.9375	2.6250
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth (inches) : 8.0625
Purlin thickness (inches) : 0.0720

MATERIAL PROPERTIES

Material yield stress (ksi) : 56.6
Modulus of elasticity (ksi) : 29500.0

GENERAL

Flat width of compression flange (inches) : 2.3155
Gross moment of inertia (in^4) : 10.30

1986 AISI PROCEDURE

Flange is not fully effective
Effective flange width : 1.7168 inches
Effective moment of inertia : 9.23 in^4

Allowable flexural capacity : 73.63 kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate
Effective flange width : 2.2035 inches
Effective moment of inertia : 10.17 in^4

Allowable stress at flange : 33.96 ksi controls
Allowable stress at web : 31.54 ksi (at flange : 34.13 ksi)

Allowable flexural capacity : 86.10 kip-in

Figure A.14 Strength Calculations, Test R2/2-T-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.7813
Lip angles	(degrees) :		79.0000	76.0000
Flange widths	(inches) :		2.9688	2.5938
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0313		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3450
Gross moment of inertia	(in^4) :	10.36

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7921	inches
Effective moment of inertia	: 9.34	in^4
Allowable flexural capacity	: 75.67	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2331	inches	
Effective moment of inertia	: 10.24	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.71	ksi	(at flange : 34.37 ksi)
Allowable flexural capacity	: 87.90	kip-in	

Figure A.14 Strength Calculations, Test R2/2-T-1

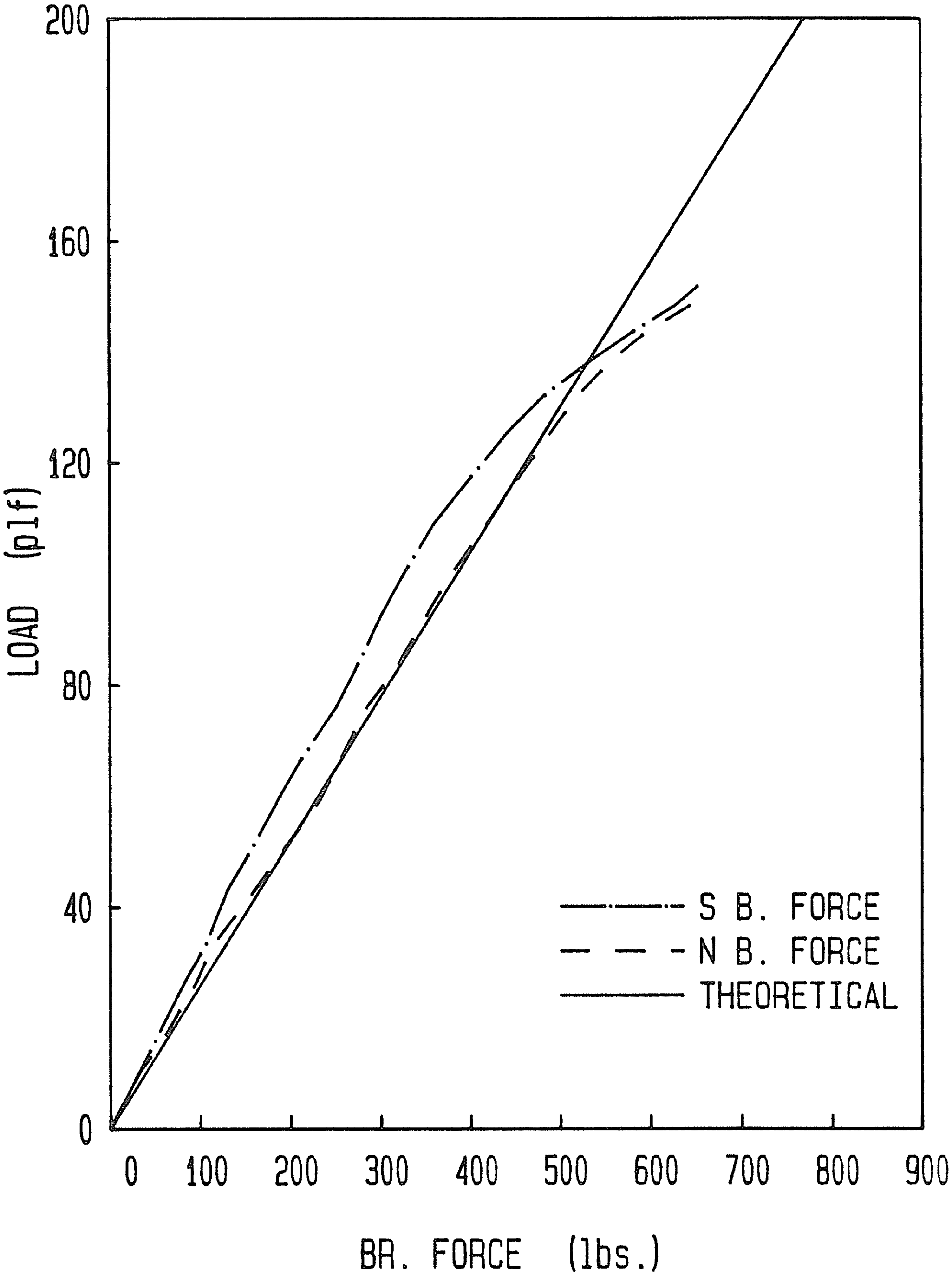
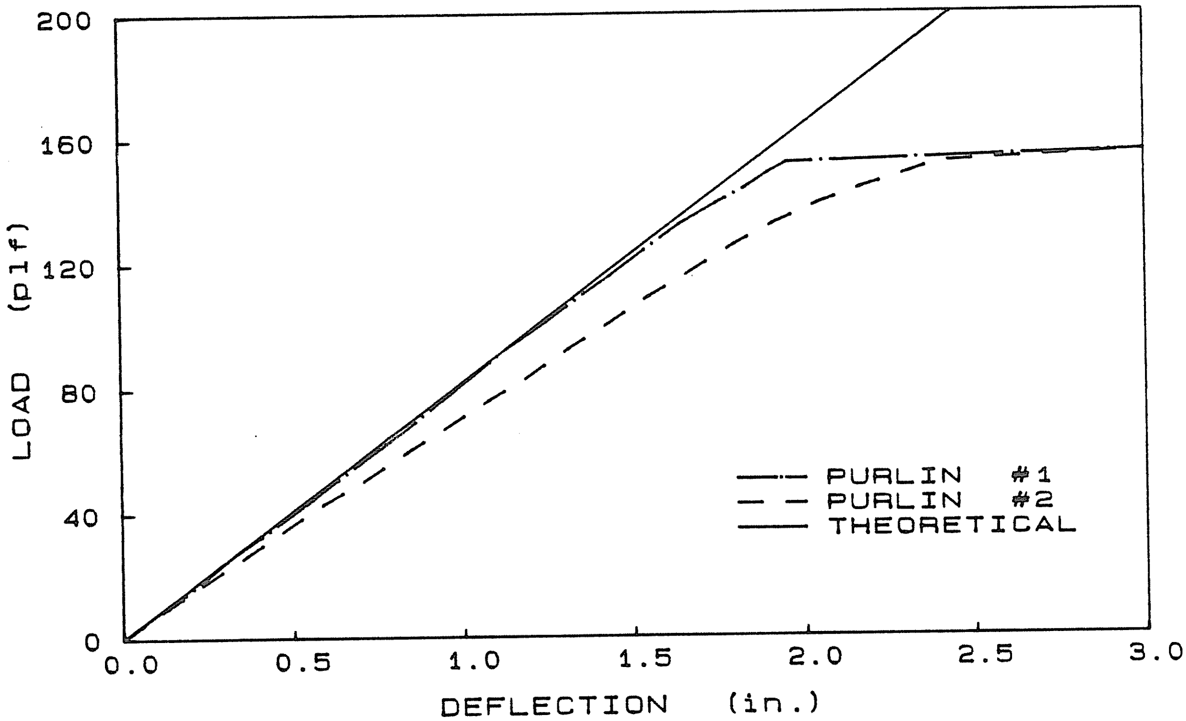
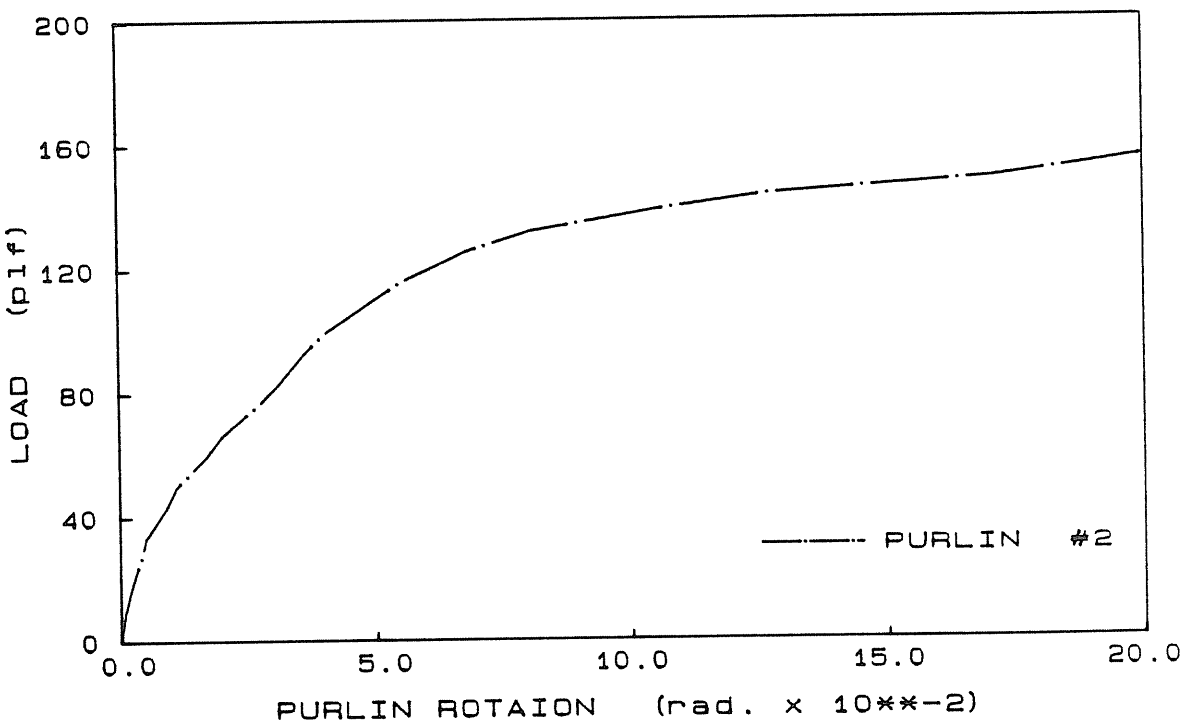


Figure A.15 Load vs. External Brace Forces, Test R2/2-T-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.16 Load vs. Purlin Movement, Test R2/2-T-1

STANDING SEAM ROOF SYSTEMS SINGLE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: P1/2-T-1 Test Date: 7-2-86

Span: 20 ft. Deck Type: Pan

Restraint Configuration: ____ Supports

____ Midspan

X Third Pts.

Purlin Data: Thickness .075 in. Moment of Inertia 10.52 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 1/2"

Purlin #2 5/8"

Predictions: Failure Load 216.4 plf (1986 AISI)

251.7 plf (1980 AISI)

Brace Force @ 100 plf 368.5 lbs/brace

Vertical Deflection @ 100 plf 1.18 in.

Restraint: Braces between Purlins #1 and #2 @ third points

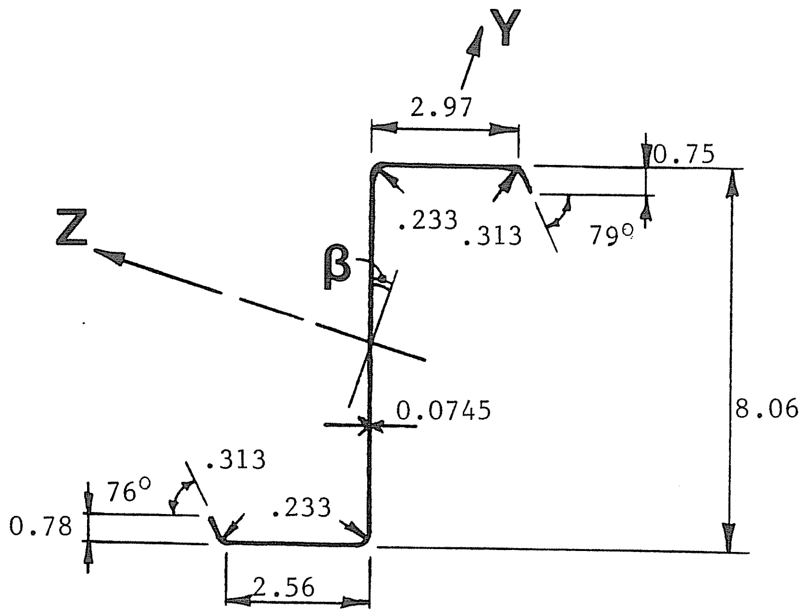
Experimental Failure Load: 141.0 plf

Failure Mode: Compression failure of clips; local buckling of compression flange on Purlin #2

Discussion:

- Purlin rotation @ 141 plf = 0.192 radians.
- Maximum clip movement = 0.13 inches.
- Good correlation between theoretical and experimental predictions for both brace force and deflections.
- Experimental failure load was 65.2% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1



Properties: Span (ft) = 20.0

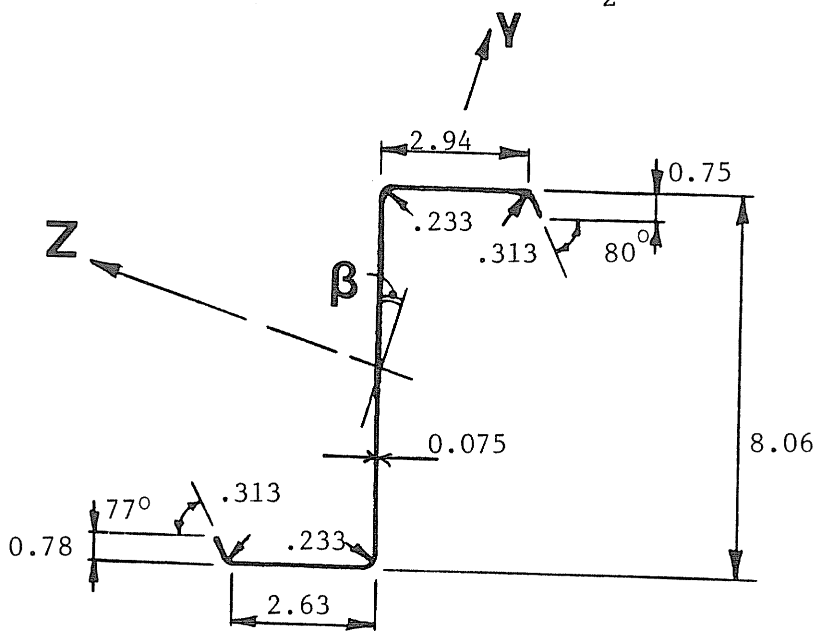
Area (in^2) = 1.1033

β(deg) = 18.2105

I_x(in^4) = 0.0021

I_y(in^4) = 0.8190

I_z(in^4) = 12.2030



Properties: Span (ft) = 20.0

Area (in^2) = 1.1143

β(deg) = 18.1585

I_x(in^4) = 0.0021

I_y(in^4) = 0.8279

I_z(in^4) = 12.4196

Figure A.17 Measured Purlin Dimensions and Calculated Properties, Test P1/2-T-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.7813
Lip angles	(degrees) :		79.0000	76.0000
Flange widths	(inches) :		2.9690	2.5630
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0745		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3425
Gross moment of inertia	(in^4) :	10.63

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.8095	inches
Effective moment of inertia	: 9.61	in^4
Allowable flexural capacity	: 77.76	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2582	inches		
Effective moment of inertia	: 10.54	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.86	ksi	(at flange : 34.55 ksi)	
Allowable flexural capacity	: 90.44	kip-in		

Figure A.18 Strength Calculations, Test P1/2-T-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.7813
Lip angles	(degrees) :		80.0000	77.0000
Flange widths	(inches) :		2.9375	2.6250
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0940		
Purlin thickness	(inches) :	0.0750		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3043
Gross moment of inertia	(in^4) :	10.82

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7979	inches
Effective moment of inertia	:	9.81	in^4
Allowable flexural capacity	:	78.74	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2504	inches	
Effective moment of inertia	:	10.76	in^4	
Allowable stress at flange	:	33.96	ksi	controls
Allowable stress at web	:	31.89	ksi	(at flange : 34.56 ksi)
Allowable flexural capacity	:	91.58	kip-in	

Figure A.18 Strength Calculations, Test P1/2-T-1

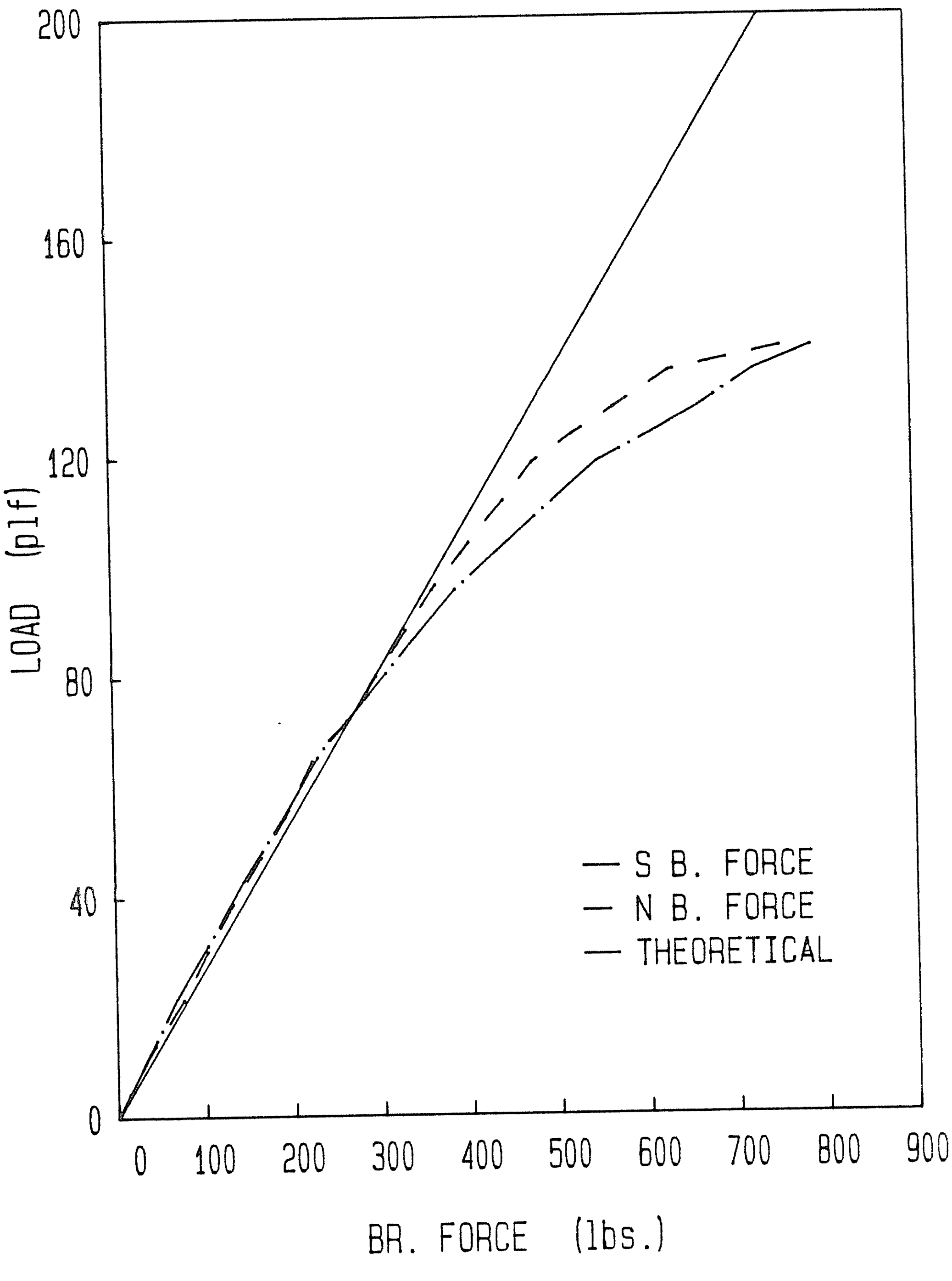
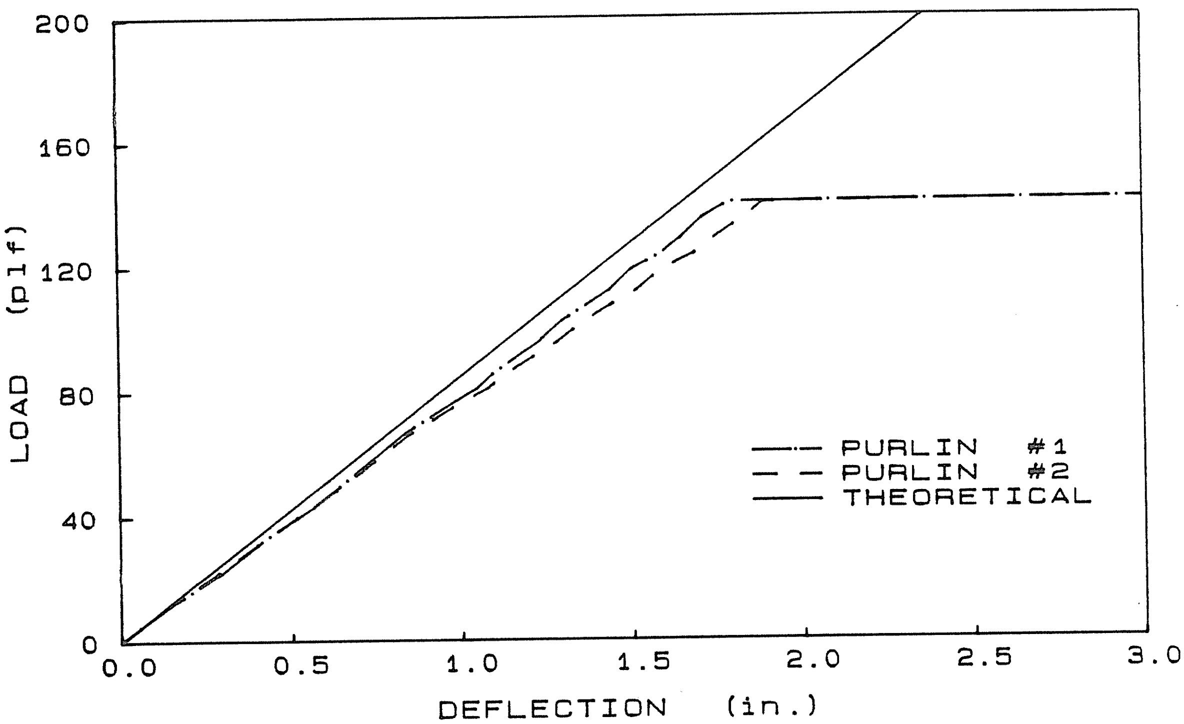
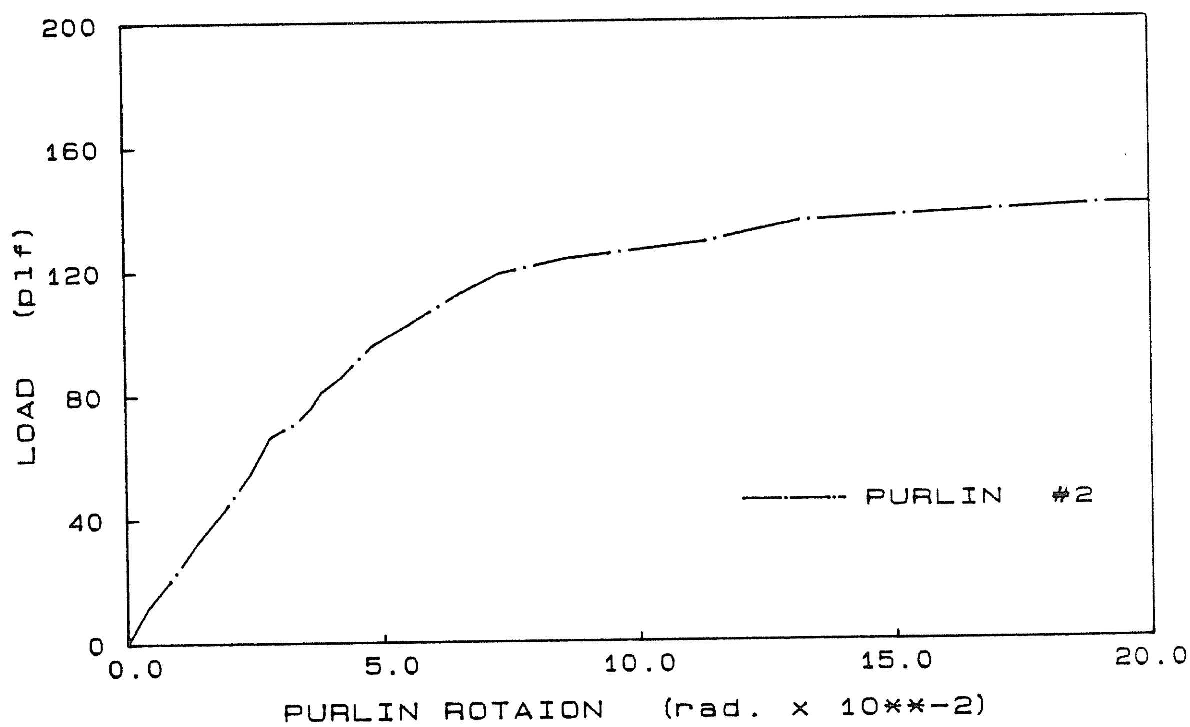


Figure A.19 Load vs. External Brace Forces, Test P1/2-T-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.20 Load vs. Purlin Movement, Test P1/2-T-1

STANDING SEAM ROOF SYSTEMS
SINGLE SPAN RESTRAINT
FORCE TESTS

TEST SUMMARY

Test No: R2/2-M-1 Test Date: 7-24-86

Span: 20 ft. Deck Type: Rib

Restraint Configuration: ______ Supports
X Midspan
______ Third Pts.

Purlin Data: Thickness .0725 in. Moment of Inertia 10.17 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 1/8"

Purlin #2 1/8"

Predictions: Failure Load 205.6 plf (1986 AISI)

240.2 plf (1980 AISI)

Brace Force @ 100 plf 667.1 lbs/brace

Vertical Deflection @ 100 plf 1.22 in.

Restraint: Midspan brace between Purlin #1 and Purlin #2.

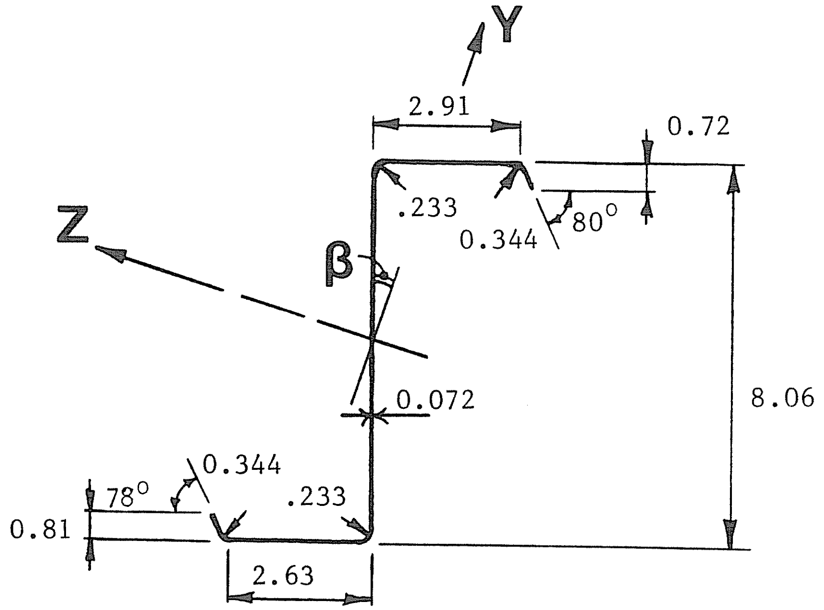
Experimental Failure Load: 160.1 plf

Failure Mode: Local buckling of compression flange at midspan of Purlin #2.

Discussion:

- Purlin #2 rotation @ failure = 0.084 radians.
- Maximum horizontal deflection = 0.025 inches.
- Very little clip movement.
- Good correlation between theoretical and experimental predictions for both brace force and deflections.
- Experimental failure load was 77.9% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1



Properties: Span (ft) = 20.0

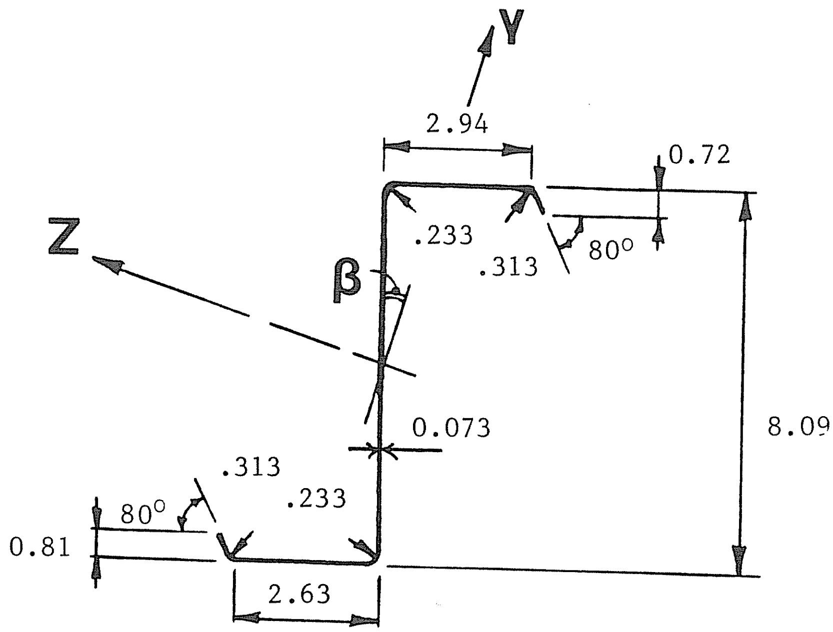
Area (in^2) = 1.0636

β(deg) = 18.0511

I_x (in^4) = 0.0019

I_y (in^4) = 0.7816

I_z (in^4) = 11.7335



Properties: Span (ft) = 20.0

Area (in^2) = 1.0832

β(deg) = 18.0696

I_x (in^4) = .0020

I_y (in^4) = 0.7990

I_z (in^4) = 12.0541

Figure A.21 Measured Purlin Dimensions and Calculated Properties, Test R2/2-M-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7188	0.8125
Lip angles	(degrees) :	80.0000	78.0000
Flange widths	(inches) :	2.9063	2.6250
Radii	(inches)		
Lip to flange	:	0.3428	0.3438
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0720

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2532
Gross moment of inertia	(in^4) :	10.25

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6918	inches
Effective moment of inertia	: 9.24	in^4
Allowable flexural capacity	: 73.90	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.1780	inches		
Effective moment of inertia	: 10.17	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.54	ksi	(at flange : 34.14 ksi)	
Allowable flexural capacity	: 86.29	kip-in		

Figure A.22 Strength Calculations, Test R2/2-M-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.8125
Lip angles	(degrees) :		80.0000	80.0000
Flange widths	(inches) :		2.9375	2.6250
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0938		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3080
Gross moment of inertia	(in^4) :	10.52

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7483	inches
Effective moment of inertia	: 9.47	in^4
Allowable flexural capacity	: 75.70	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2180	inches	
Effective moment of inertia	: 10.42	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.63	ksi	(at flange : 34.25 ksi)
Allowable flexural capacity	: 88.27	kip-in	

Figure A.22 Strength Calculations, Test R2/2-M-1

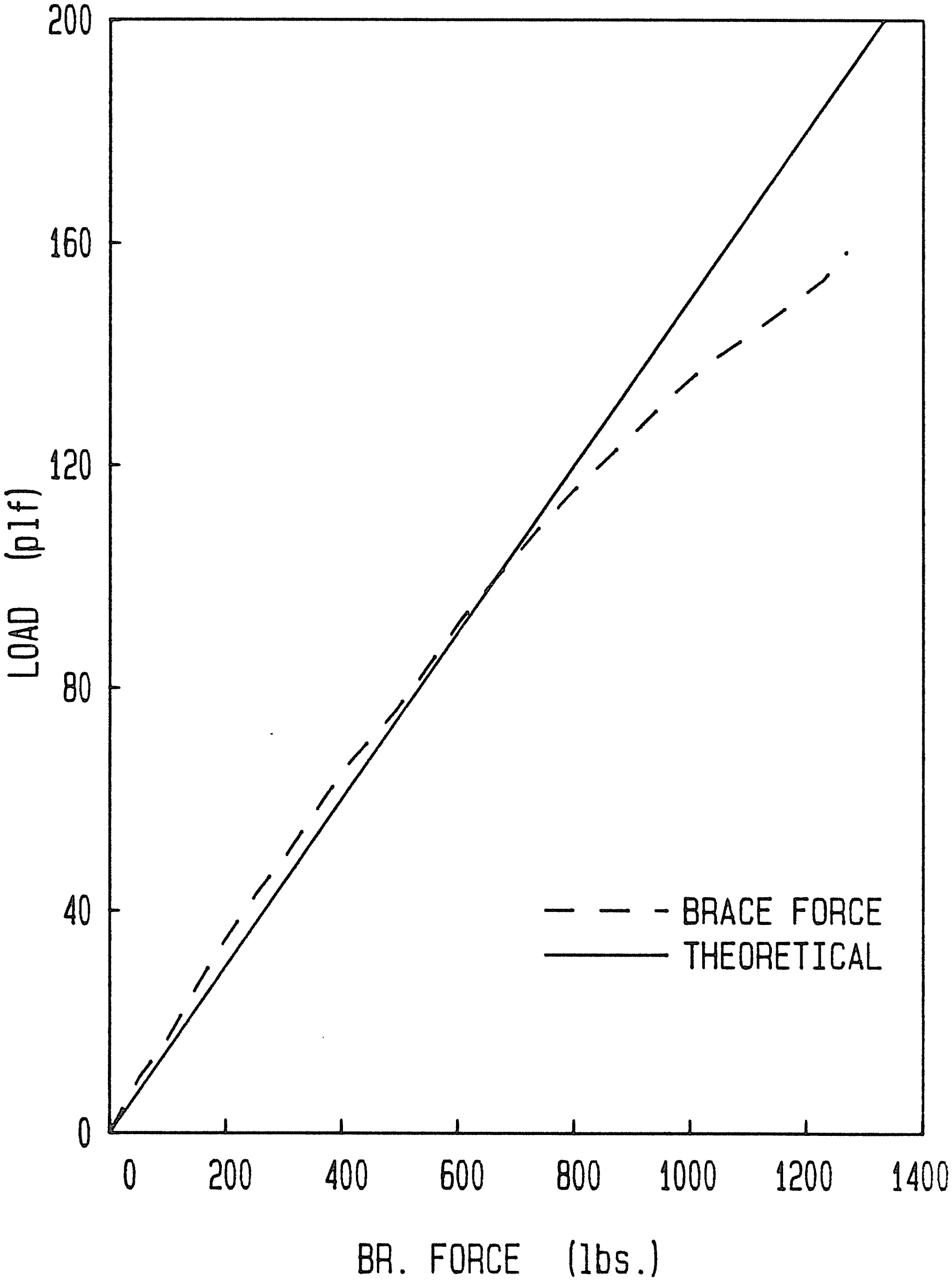
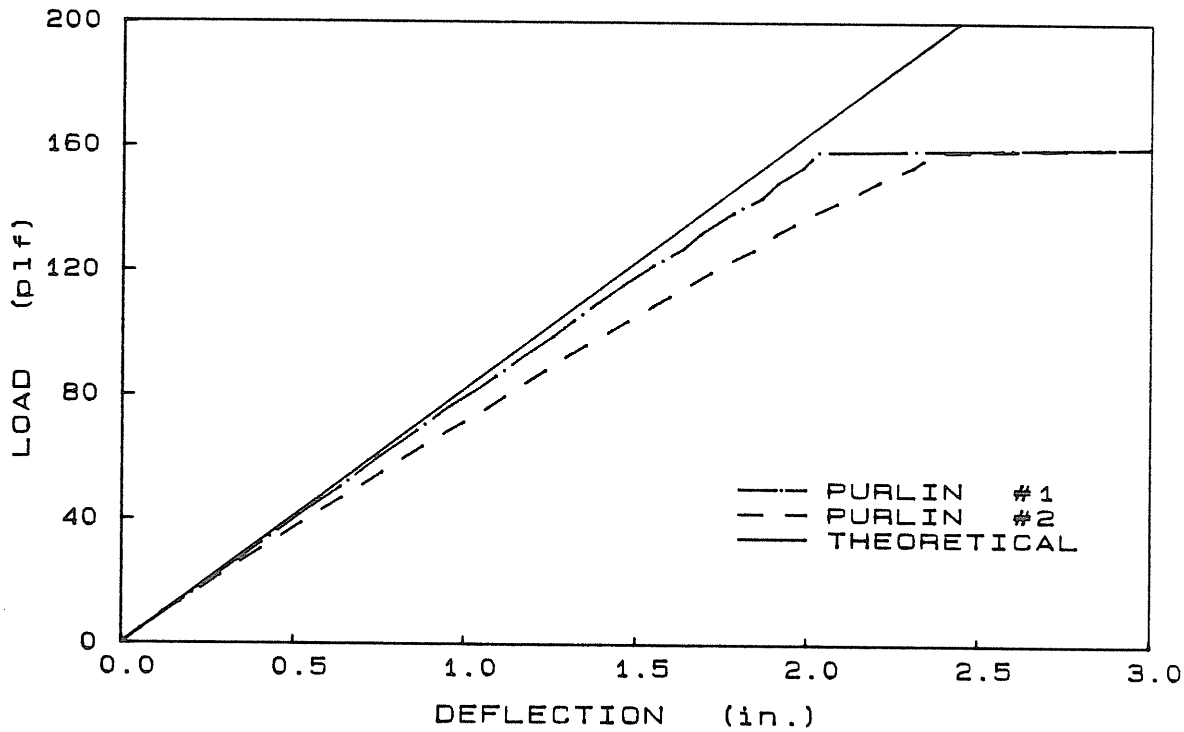
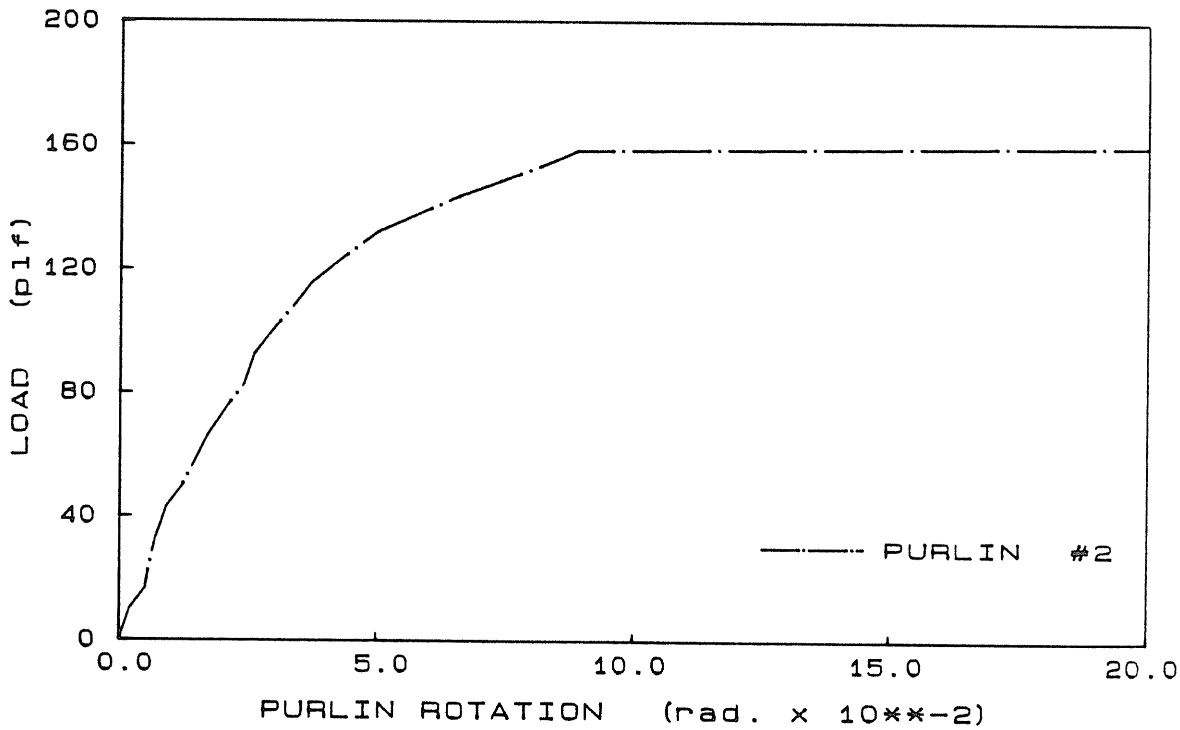


Figure A.23 Load vs. External Brace Force, Test R2/2-M-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.24 Load vs. Purlin Movement, Test R2/2-M-1

STANDING SEAM ROOF SYSTEMS
SINGLE SPAN RESTRAINT
FORCE TESTS

TEST SUMMARY

Test No: P1/2-M-1 Test Date: 7-10-86

Span: 20 ft. Deck Type: Pan

Restraint Configuration: ______ Supports

X Midspan

______ Third Pts.

Purlin Data: Thickness .073 in. Moment of Inertia 10.29 in^4

Yield Stress 56.6 ksi

Initial Sweep: Purlin #1 5/16"

Purlin #2 1/4"

Predictions: Failure Load 210.8 plf (1986 AISI)

245.3 plf (1980 AISI)

Brace Force @ 100 plf 670.3 lbs/brace

Vertical Deflection @ 100 plf 1.21 in.

Restraint: Brace between Purlins #1 and #2 @ midspan.

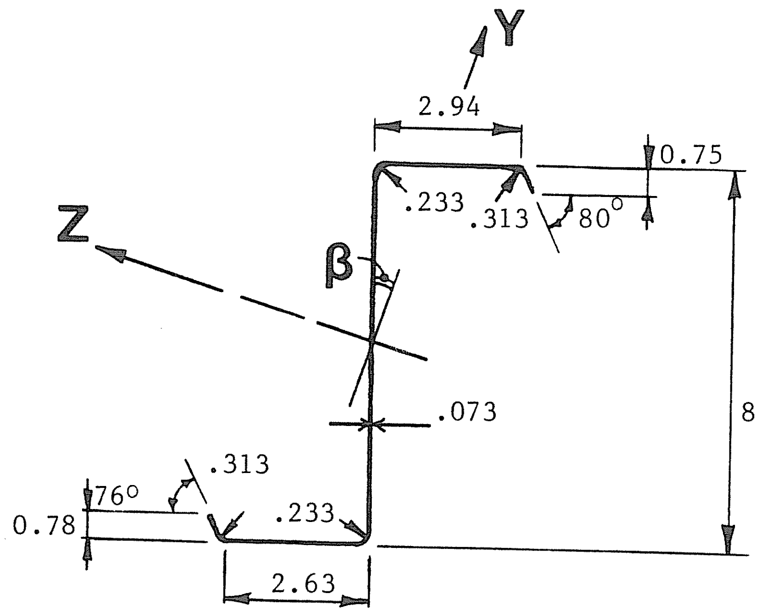
Experimental Failure Load: 138.3 plf

Failure Mode: Local buckling of the compression flange at the location of the midspan brace.

Discussion:

- Purlin rotation at failure = 0.059 radians.
- Maximum clip movement = 0.15 inches.
- Good correlation between theoretical and experimental predictions for both brace force and deflections.
- Experimental failure load was 65.6% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1



Properties: Span (ft) = 20.0

Area (in^2) = 1.0832

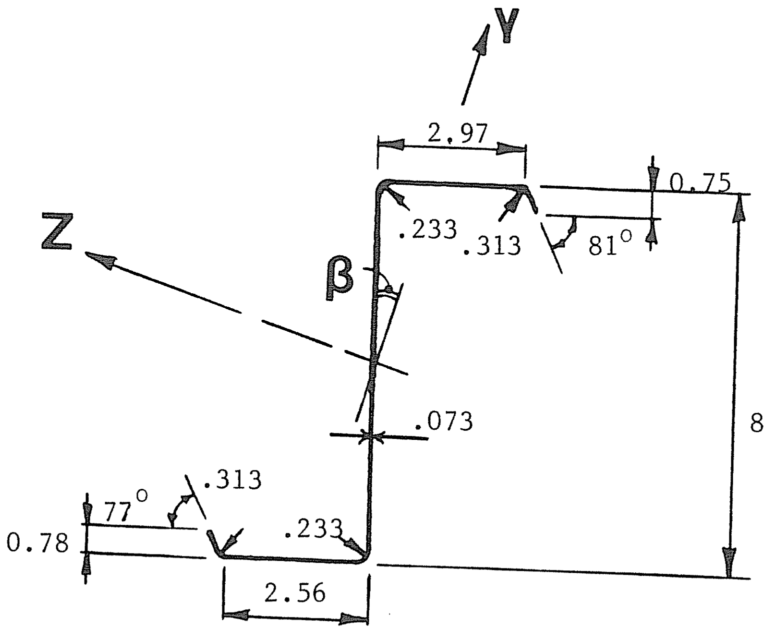
β(deg) = 18.2635

$I_x(in^4)$ = 0.002

$I_y(in^4)$ = 0.8071

$I_z(in^4)$ = 12.0215

Purlin #2



Properties: Span (ft) = 20.0

Area (in^2) = 1.0797

β(deg) = 18.1263

I_x (in^4) = .0019

I_y (in^4) = 0.7964

I_z (in^4) = 11.9255

Figure A.25 Measured Purlin Dimensions and Calculated Properties, Test P1/2-M-1

(a) Purlin #1

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7500	0.7810
Lip angles	(degrees) :	80.0000	76.0000
Flange widths	(inches) :	2.9380	2.6250
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0680
Purlin thickness	(inches) :	0.0730

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3085
Gross moment of inertia	(in^4) :	10.48

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7754	inches
Effective moment of inertia	:	9.46	in^4
Allowable flexural capacity	:	76.05	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2183	inches	
Effective moment of inertia	:	10.37	in^4	
Allowable stress at flange	:	33.96	ksi	controls
Allowable stress at web	:	31.66	ksi	(at flange : 34.30 ksi)
Allowable flexural capacity	:	88.33	kip-in	

Figure A.26 Strength Calculations, Test P1/2-M-1, Continued

(b) Purlin #2

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7500	0.7810
Lip angles	(degrees) :	81.0000	77.0000
Flange widths	(inches) :	2.9690	2.5630
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0630
Purlin thickness	(inches) :	0.0730

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3338
Gross moment of inertia	(in^4) :	10.40

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7741	inches
Effective moment of inertia	: 9.37	in^4
Allowable flexural capacity	: 75.74	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2285	inches		
Effective moment of inertia	: 10.29	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.32 ksi)	
Allowable flexural capacity	: 88.12	kip-in		

Figure A.26 Strength Calculations, Test P1/2-M-1

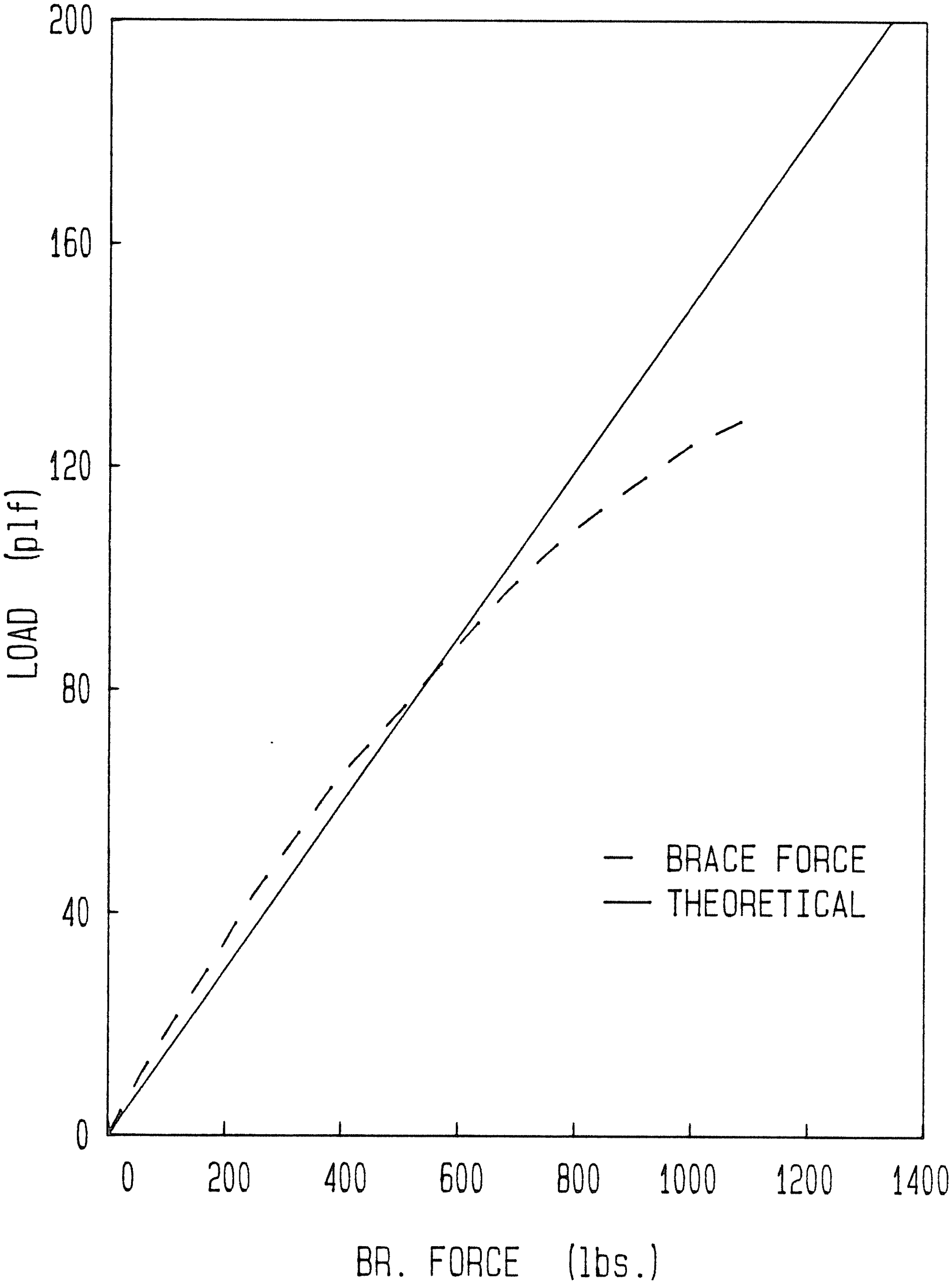
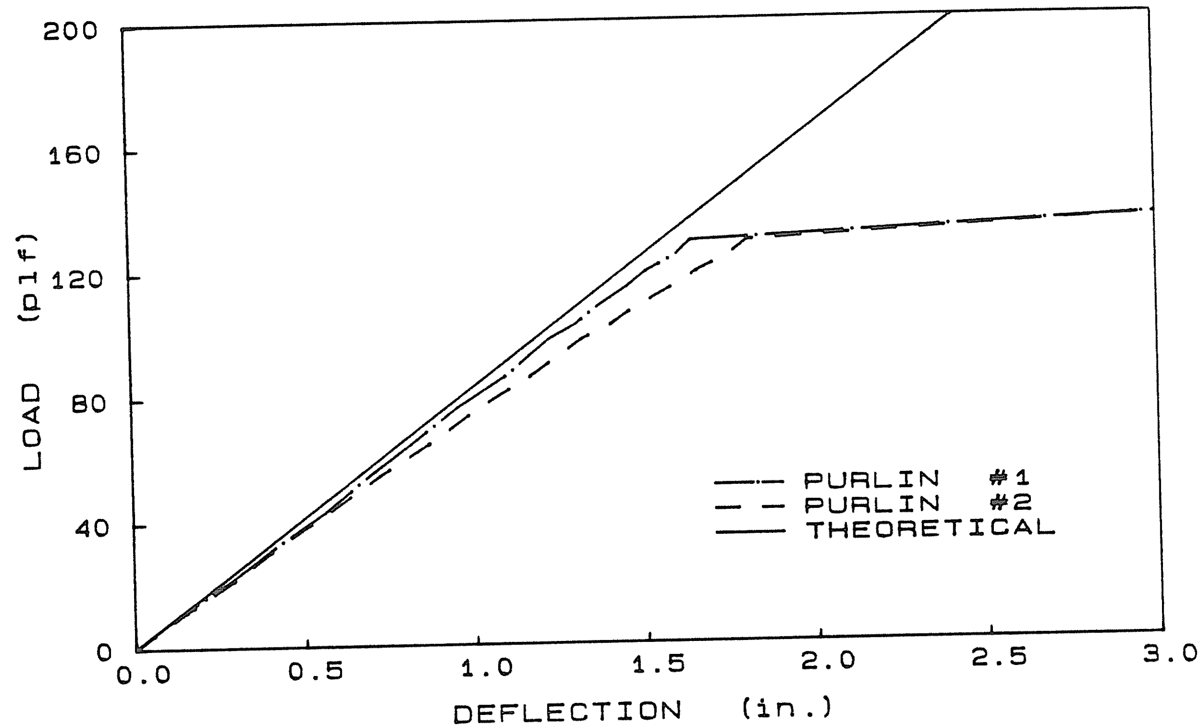
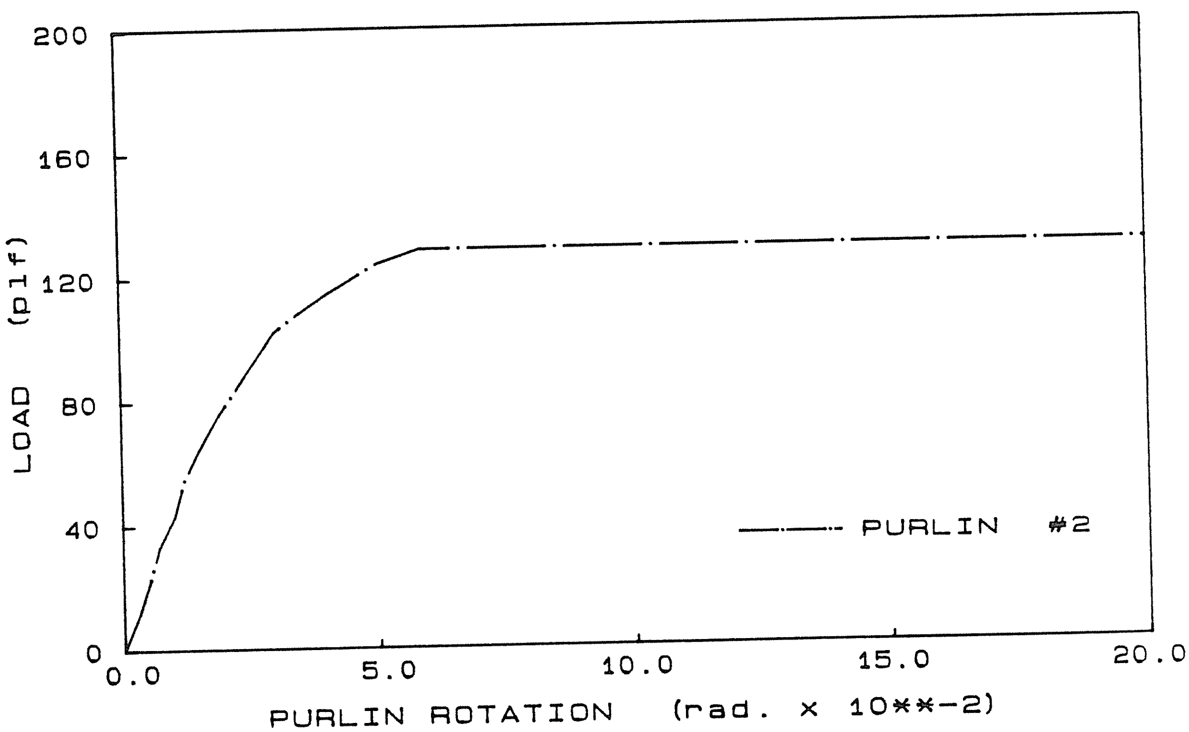


Figure A.27 Load vs. External Brace Force, Test P1/2-M-1



(a) Load vs. Deflection



(b) Load vs. Purlin Rotation

Figure A.28 Load vs. Purlin Movement, Test P1/2-M-1

APPENDIX B
CONTINUOUS SPAN TEST SUMMARIES

STANDING SEAM ROOF SYSTEMS THREE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: R3/2-R-3 Test Date: 8-15-86

Three Spans @ 23.0 ft. Deck Type: Rib

Restraint Configuration: X Supports

____ Midspan

____ Third Pts.

Purlin Data: Thickness 0.073 in. Moment of Inertia 10.30 in^4

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

-0.01 in. (Center Bay)

1.05 in. (N.& S. Bays)

Failure Load 252.6 plf (1986 AISI)

293.9 plf (1980 AISI)

Brace Force @ 100 plf

426.0 lbs/brace (#1 & #4)

653.4 lbs/brace (#2 & #3)

Restraint: Bracing between purlins #1 and #2 at the supports

Experimental Failure Load: 85.1 plf

Failure Mode: Local buckling of south bay, purlin #2, at midspan

Discussion:

- South bay purlin #2 rotation @ 75.1 plf = 0.321 rad.
- Horizontal deflection of the south bay purlin #2 = 2.93 in.
- Deflections were much greater than full lateral restraint predictions
- Good correlation was found between theoretical and experimental predictions for exterior braces #1 & #4
- Brace force predictions were very conservative for interior braces #2 & #3

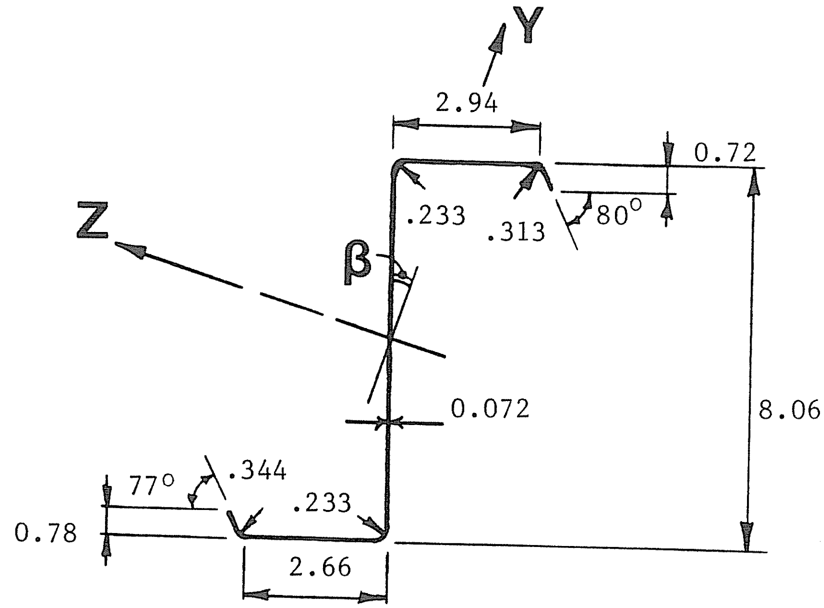
- Large clip movement at midspans, up to 0.17" @ 45.4 plf.
- Experimental failure load was 33.7% of 1986 AISI/constained bending/full lateral restraint predictions.

Initial purlin readings:

	Purlin #1	Purlin #2
North span	Sweep 3/8" Camber 0.0	1/4" 1/8"
Center span	Sweep 3/16" Camber -3/16"	0.0" -5/16" (upward)
South span	Sweep 7/16" Camber 3/8"	1/8" 0.0"

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0669

β(deg) = 18.2531

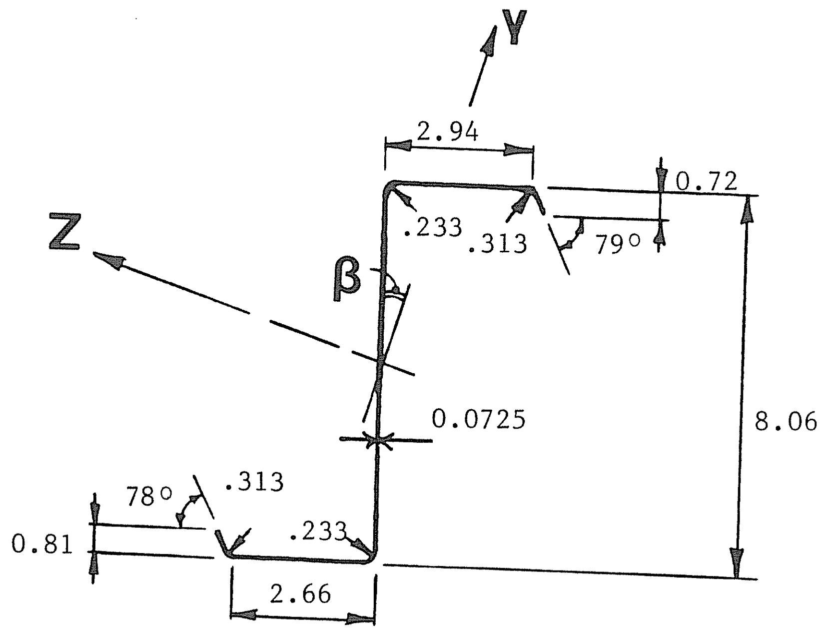
$I_x(in^4)$ = 0.0019

$I_y(in^4)$ = 0.7950

$I_z(in^4)$ = 11.8301

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0772

β(deg) = 18.3530

I_x (in^4) = 0.0019

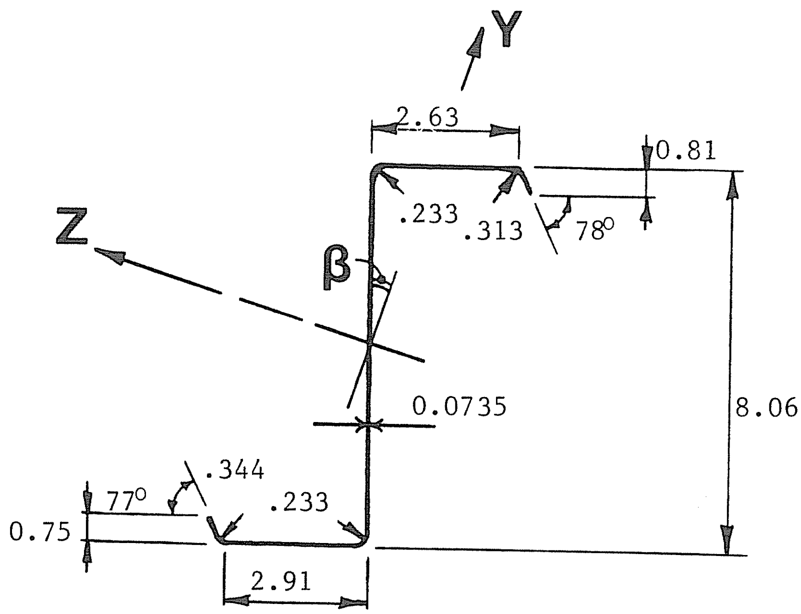
I_y (in^4) = 0.8065

I_z (in^4) = 11.9653

Figure B.1 Measured Purlin Dimensions and Calculated Properties, Test R3/2-R-3 Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0901

β(deg) = 18.2603

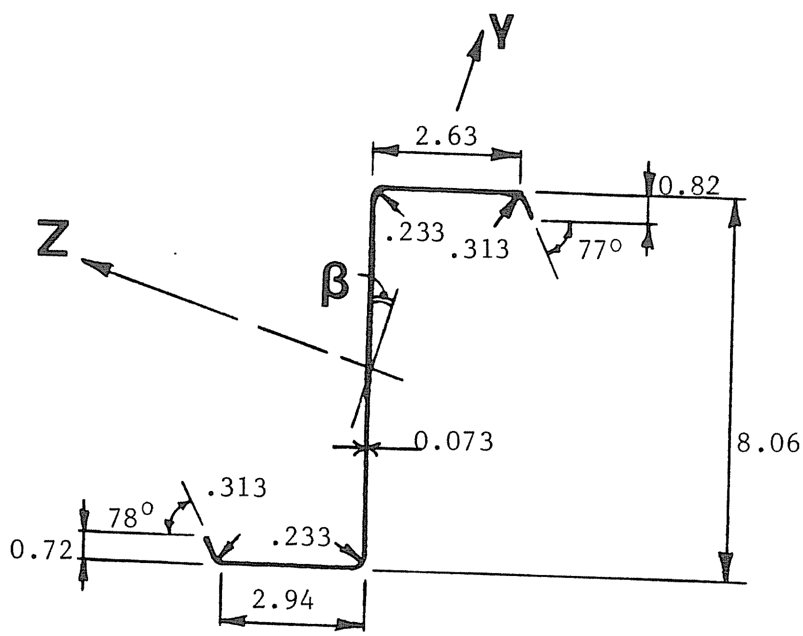
$I_x(in^4)$ = 0.0020

$I_y(in^4)$ = 0.8146

$I_z(in^4)$ = 12.0635

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0833

β(deg) = 18.2974

$I_x(in^4)$ = 0.0020

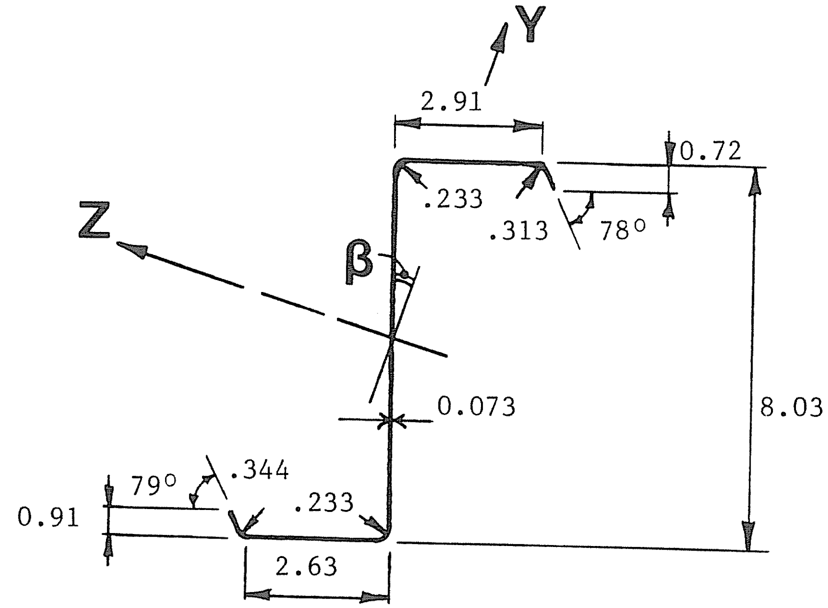
$I_y(in^4)$ = 0.8076

$I_z(in^4)$ = 12.0150

Figure B.1 Measured Purlin Dimensions and Calculated Properties, Test R3/2-R-3, Continued

Purlin #1

South Span



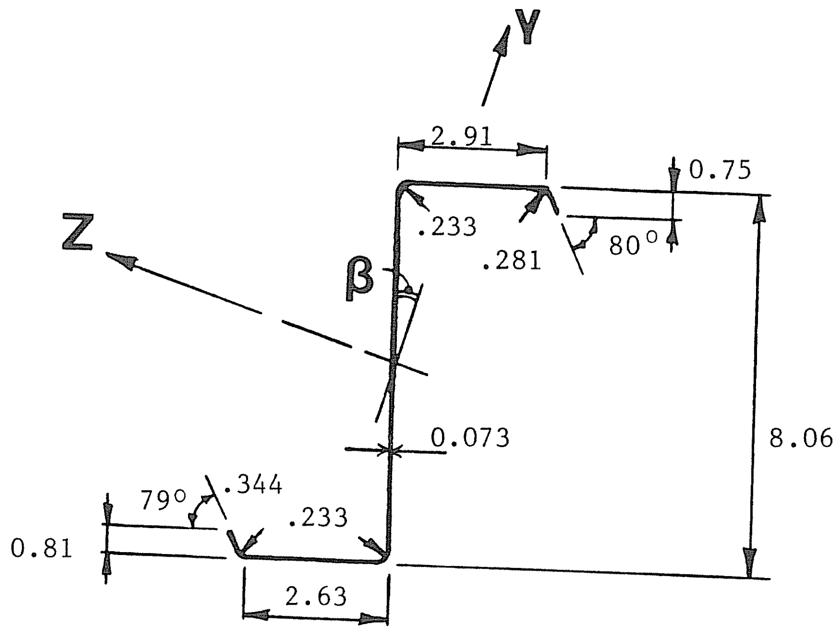
Properties: Span (ft) = 23.0 $I_x(in^4)$ = 0.0020

Area (in^2) = 1.0841 $I_y(in^4)$ = 0.8125

β(deg) = 18.4315 $I_z(in^4)$ = 11.9414

Purlin #2

South Span



Properties: Span (ft) = 23.0 $I_x(in^4)$ = 0.0020

Area (in^2) = 1.0808 $I_y(in^4)$ = 0.7978

β(deg) = 18.1372 $I_z(in^4)$ = 11.9384

Figure B.1 Measured Purlin Dimensions and Calculated Properties, Test R3/2-R-3

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.7813
Lip angles	(degrees) :		80.0000	77.0000
Flange widths	(inches) :		2.9380	2.6560
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0720		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3104
Gross moment of inertia	(in^4) :	10.32

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7369	inches
Effective moment of inertia	: 9.27	in^4
Allowable flexural capacity	: 74.21	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2015	inches		
Effective moment of inertia	: 10.19	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.54	ksi	(at flange : 34.14 ksi)	
Allowable flexural capacity	: 86.48	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.8125
Lip angles	(degrees) :		79.0000	78.0000
Flange widths	(inches) :		2.9375	2.6563
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0725		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3146
Gross moment of inertia	(in^4) :	10.42

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7519	inches
Effective moment of inertia	: 9.38	in^4
Allowable flexural capacity	: 74.96	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2120	inches		
Effective moment of inertia	: 10.30	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.61	ksi	(at flange : 34.21 ksi)	
Allowable flexural capacity	: 87.33	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7500
Lip angles	(degrees) :		78.0000	77.0000
Flange widths	(inches) :		2.6250	2.9063
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0735		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0059
Gross moment of inertia	(in^4) :	10.52

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6806	inches
Effective moment of inertia	: 9.75	in^4
Allowable flexural capacity	: 77.12	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0059	inches		
Effective moment of inertia	: 10.52	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.74	ksi	(at flange : 34.31 ksi)	
Allowable flexural capacity	: 87.25	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7188
Lip angles	(degrees) :		77.0000	78.0000
Flange widths	(inches) :		2.6250	2.9375
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0124
Gross moment of inertia	(in^4) :	10.47

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6785	inches
Effective moment of inertia	: 9.69	in^4
Allowable flexural capacity	: 76.61	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0124	inches		
Effective moment of inertia	: 10.47	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.23 ksi)	
Allowable flexural capacity	: 86.86	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3, Continued

(e) Purlin #1, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.8125
Lip angles	(degrees) :		80.0000	79.0000
Flange widths	(inches) :		2.9063	2.6250
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2768
Gross moment of inertia	(in^4) :	10.41

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7671	inches
Effective moment of inertia	:	9.43	in^4
Allowable flexural capacity	:	75.82	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2050	inches		
Effective moment of inertia	:	10.33	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.67	ksi	(at flange : 34.30 ksi)	
Allowable flexural capacity	:	87.99	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.9063
Lip angles	(degrees) :		78.0000	79.0000
Flange widths	(inches) :		2.9063	2.6250
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0313		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2881
Gross moment of inertia	(in^4) :	10.39

1986 AISI PROCEDURE

Flange is not fully effective

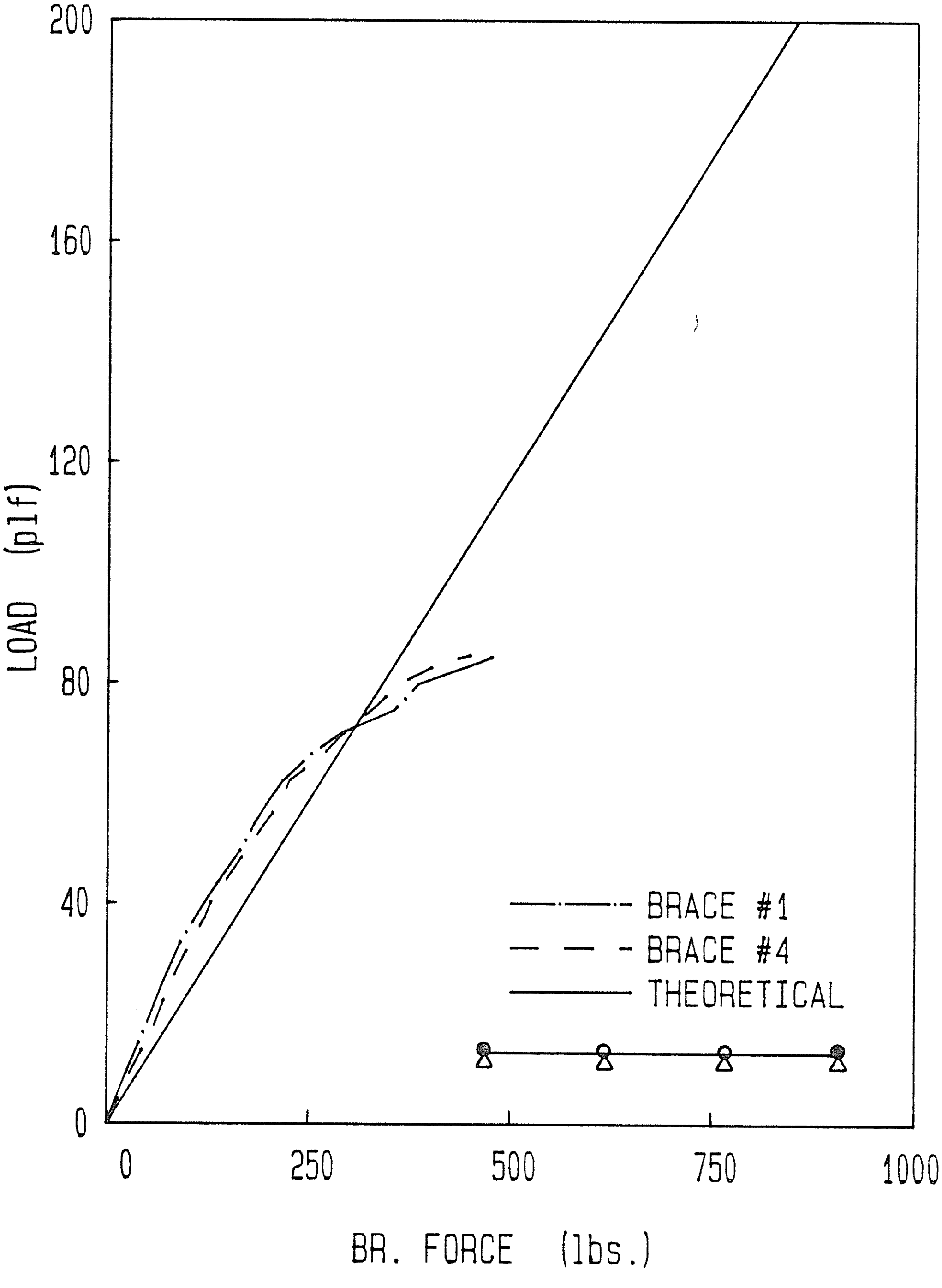
Effective flange width	: 1.7591	inches
Effective moment of inertia	: 9.38	in^4
Allowable flexural capacity	: 75.14	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

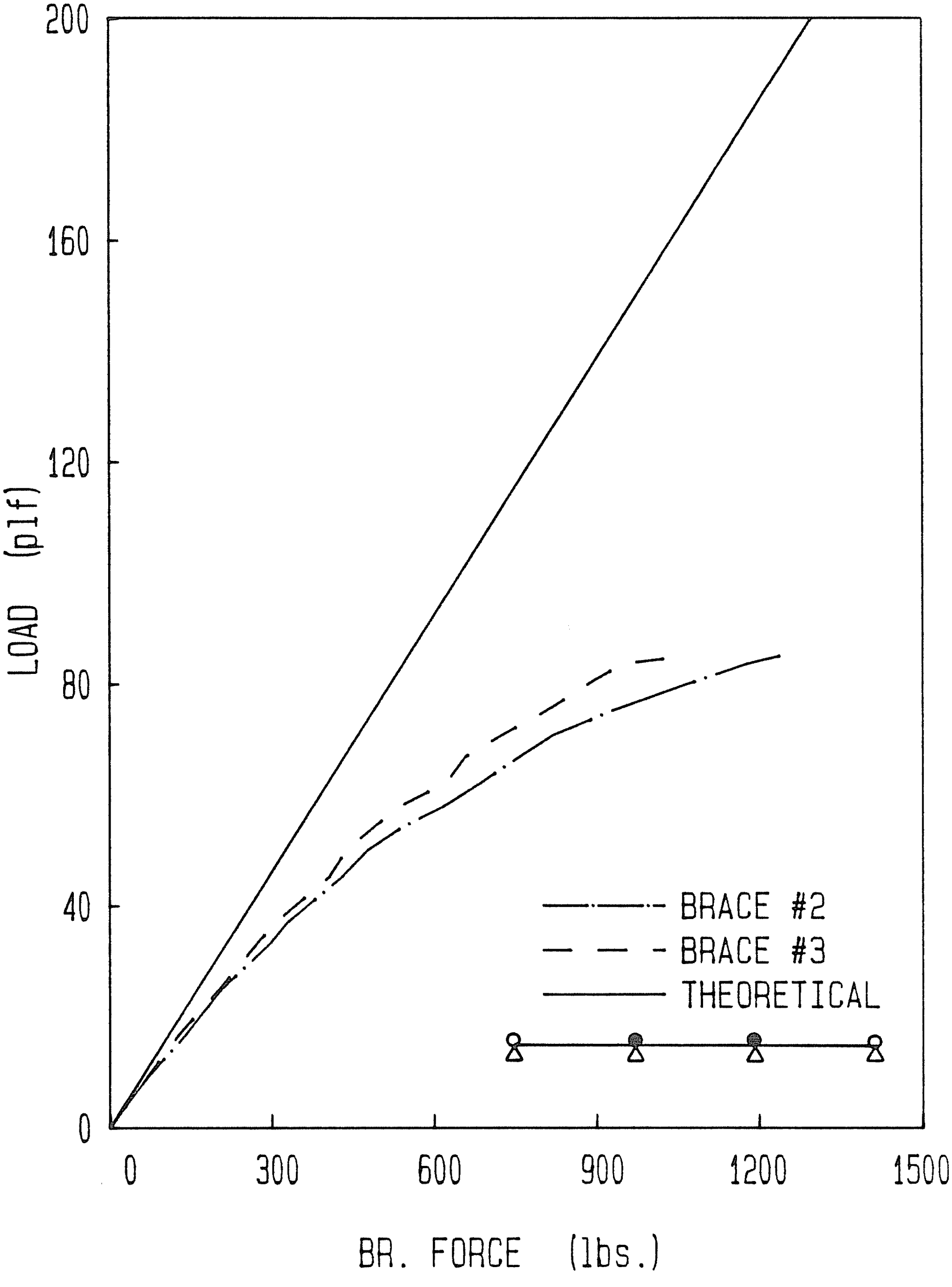
Effective flange width	: 2.2098	inches		
Effective moment of inertia	: 10.30	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.71	ksi	(at flange : 34.34 ksi)	
Allowable flexural capacity	: 87.45	kip-in		

Figure B.2 Strength Calculations, Test R3/2-R-3



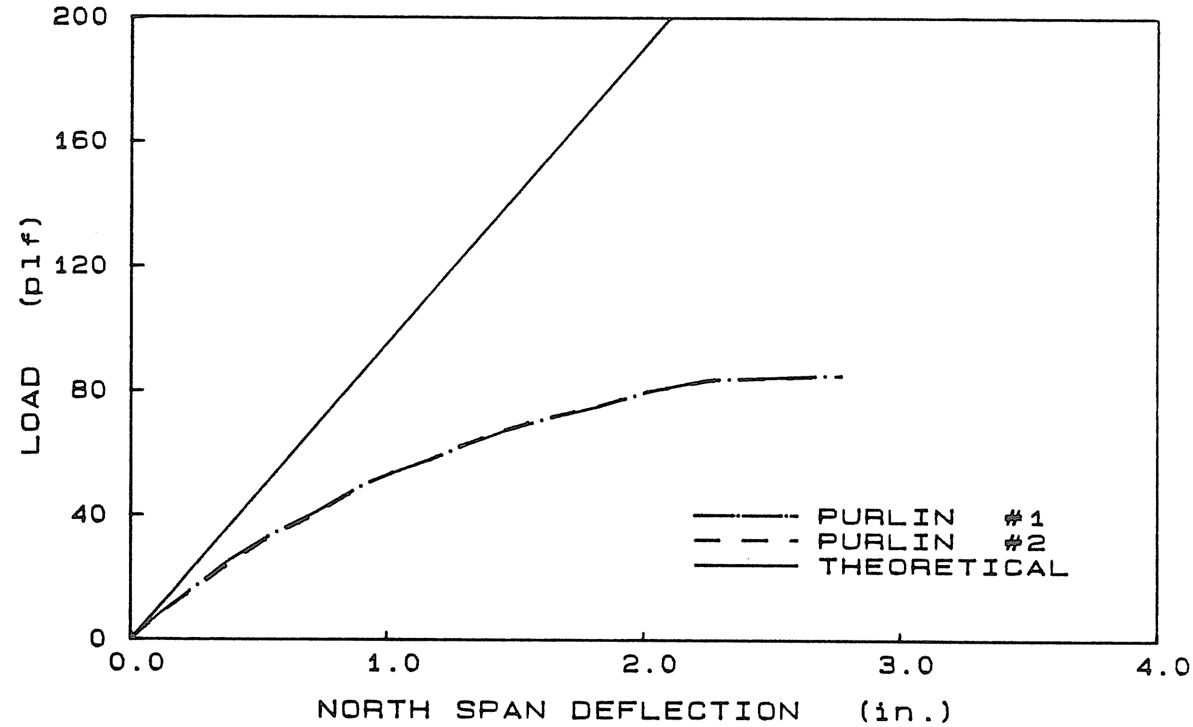
(a) Braces #1 and #4

Figure B.3 Load vs. External Brace Forces, Test R3/2-R-3, Continued

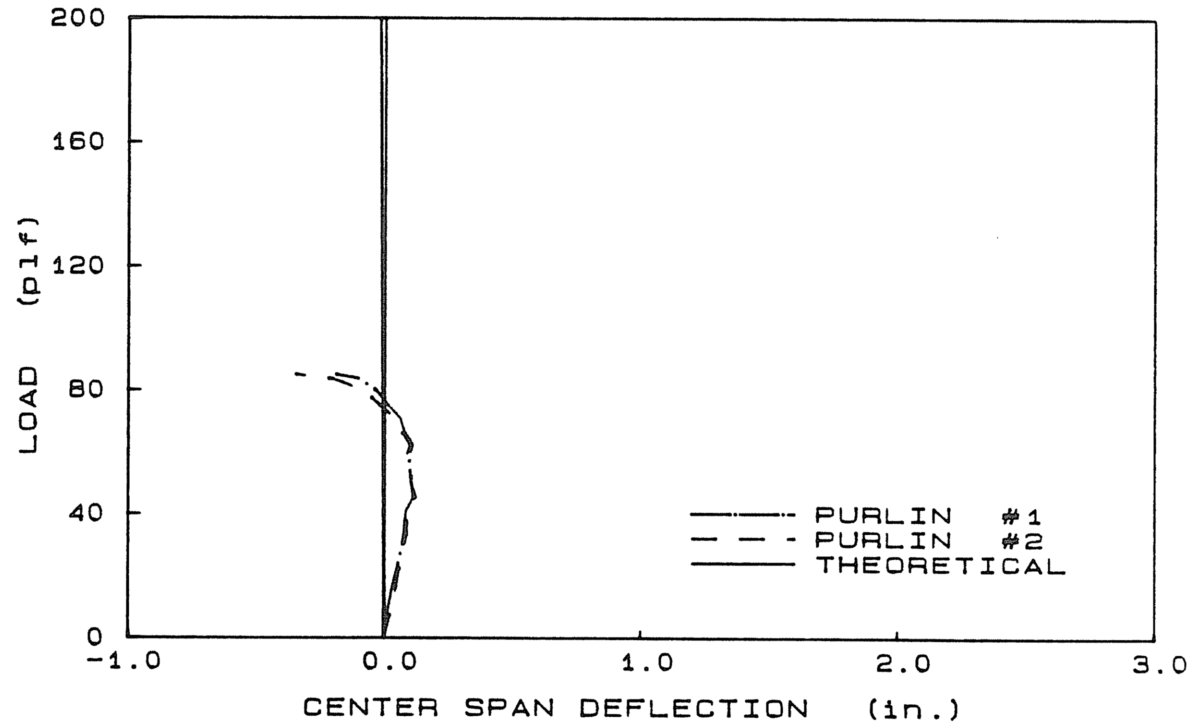


(b) Braces #2 and #3

Figure B.3 Load vs. External Braces Forces, Test R3/2-R-3

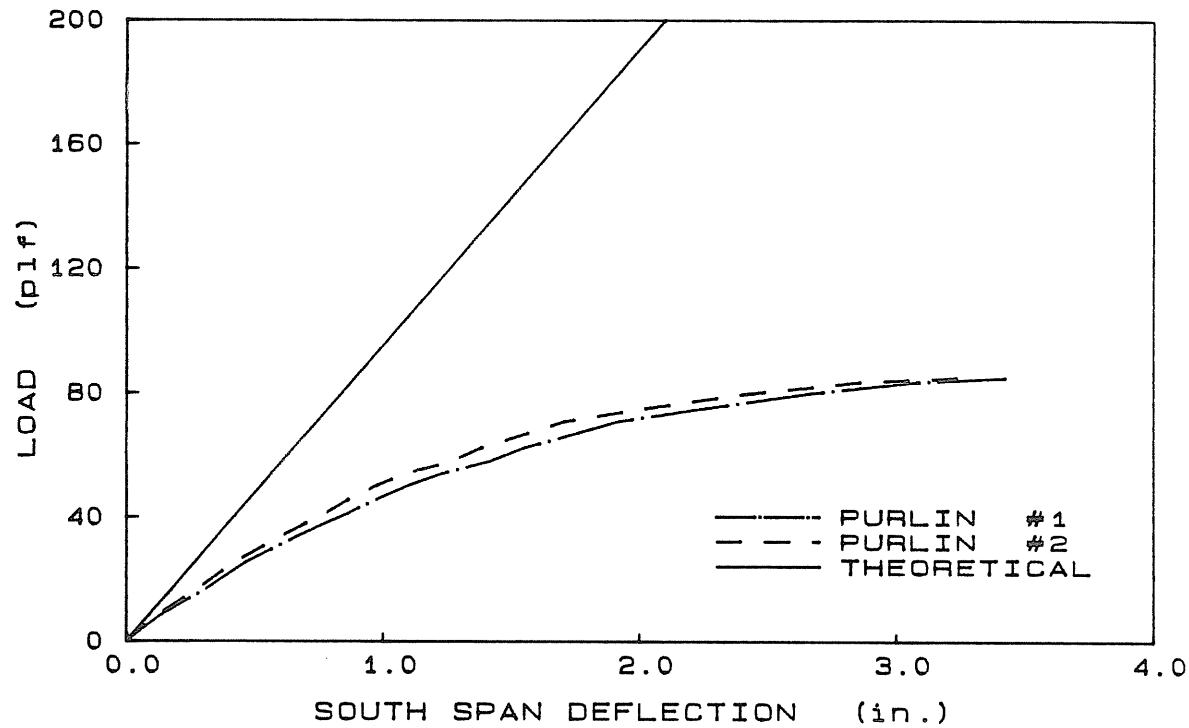


(a) Load vs. Deflection

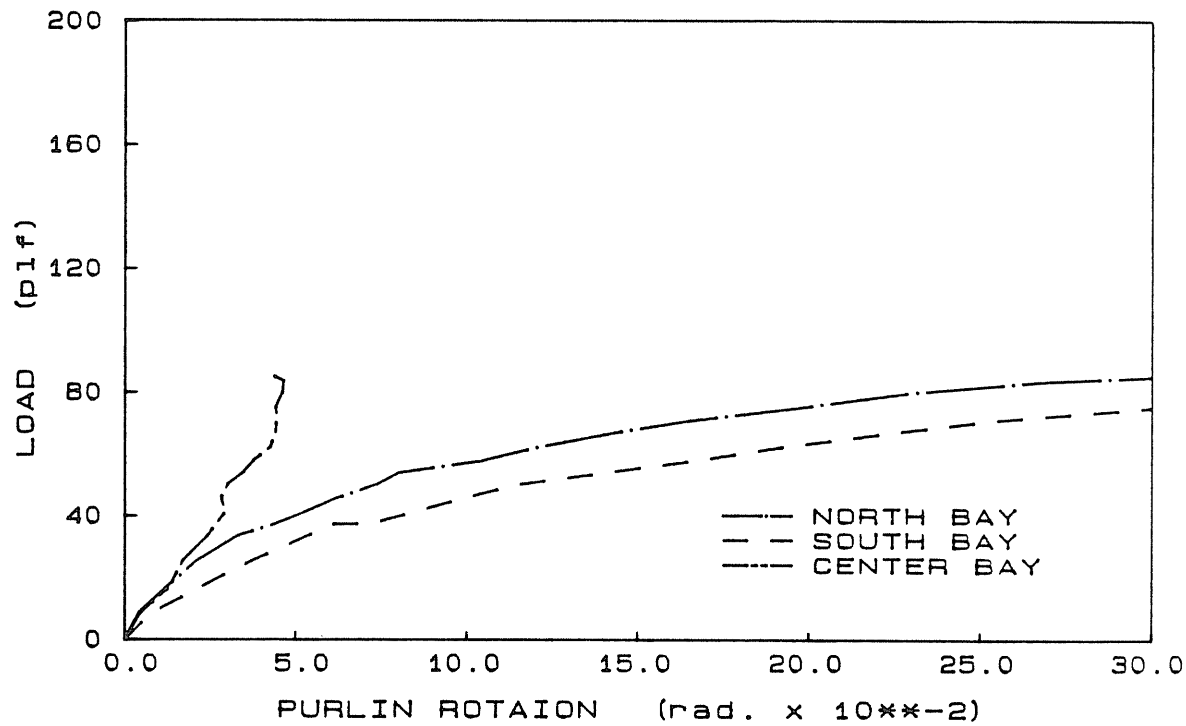


(b) Load vs. Deflection

Figure B.4 Load vs. Purlin Movement, Test R3/2-R-3, Continued



(c) Load vs. Deflection



(d) Load vs. Purlin Rotation

Figure B.4 Load vs. Purlin Movement, Test R3/2-R-3

STANDING SEAM ROOF SYSTEMS THREE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: P2/2-R-3 Test Date: 9/15/86

Three Spans @: 23.0 ft. Deck Type: Pan

Restraint Configuration: X Supports

________ Midspan

________ Third Pts.

Purlin Data: Thickness 0.069 in.

Moment of Inertia 9.64 in^4 (North Bay)

Thickness 0.08 in^4

Moment of Inertia 11.25 in^4 (C.& S. Bays)

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

-0.02 in. (Center Bay)

0.97 in. (South Bay)

1.11 in. (North Bay)

Failure Load 233.3 plf (1986 AISI)

264.8 plf (1980 AISI)

Brace Force @ 100 plf 412.0 lbs/brace (#1 & #4)

616.7 lbs/brace (#2 & #3)

Restraint: Bracing between purlin #1 and #2 at the supports

Experimental Failure Load: 99.5 plf

Failure Mode: Lateral buckling of north bay purlins #1 & #2

Discussion:

- North bay purlin #2 rotation @ 93.3 plf = 0.131 rad.

- Horizontal deflection of the north bay purlin #2 = 1.11 in. @ 93.3 plf.

- Good correlation was found between theoretical and experimental predictions for exterior braces #1 & $4.

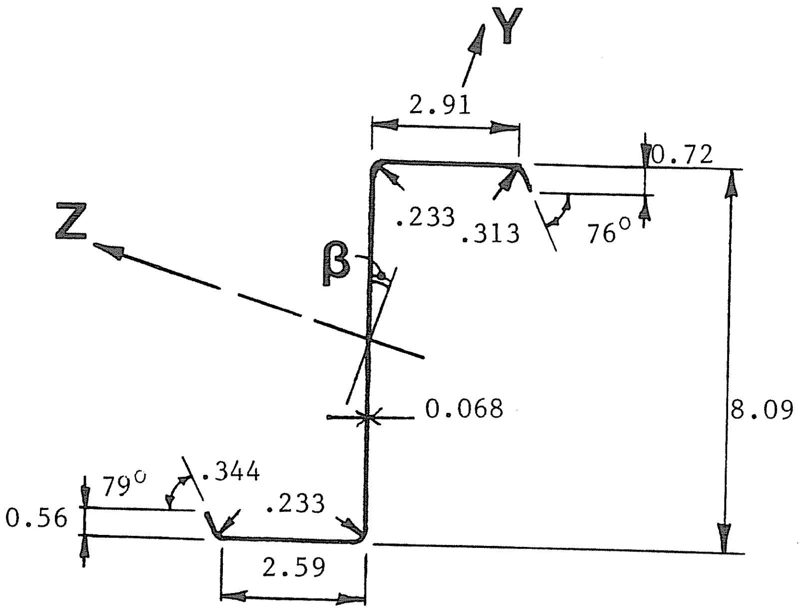
- Brace force predictions were unconservative for interior braces #2 & #3.

- Large clip movement at end and midspans, up to 0.15" @ 50 plf.

- Experimental failure load was 42.6% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 0.9890

β(deg) = 17.3001

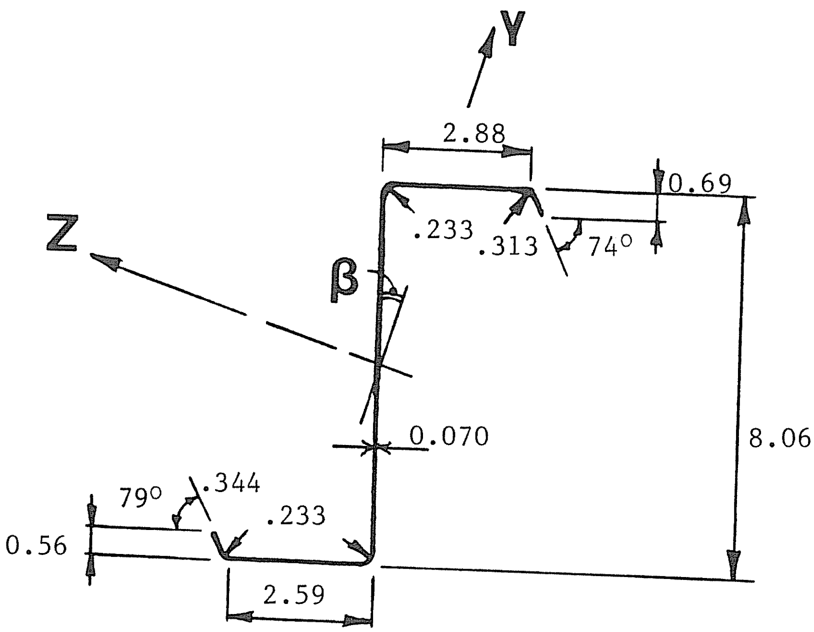
$I_x(in^4)$ = 0.0015

$I_y(in^4)$ = 0.6924

$I_z(in^4)$ = 10.8555

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0051

β(deg) = 17.2361

$I_x(in^4)$ = 0.0016

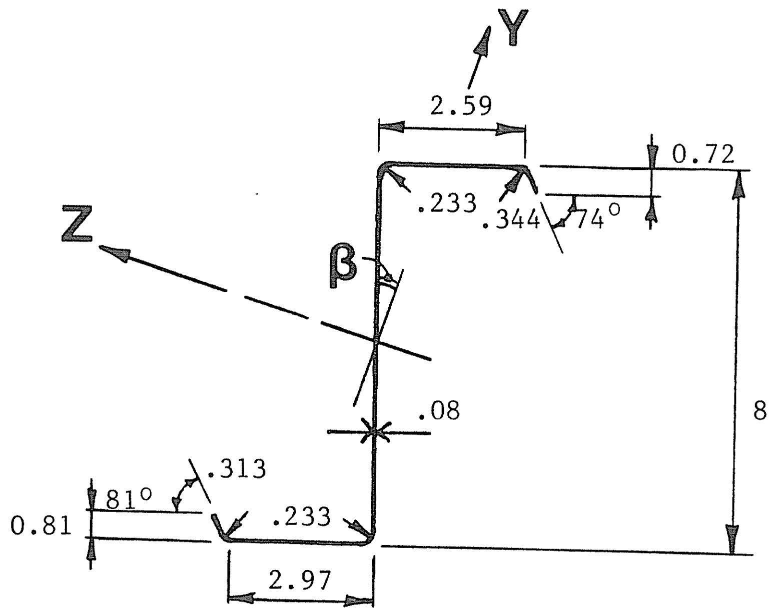
$I_y(in^4)$ = 0.6927

$I_z(in^4)$ = 10.9396

Figure B.5 Measured Purlin Dimensions and Calculated Properties, Test P2/2-R-3, Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1866

β(deg) = 18.3066

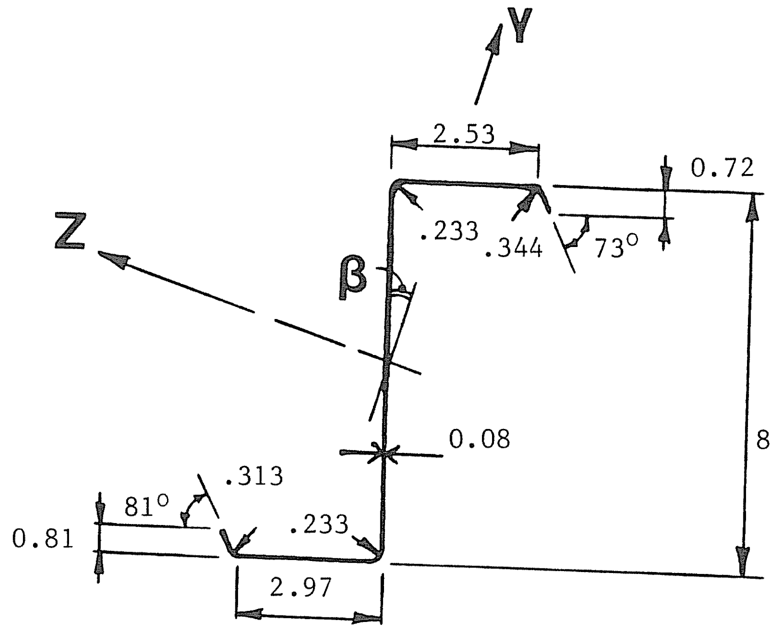
$I_x(in^4)$ = 0.0026

$I_y(in^4)$ = 0.8901

$I_z(in^4)$ = 13.1412

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1822

β(deg) = 18.1213

$I_x(in^4)$ = 0.0026

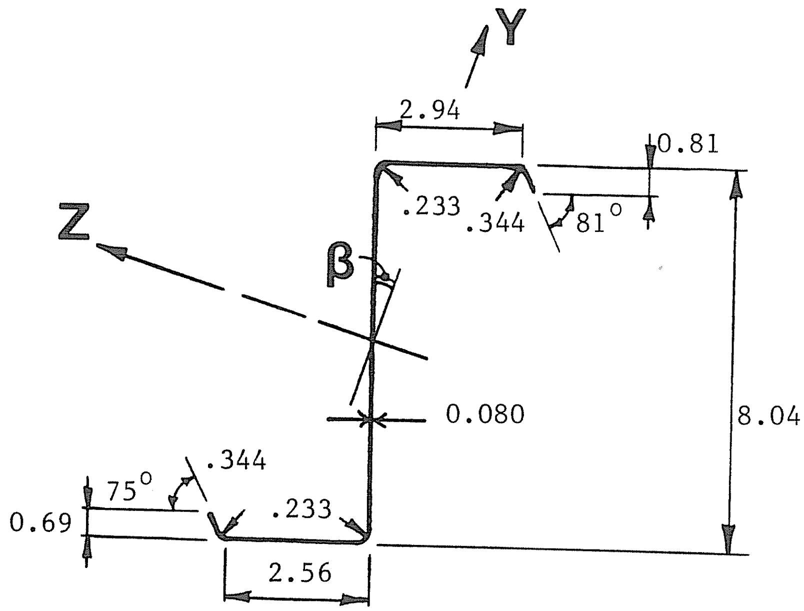
$I_y(in^4)$ = 0.8751

$I_z(in^4)$ = 13.0318

Figure B.5 Measured Purlin Dimensions and Calculated Properties, Test P2/2-R-3, Continued

Purlin #1

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1759

β(deg) = 18.0085

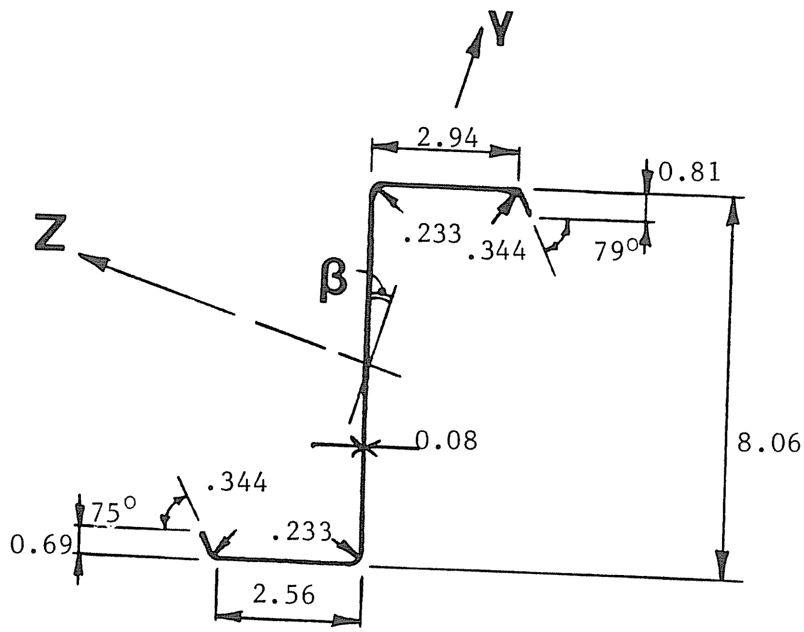
$I_x(in^4)$ = 0.0025

$I_y(in^4)$ = 0.8597

$I_z(in^4)$ = 12.8681

Purlin #2

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1786

β(deg) = 18.0086

$I_x(in^4)$ = 0.0025

$I_y(in^4)$ = 0.8662

$I_z(in^4)$ = 12.9600

Figure B.5 Measured Purlin Dimensions and Calculated Properties, Test P2/2-R-3

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7190	0.5630
Lip angles	(degrees) :		76.0000	79.0000
Flange widths	(inches) :		2.9060	2.5940
Radii	(inches)			
Lip to flange	:		0.3130	0.3440
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0900		
Purlin thickness	(inches) :	0.0680		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3073
Gross moment of inertia	(in^4) :	9.49

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width :	1.7214	inches
Effective moment of inertia :	8.54	in^4
Allowable flexural capacity :	69.37	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width :	2.1359	inches	
Effective moment of inertia :	9.31	in^4	
Allowable stress at flange :	33.96	ksi	
Allowable stress at web :	30.93	ksi	(at flange : 33.48 ksi) controls
Allowable flexural capacity :	78.75	kip-in	

Figure B.6 Strength Calculations, Test P2/2-R-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.6880	0.5630
Lip angles	(degrees) :	74.0000	79.0000
Flange widths	(inches) :	2.8750	2.5940
Radii	(inches)		
Lip to flange	:	0.3130	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0600
Purlin thickness	(inches) :	0.0700

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2834
Gross moment of inertia	(in^4) :	9.63

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7292	inches
Effective moment of inertia	:	8.69	in^4
Allowable flexural capacity	:	70.79	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.1567	inches	
Effective moment of inertia	:	9.49	in^4	
Allowable stress at flange	:	33.96	ksi	
Allowable stress at web	:	31.26	ksi	(at flange : 33.87 ksi) controls
Allowable flexural capacity	:	81.54	kip-in	

Figure B.6 Strength Calculations, Test P2/2-R-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7190	0.8130
Lip angles	(degrees) :		74.0000	81.0000
Flange widths	(inches) :		2.5940	2.9690
Radii	(inches)			
Lip to flange	:		0.3440	0.3130
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0600		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	1.9615
Gross moment of inertia	(in^4) :	11.29

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7242	inches
Effective moment of inertia	: 10.62	in^4
Allowable flexural capacity	: 83.77	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 1.9615	inches		
Effective moment of inertia	: 11.29	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.17 ksi)	
Allowable flexural capacity	: 92.56	kip-in		

Figure B.6 Strength Calculations, Test P2/2-R-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7190	0.8130
Lip angles	(degrees) :	73.0000	81.0000
Flange widths	(inches) :	2.5310	2.9690
Radii	(inches)		
Lip to flange	:	0.3440	0.3130
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0600
Purlin thickness	(inches) :	0.0800

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	1.9043
Gross moment of inertia	(in^4) :	11.22

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7383	inches
Effective moment of inertia	: 10.66	in^4
Allowable flexural capacity	: 84.28	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 1.9043	inches	
Effective moment of inertia	: 11.22	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.16 ksi)
Allowable flexural capacity	: 91.59	kip-in	

Figure B.6 Strength Calculations, Test P2/2-R-3, Continued

(e) Purlin #1, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8100	0.6900
Lip angles	(degrees) :		81.0000	75.0000
Flange widths	(inches) :		2.9400	2.5600
Radii	(inches)			
Lip to flange	:		0.3440	0.3440
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0400		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2649
Gross moment of inertia	(in^4) :	11.09

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7206	inches
Effective moment of inertia	:	10.05	in^4
Allowable flexural capacity	:	82.06	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	:	2.2649	inches		
Effective moment of inertia	:	11.09	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	32.54	ksi	(at flange : 35.38 ksi)	
Allowable flexural capacity	:	96.63	kip-in		

Figure B.6 Strength Calculations, Test P2/2-R-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.8100	0.6900
Lip angles	(degrees) :	79.0000	75.0000
Flange widths	(inches) :	2.9400	2.5600
Radii	(inches)		
Lip to flange	:	0.3440	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0600
Purlin thickness	(inches) :	0.0800

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2775
Gross moment of inertia	(in^4) :	11.18

1986 AISI PROCEDURE

Flange is not fully effective

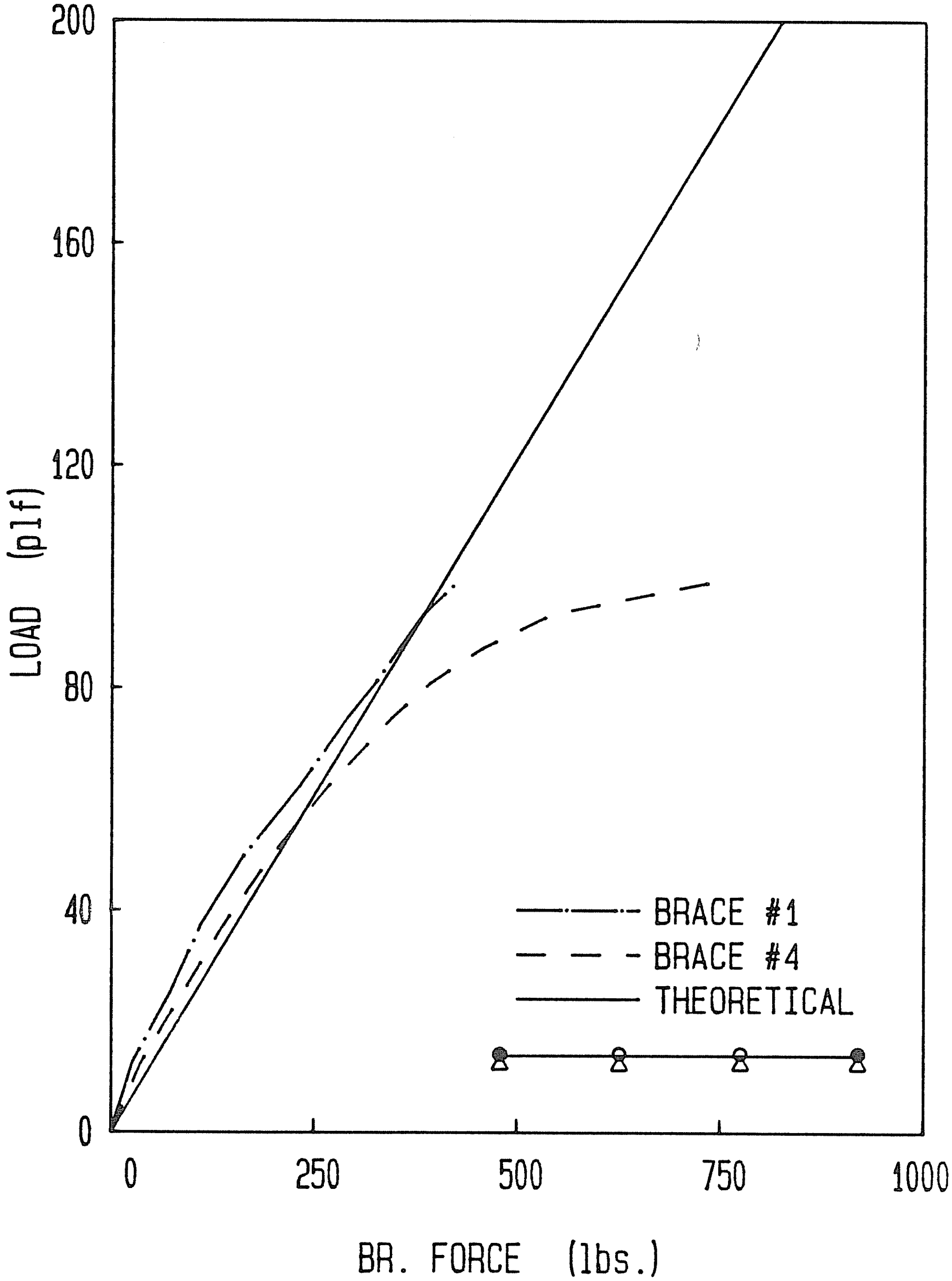
Effective flange width	: 1.7406	inches
Effective moment of inertia	: 10.13	in^4
Allowable flexural capacity	: 82.61	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

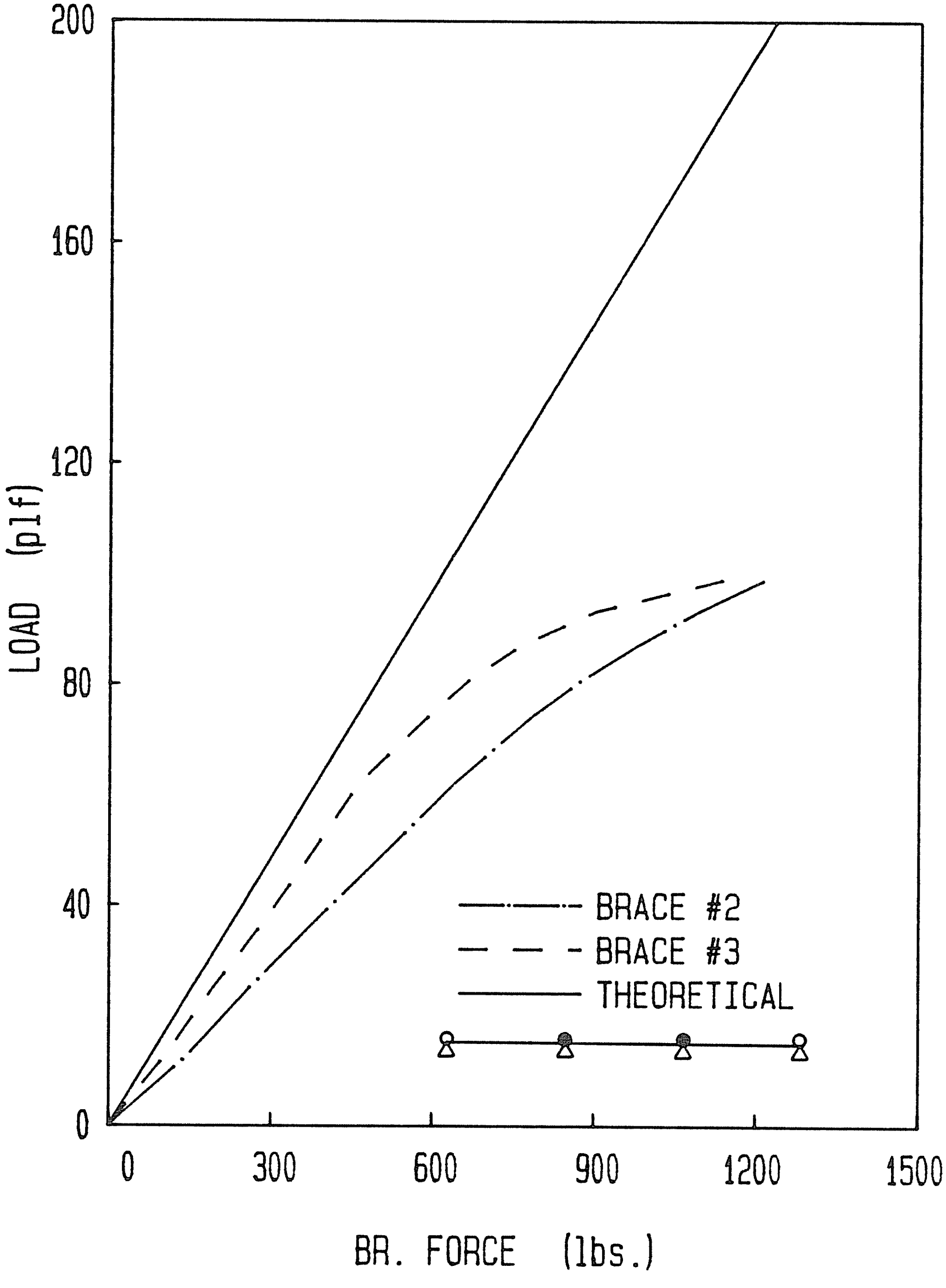
Effective flange width	: 2.2775	inches	
Effective moment of inertia	: 11.18	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.35 ksi)
Allowable flexural capacity	: 97.20	kip-in	

Figure B.6 Strength Calculations, Test P2/2-R-3



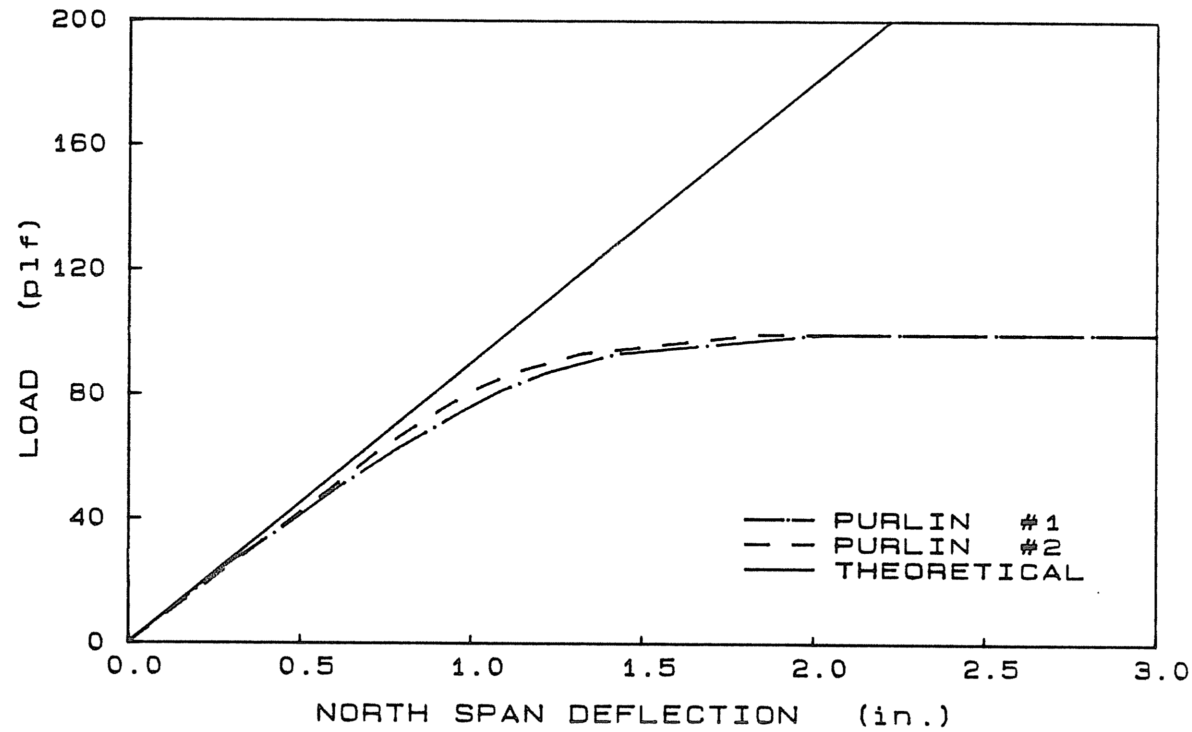
(a) Braces #1 and #4

Figure B.7 Load vs. External Brace Forces, Test P2/2-R-3, Continued

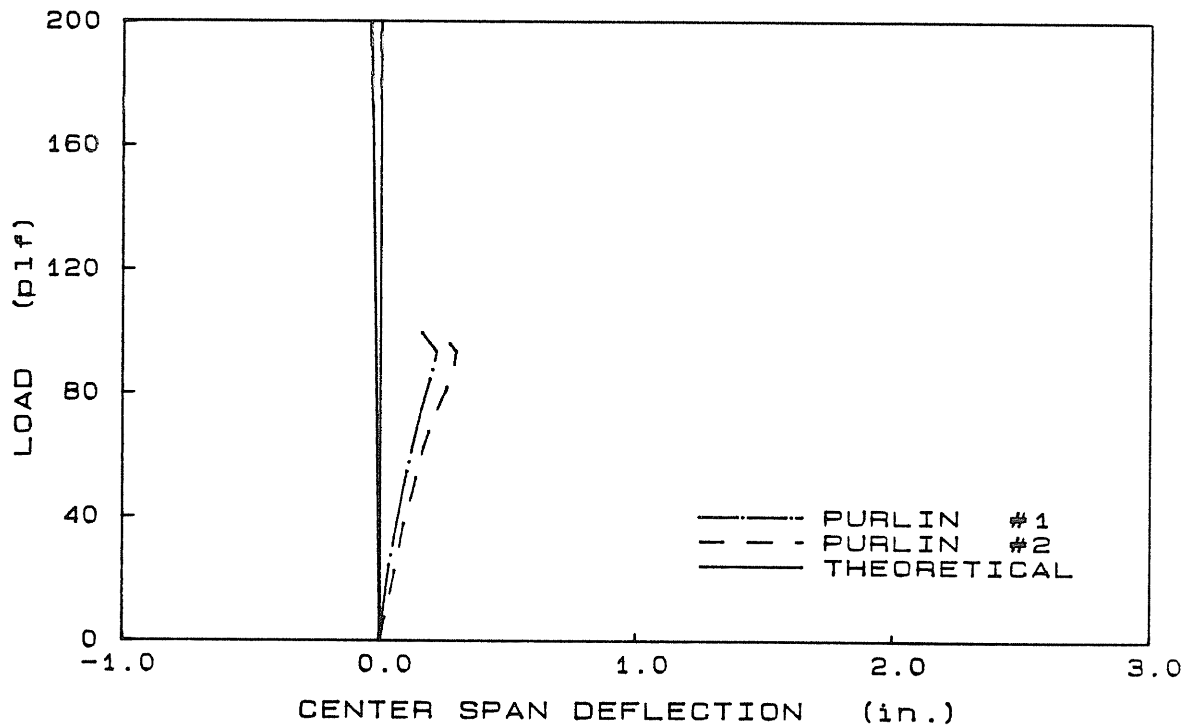


(b) Braces #2 and #3

Figure B.7 Load vs. External Brace Forces, Test P2/2-R-3

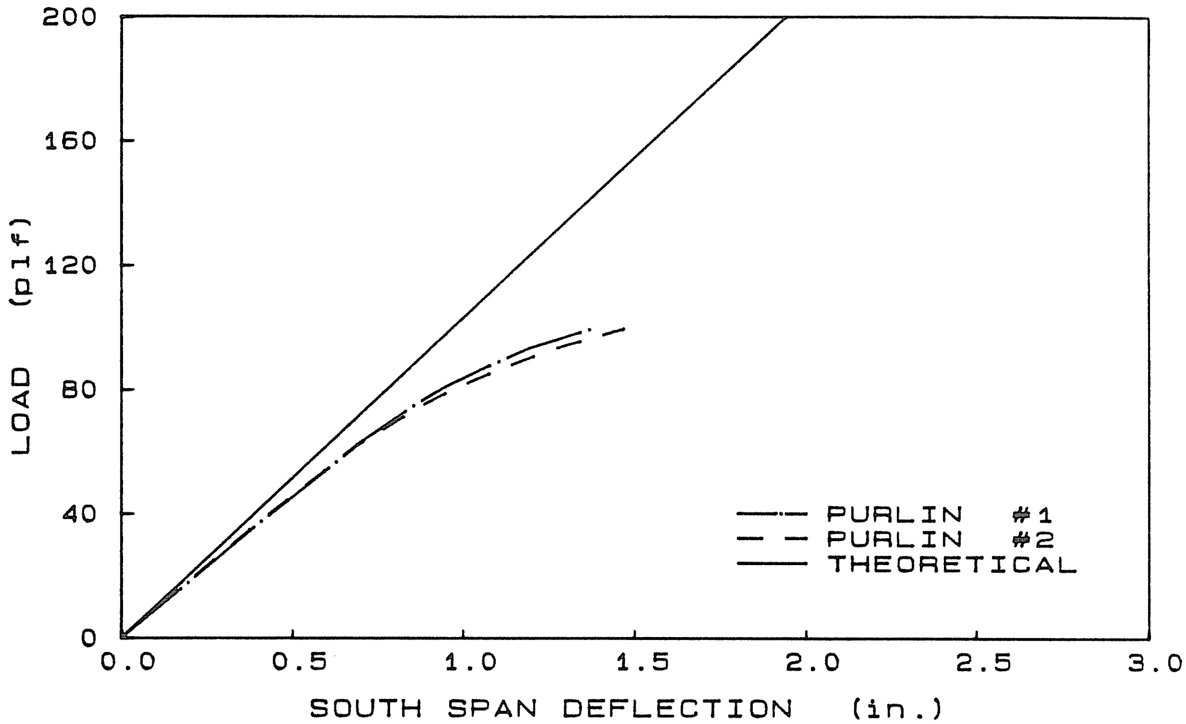


(a) Load vs. Deflection

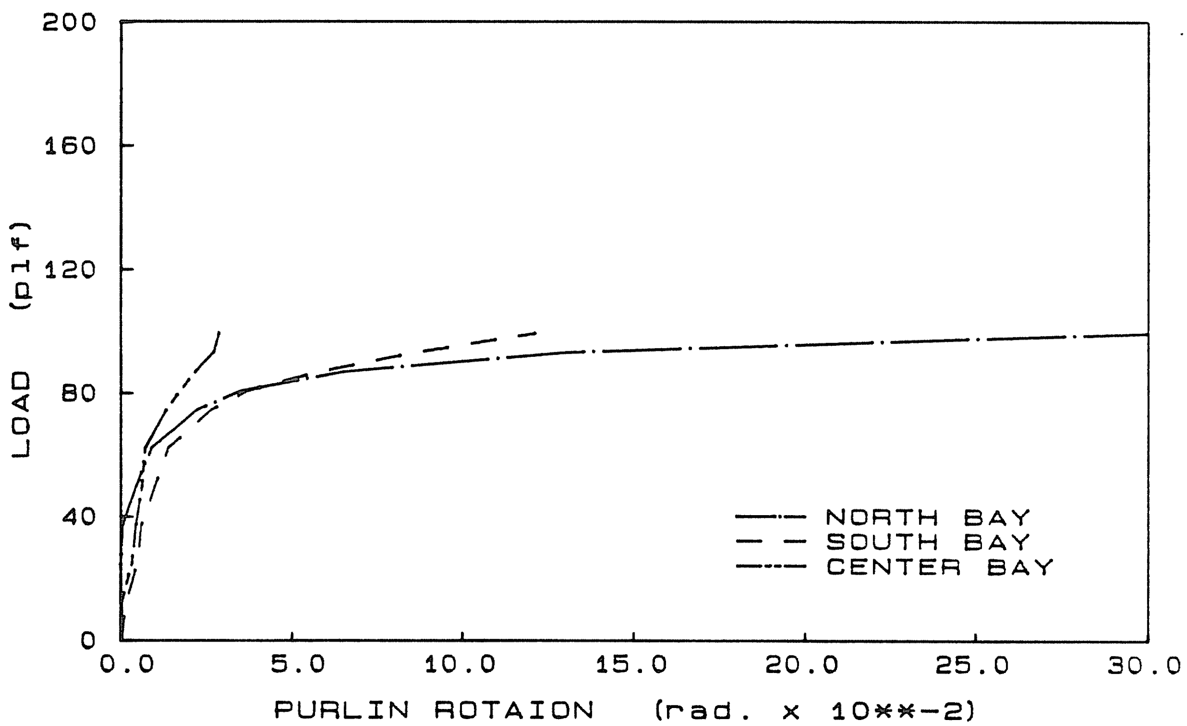


(b) Load vs. Deflection

Figure B.8 Load vs. Purlin Movement, Test P2/2-R-3, Continued



(c) Load vs. Deflection



(d) Load vs. Purlin Rotation

Figure B.8 Load vs. Purlin Movement, Test P2/2-R-3

STANDING SEAM ROOF SYSTEMS THREE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: R3/2-T-3 Test Date: 8-12-86

Three Spans @ 23.0 ft. Deck Type: Rib

Restraint Configuration: ______ Supports

______ Midspan

X Third Pts.

Purlin Data: Thickness .0725 in. Moment of Inertia 10.41 in^4

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

-0.01 in. (Center Bay)

1.04 in. (N.& S. Bays)

Failure Load 252.8 plf (1986 AISI)

294.8 plf (1980 AISI)

Brace Force @ 100 plf 476.4 lbs/brace (#1 & #6)

362.7 lbs/brace (#2 & #5)

372.6 lbs/brace (#3 & #4)

Restraint: Bracing between purlins #1 and #2 at third points.

Experimental Failure Load: 175.5 plf

Failure Mode: Local buckling of compression flange on Purlin #2 of the North bay

Discussion:

- North bay Purlin #2 rotation @ 175.5 plf = 0.136 rad.
- Horizontal deflection of the North bay Purlin #2 = 0.034 in.
- Very conservative predictions on center brace forces #2 through #5.

- Good correlation between theoretical and experimental predictions for exterior braces and end span deflections.

- Experimental failure load was 69.4% of 1986 AISI/constrained bending/full lateral restraint predictions.

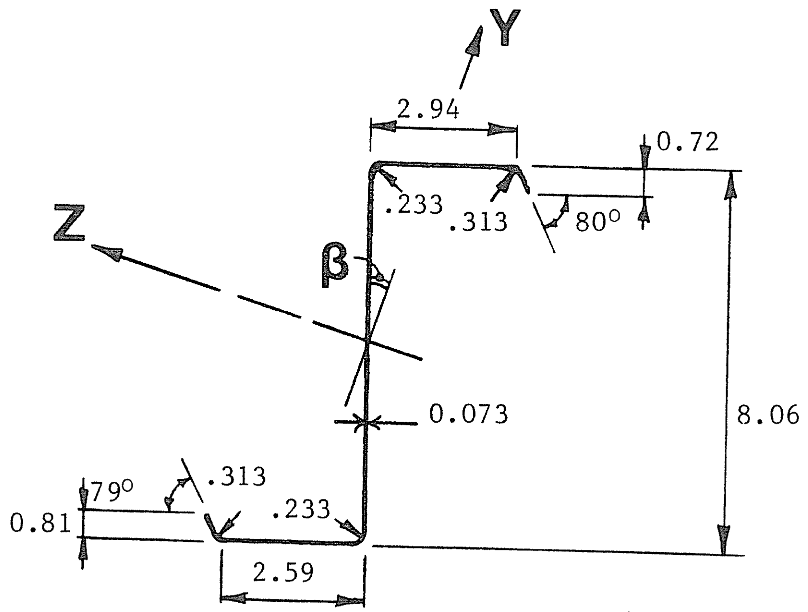
- Very little clip movement was observed.

Initial purlin readings:

	Purlin #1	Purlin #2
North span	Sweep 1/2" Camber 0.0"	1/4" 1/8"
Center span	Sweep 3/16" Camber -1/8"	0.0" -1/4" (upward)
South span	Sweep 1/4" Camber 0.0"	1/8" 0.0"

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0791

β(deg) = 18.0803

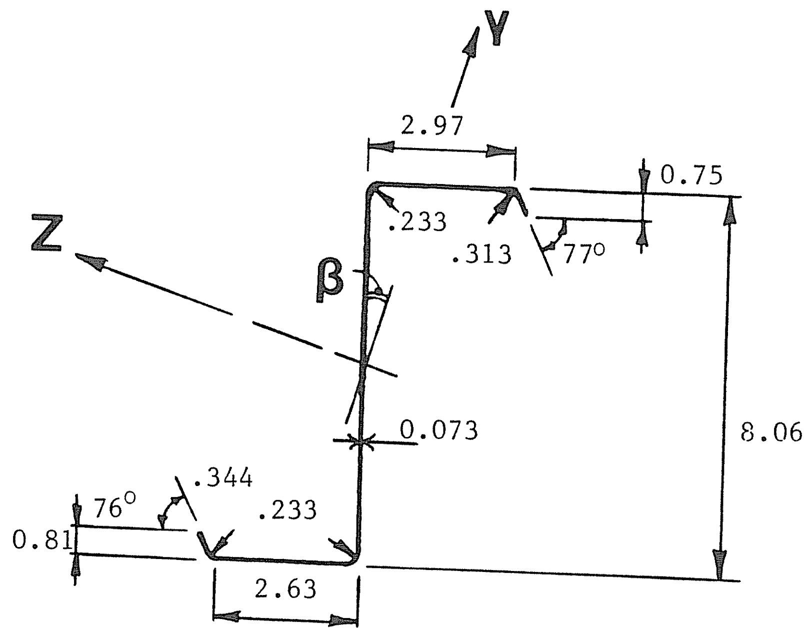
I_x (in^4) = 0.0019

I_y (in^4) = 0.7909

I_z (in^4) = 11.9140

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0888

β(deg) = 18.5602

I_x (in^4) = 0.0020

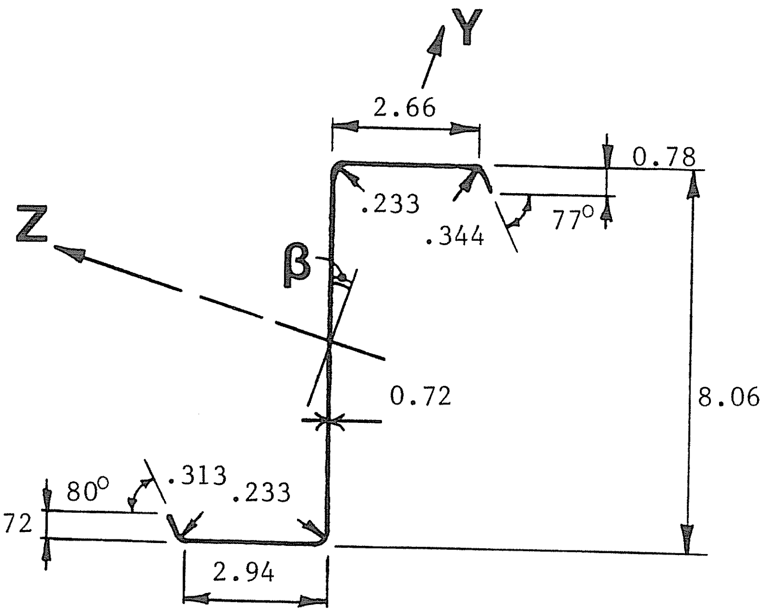
I_y (in^4) = 0.8303

I_z (in^4) = 12.1325

Figure B.9 Measured Purlin Dimensions and Calculated Properties, Test R3/2-T-3, Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0669

β(deg) = 18.2522

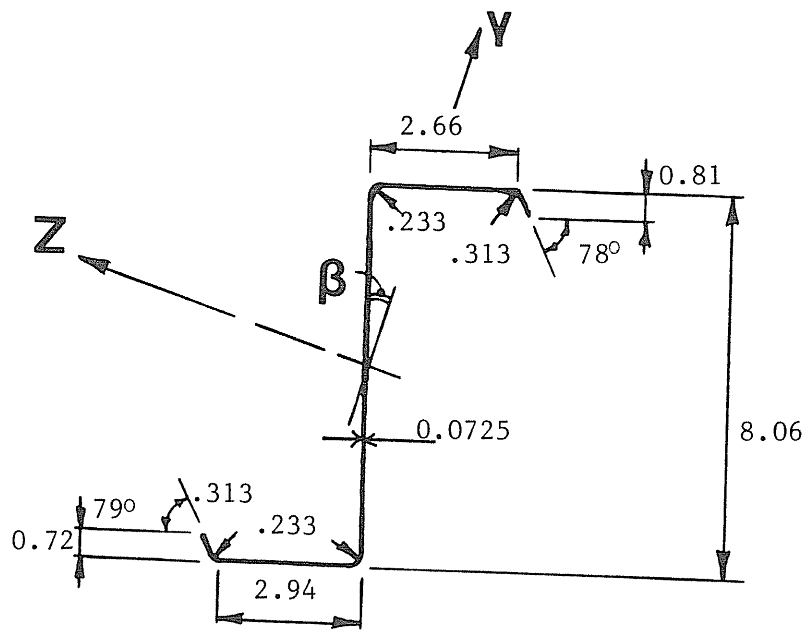
I_x (in^4) = 0.0019

I_y (in^4) = 0.7949

I_z (in^4) = 11.8297

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0772

β(deg) = 18.3530

I_x (in^4) = 0.0019

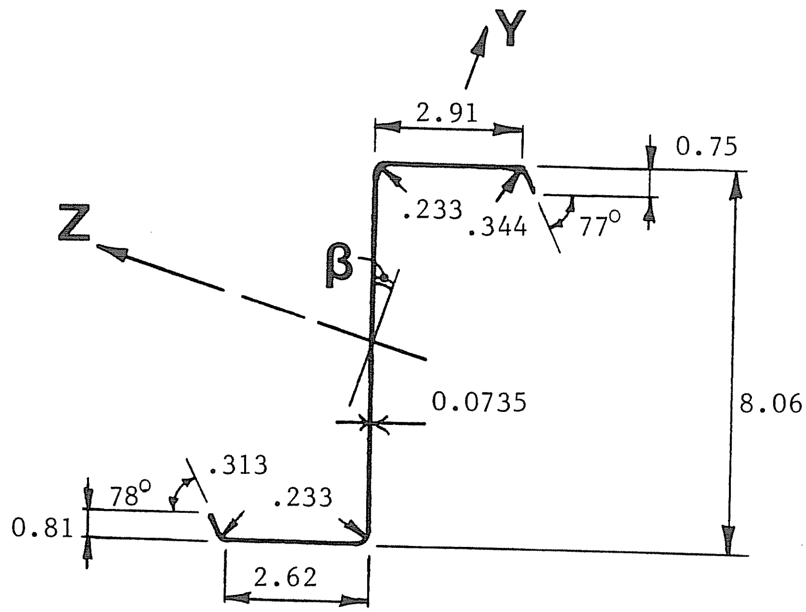
I_y (in^4) = 0.8065

I_z (in^4) = 11.9653

Figure B.9 Measured Purlin Dimensions and Calculated Properties, Test R3/2-T-3, Continued

Purlin #1

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0901

β(deg) = 18.2457

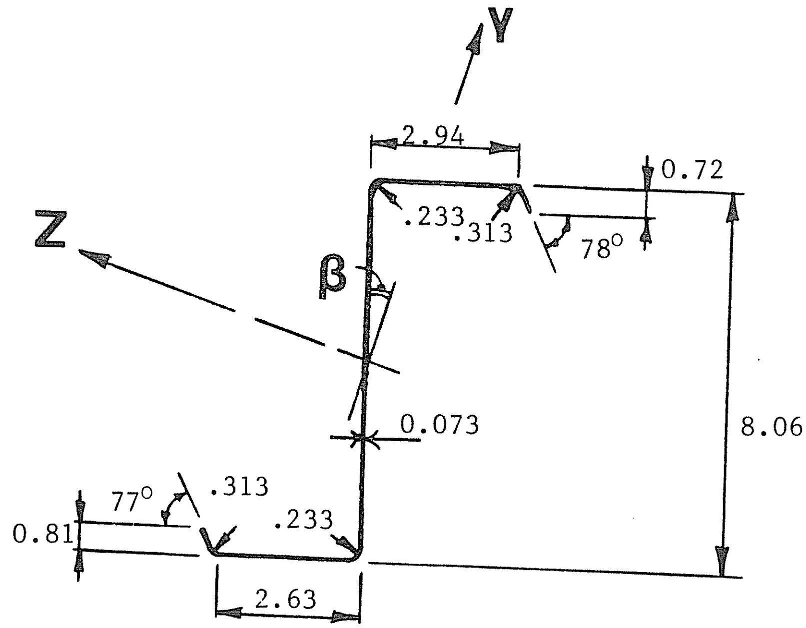
I_x (in^4) = 0.0020

I_y (in^4) = 0.8116

I_z (in^4) = 12.0673

Purlin #2

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0969

β(deg) = 18.9657

I_x (in^4) = 0.0020

I_y (in^4) = 0.8614

I_z (in^4) = 12.3503

Figure B.9 Measured Purlin Dimensions and Calculated Properties, Test R3/2-T-3

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.8125
Lip angles	(degrees) :		77.0000	78.0000
Flange widths	(inches) :		2.9063	2.6250
Radii	(inches)			
Lip to flange	:		0.3438	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0735		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2679
Gross moment of inertia	(in^4) :	10.52

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7643	inches
Effective moment of inertia	:	9.53	in^4
Allowable flexural capacity	:	76.67	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2096	inches	
Effective moment of inertia	:	10.45	in^4	
Allowable stress at flange	:	33.96	ksi	controls
Allowable stress at web	:	31.74	ksi	(at flange : 34.38 ksi)
Allowable flexural capacity	:	89.07	kip-in	

Figure B.10 Strength Calculations, Test R3/2-T-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.8125
Lip angles	(degrees) :		78.0000	77.0000
Flange widths	(inches) :		2.9375	2.8125
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3193
Gross moment of inertia	(in^4) :	10.69

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7668	inches
Effective moment of inertia	:	9.62	in^4
Allowable flexural capacity	:	76.21	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2227	inches		
Effective moment of inertia	:	10.58	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.67	ksi	(at flange : 34.26 ksi)	
Allowable flexural capacity	:	88.73	kip-in		

Figure B.10 Strength Calculations, Test R3/2-T-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7813	0.7188
Lip angles	(degrees) :		77.0000	80.0000
Flange widths	(inches) :		2.6563	2.9375
Radii	(inches)			
Lip to flange	:		0.3438	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0720		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0206
Gross moment of inertia	(in^4) :	10.32

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.5961	inches
Effective moment of inertia	: 9.41	in^4
Allowable flexural capacity	: 73.93	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0206	inches		
Effective moment of inertia	: 10.32	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.54	ksi	(at flange : 34.08 ksi)	
Allowable flexural capacity	: 85.66	kip-in		

Figure B.10 Strength Calculations, Test R3/2-T-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7188
Lip angles	(degrees) :		78.0000	79.0000
Flange widths	(inches) :		2.6563	2.9375
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0725		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0390
Gross moment of inertia	(in^4) :	10.42

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6584	inches
Effective moment of inertia	: 9.57	in^4
Allowable flexural capacity	: 75.56	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0390	inches		
Effective moment of inertia	: 10.42	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.61	ksi	(at flange : 34.16 ksi)	
Allowable flexural capacity	: 86.64	kip-in		

Figure B.10 Strength Calculations, Test R3/2-R-3, Continued

(e) Purlin #1, South Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7188	0.8125
Lip angles	(degrees) :	80.0000	79.0000
Flange widths	(inches) :	2.9375	2.5938
Radii	(inches)		
Lip to flange	:	0.3125	0.3125
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0730

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3080
Gross moment of inertia	(in^4) :	10.40

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7483	inches
Effective moment of inertia	: 9.36	in^4
Allowable flexural capacity	: 75.21	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2180	inches		
Effective moment of inertia	: 10.29	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.31 ksi)	
Allowable flexural capacity	: 87.71	kip-in		

Figure B.10 Strength Calculations, Test R3/2-T-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7500	0.8125
Lip angles	(degrees) :		77.0000	76.0000
Flange widths	(inches) :		2.9688	2.6250
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3562
Gross moment of inertia	(in^4) :	10.54

1986 AISI PROCEDURE

Flange is not fully effective

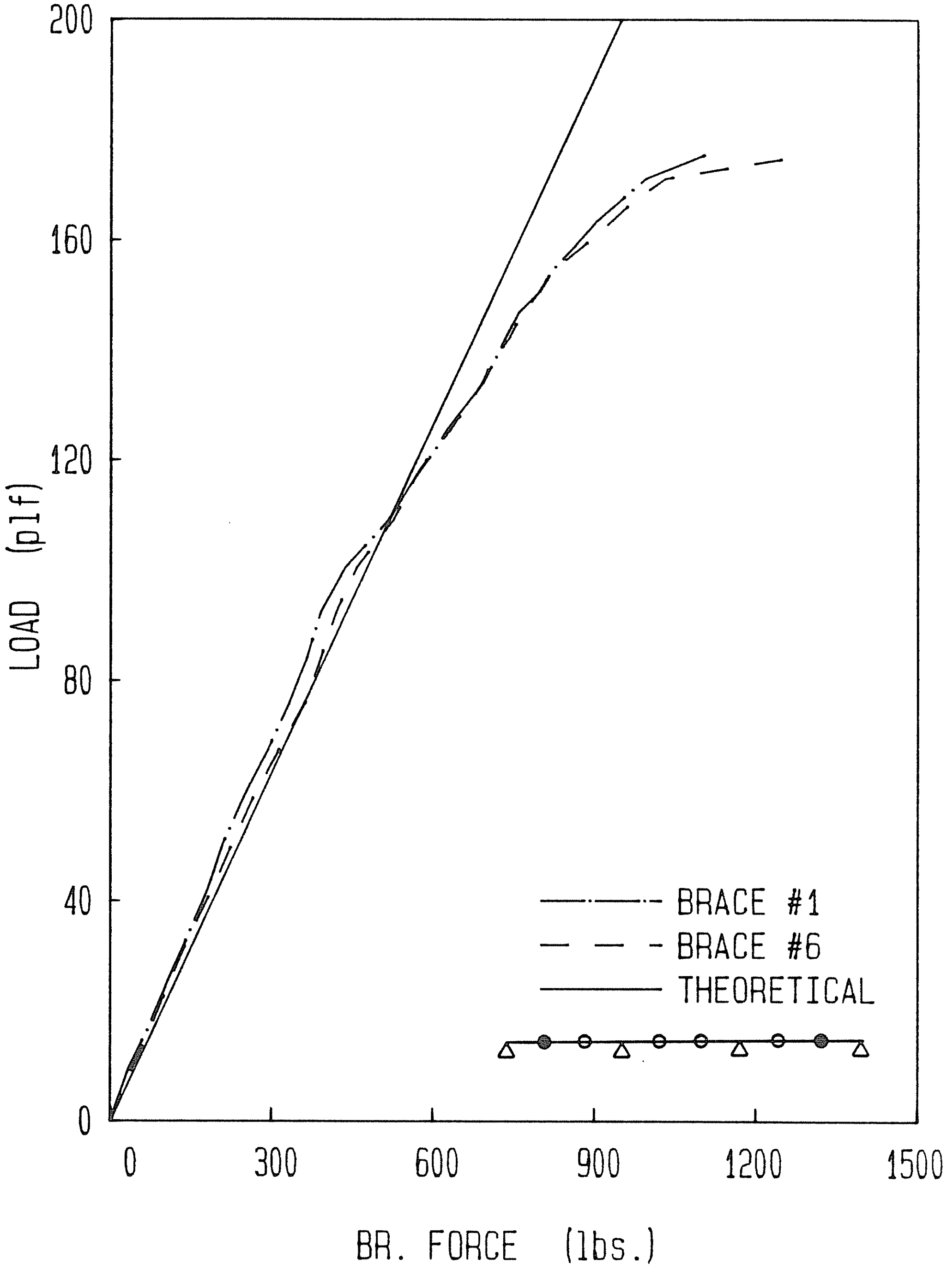
Effective flange width	: 1.8096	inches
Effective moment of inertia	: 9.50	in^4
Allowable flexural capacity	: 76.47	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

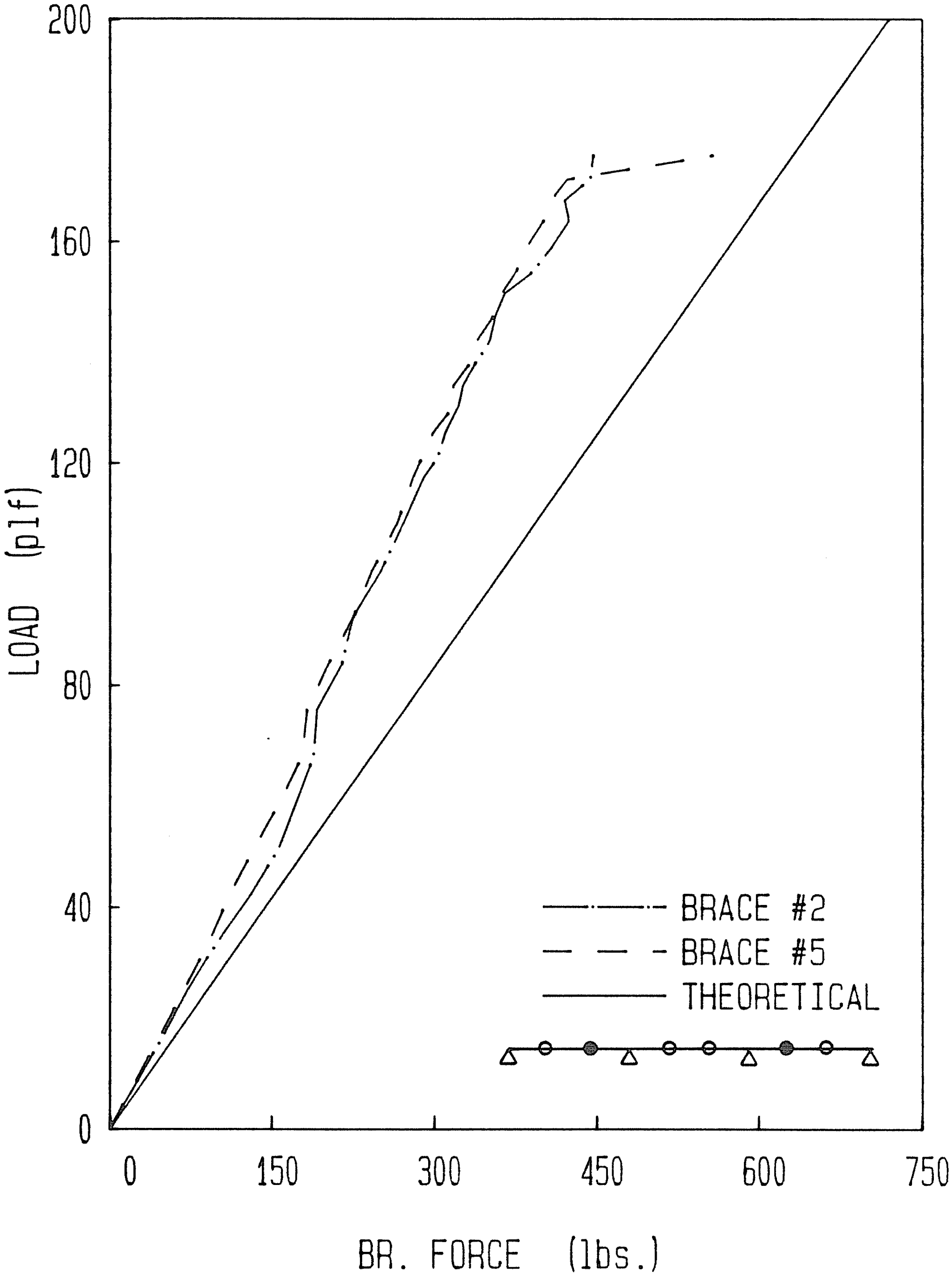
Effective flange width	: 2.2375	inches	
Effective moment of inertia	: 10.40	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.31 ksi)
Allowable flexural capacity	: 88.68	kip-in	

Figure B.10 Strength Calculations, Test R3/2-T-3



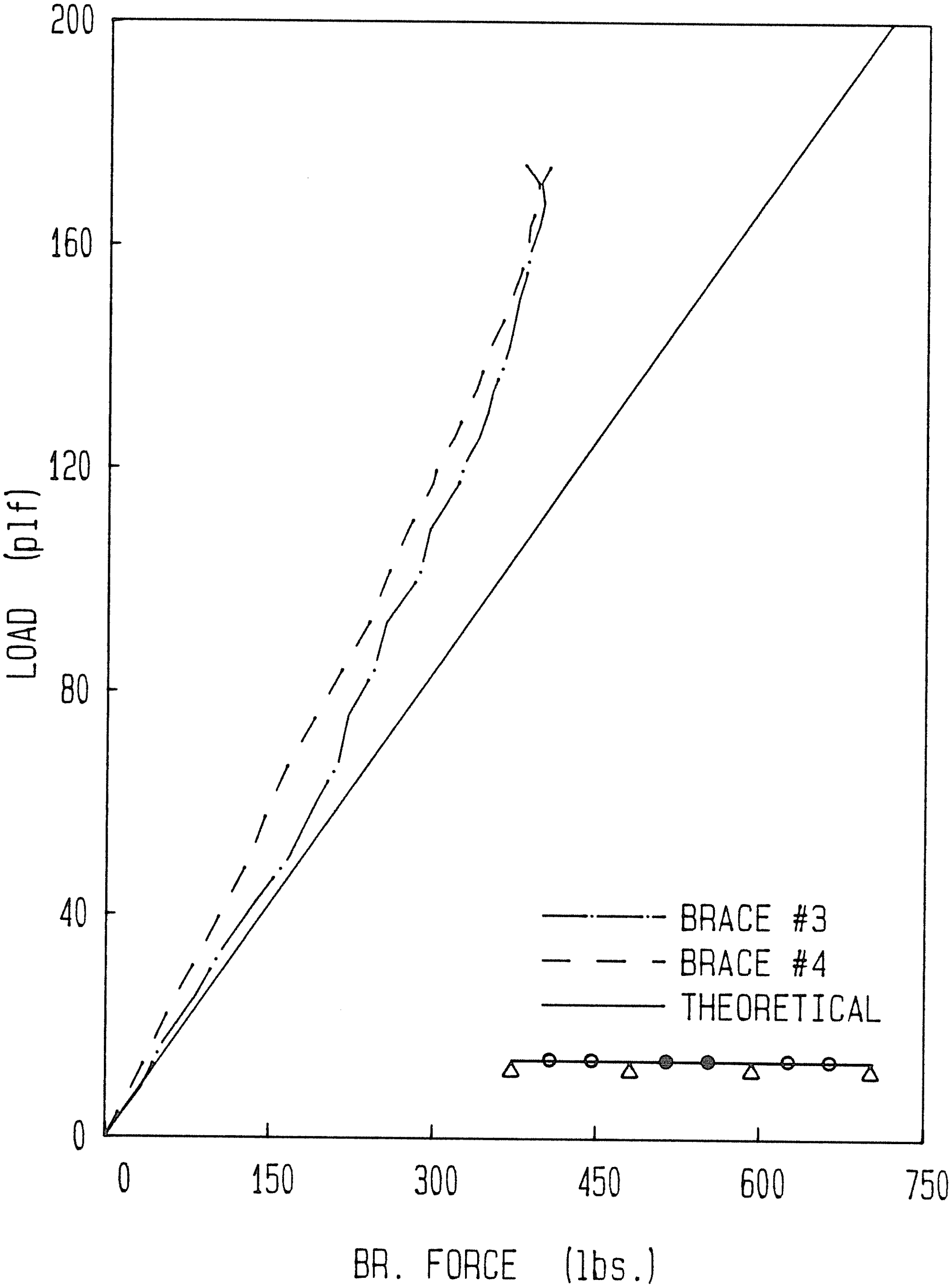
(a) Braces #1 and #6

Figure B.11 Load vs. External Brace Forces, Test R3/2-T-3, Continued



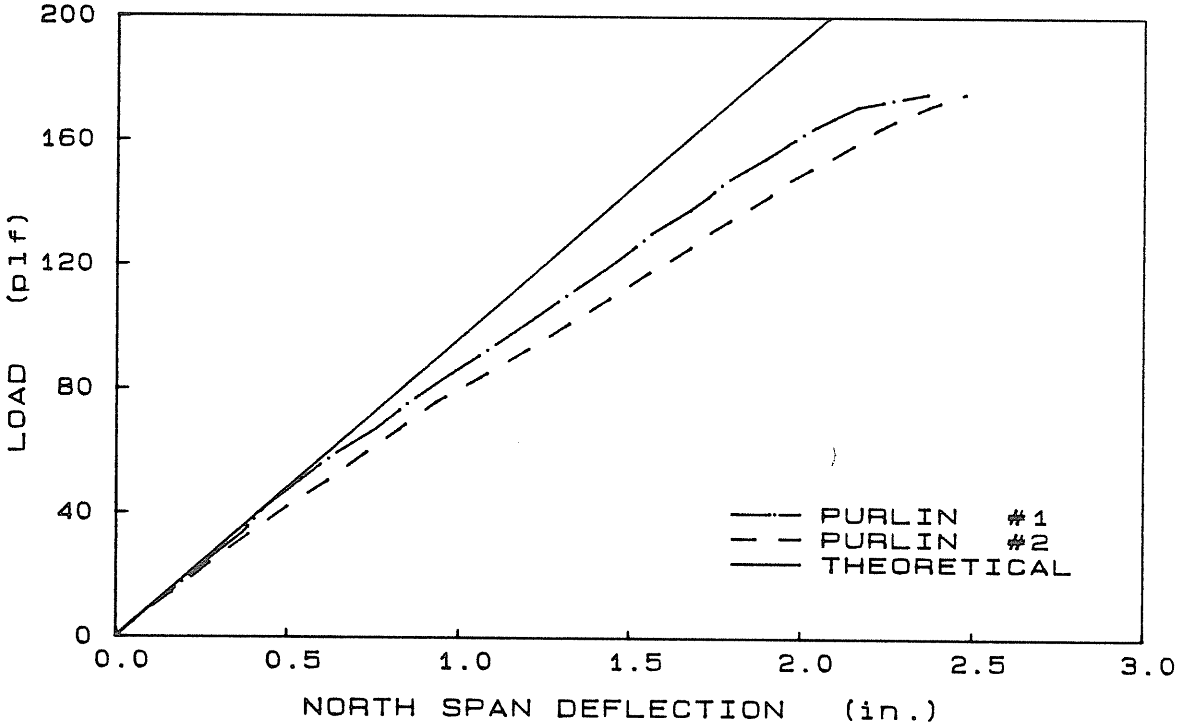
(b) Braces #2 and #5

Figure B.11 Load vs. External Brace Forces, Test R3/2-T-3, Continued

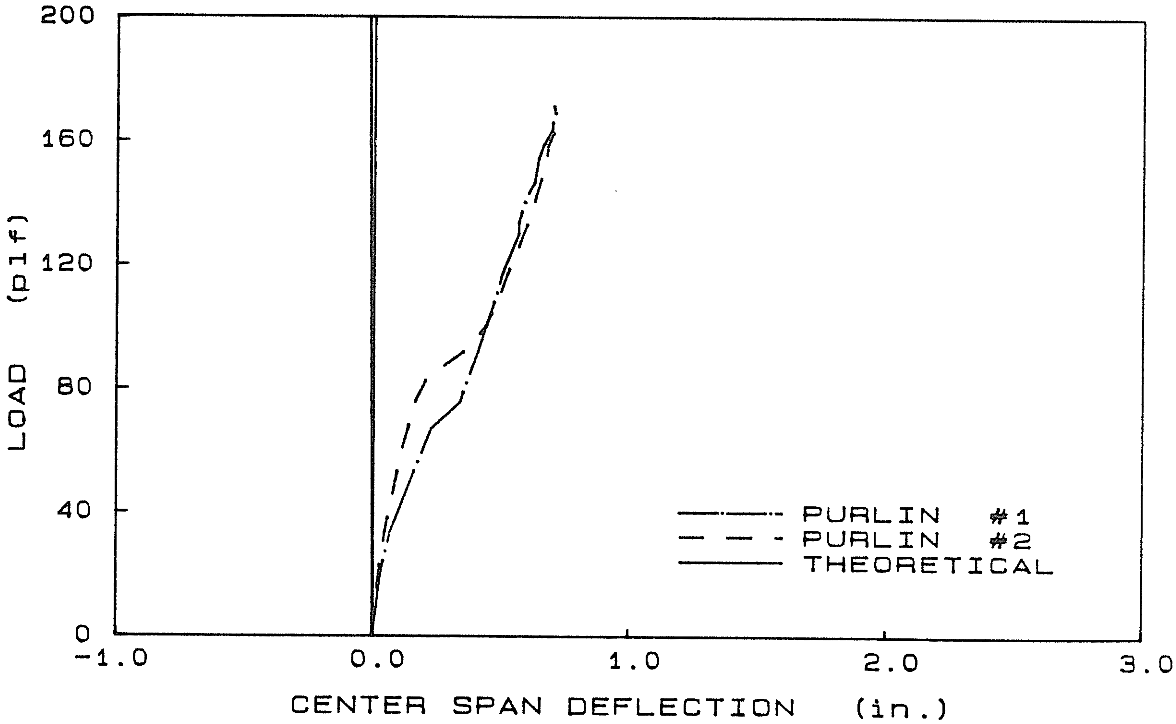


(c) Braces #3 and #4

Figure B.11 Load vs. External Brace Forces, Test R3/2-T-3

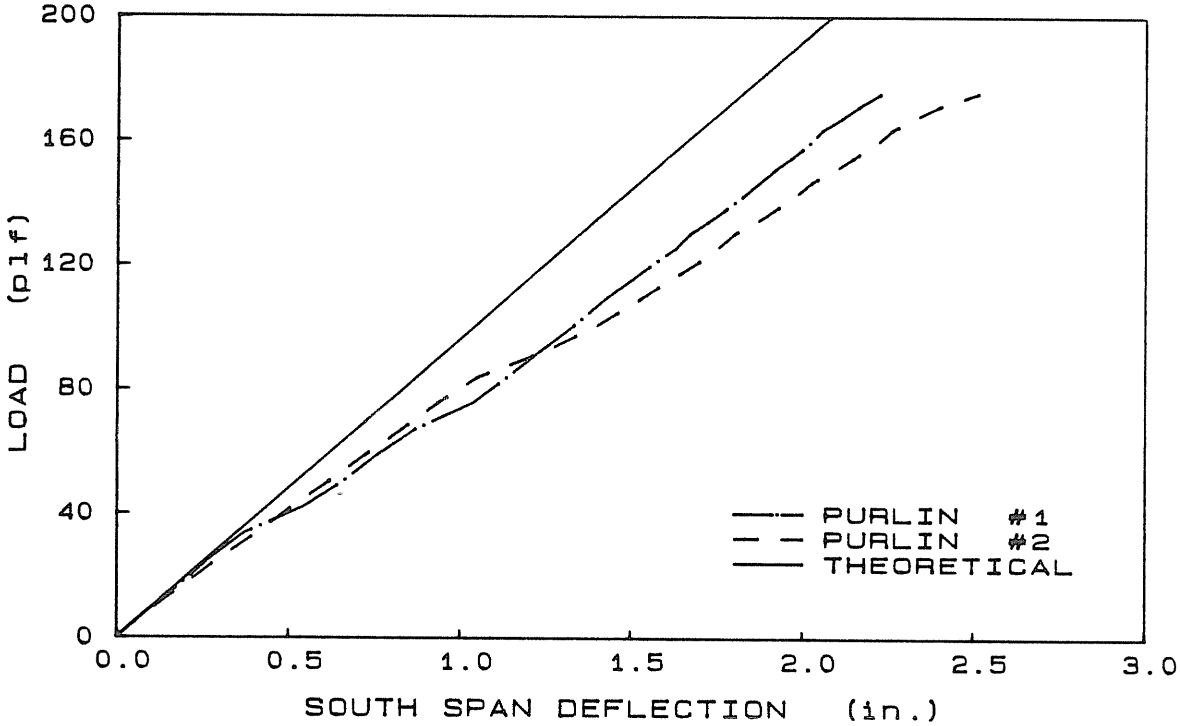


(a) Load vs. Deflection

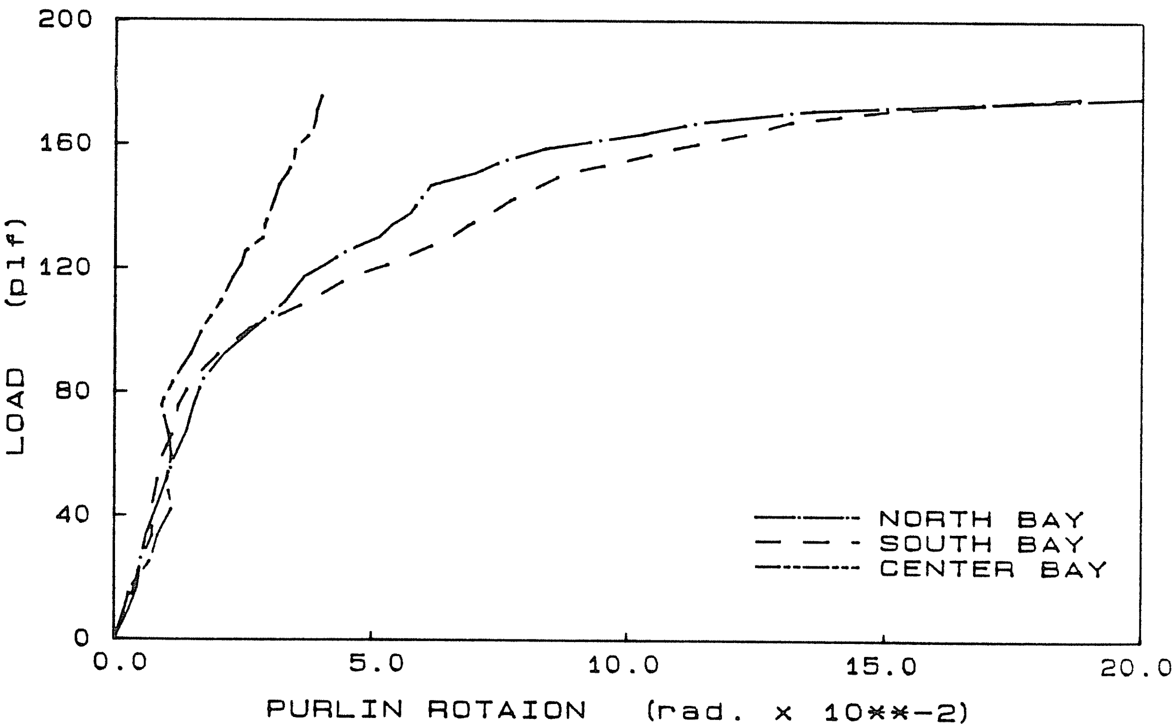


(b) Load vs. Deflection

Figure B.12 Load vs. Purlin Movement, Test R3/2-T-3, Continued



(c) Load vs. Deflection



(d) Load vs. Purlin Rotation

Figure B.12 Load vs. Purlin Movement, Test R3/2-T-3

STANDING SEAM ROOF SYSTEMS
THREE SPAN RESTRAINT
FORCE TESTS

TEST SUMMARY

Test No: P2/2-T-3 Test Date: 9/8/86

Three Spans @: 23.0 ft. Deck Type: Pan

Restraint Configuration: ______ Supports

______ Midspan

X Third Pts.

Purlin Data: Thickness 0.079 in.

Moment of Inertia 11.23 in^4 (N.& S. bays)

Thickness 0.073 in.

Moment of Inertia 10.50 in^4 (Center Bay)

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

0.01 in. (Center Bay)

0.98 in. (N.& S. Bays)

Brace Force @ 100 plf 473.0 lbs/brace

364.1 lbs/brace

374.0 lbs/brace

Failure Load 281.2 plf (1986 AISI)

325.6 plf (1980 AISI)

Restraint: Bracing between purlin #1 and #2 at third points.

Experimental Failure Load: 207.1 plf

Failure Mode: Local buckling of compression flange on north span, purlin #2 at midspan.

Discussion:

- North bay purlin #2 rotation @ 190.8 plf = 0.163 rad.

- Horizontal deflection of north bay purlin #2 = 0.07 in. @ 190.8 plf.

- Good correlation between theoretical and experimental predictions for brace forces and end span deflections.

- Very little clip movement was observed.

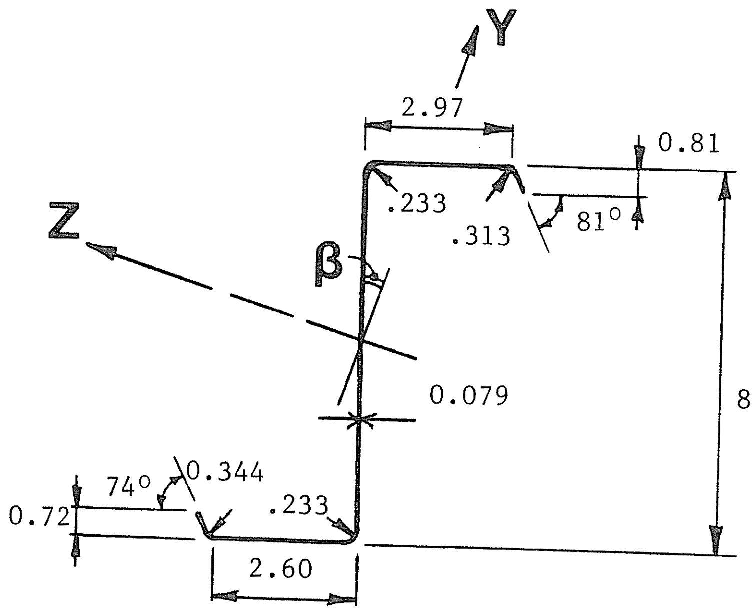
- Experimental failure load was 73.7% of 1986 AISI/constrained bending/full lateral restraint predictions.

Initial purlin readings:

	Purlin #1	Purlin #2
North Span	Sweep 1/8"	1/4"
	Camber 0.0"	1/8"
Center span	Sweep 1/4"	0.0"
	Camber 0.0"	1/4"
South span	Sweep 1/4"	0.0"
	Camber 1/4"	3/8"

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1719

β(deg) = 18.3078

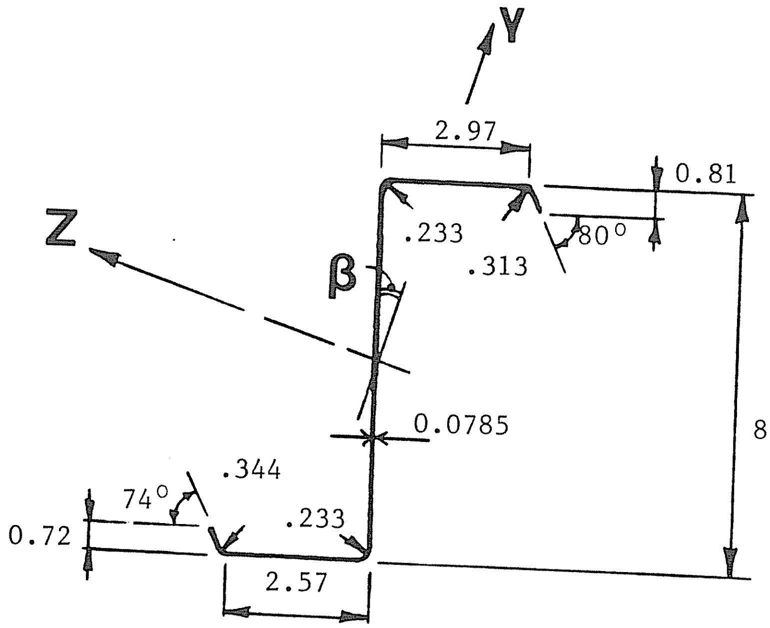
I_x (in^4) = 0.0025

I_y (in^4) = 0.8795

I_z (in^4) = 12.9806

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1626

β(deg) = 18.2302

I_x (in^4) = 0.0024

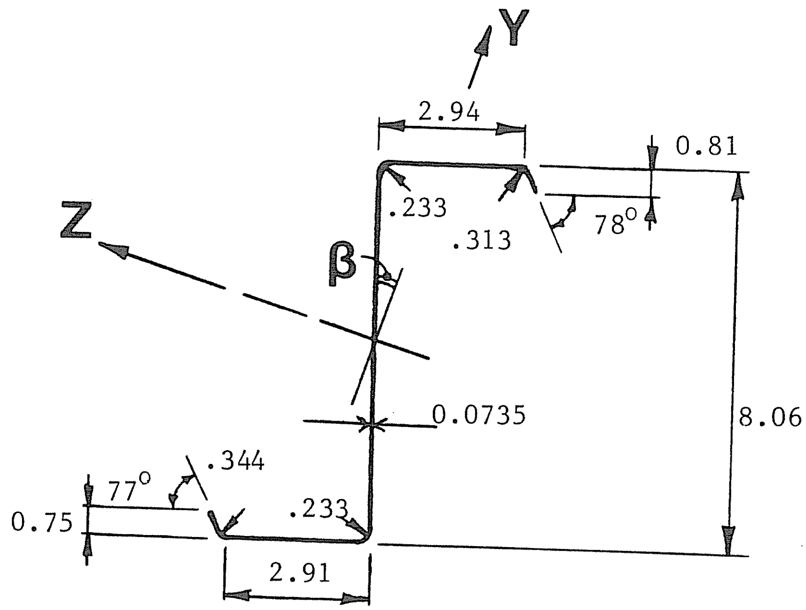
I_y (in^4) = 0.8683

I_z (in^4) = 12.8503

Figure B.13 Measured Purlin Dimensions and Calculated Properties, Test P2/2-T-3, Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0901

β(deg) = 18.2603

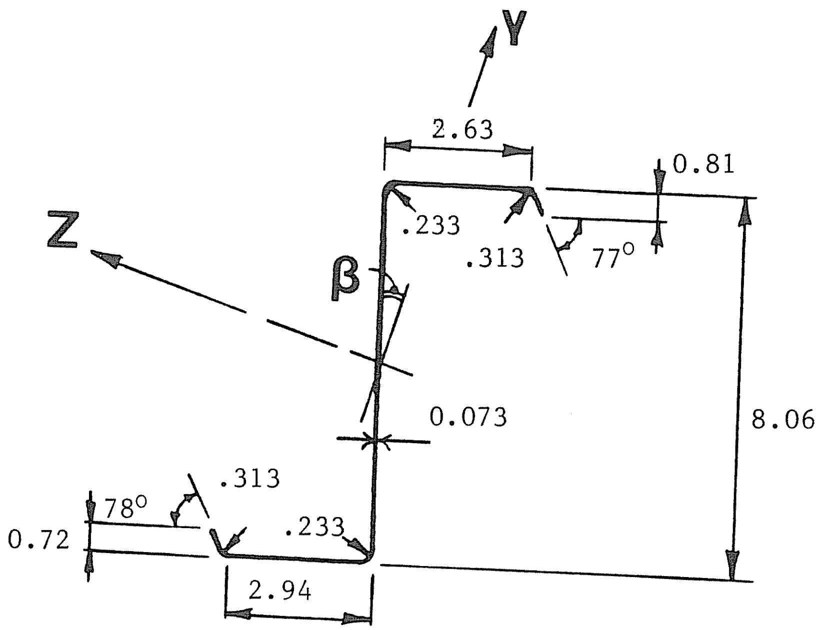
I_x (in^4) = 0.0020

I_y (in^4) = 0.8146

I_z (in^4) = 12.0635

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0833

β(deg) = 18.2974

I_x (in^4) = 0.0020

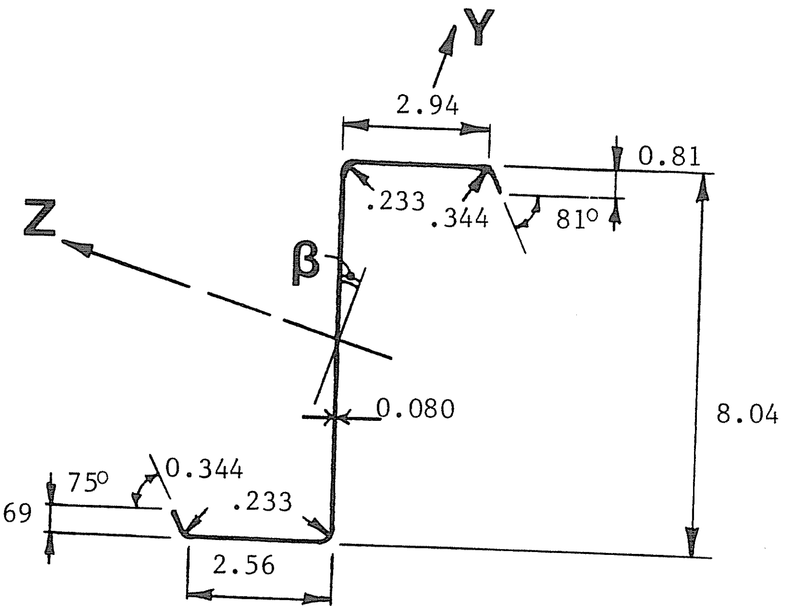
I_y (in^4) = 0.8076

I_z (in^4) = 12.0150

Figure B.13 Measured Purlin Dimensions and Calculated Properties, Test P2/2-T-3, Continued

Purlin #1

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1762

β(deg) = 17.9974

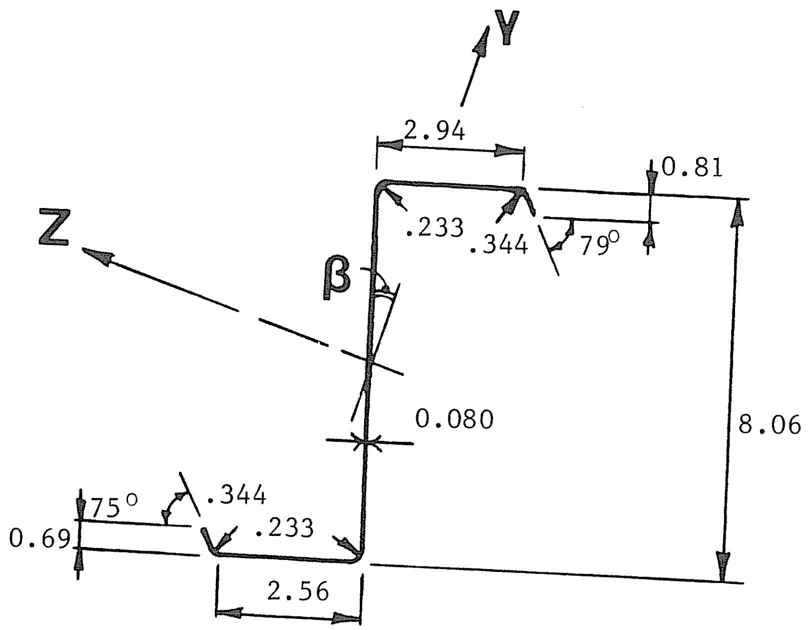
I_x (in^4) = 0.0025

I_y (in^4) = 0.8597

I_z (in^4) = 12.8797

Purlin #2

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1788

β(deg) = 18.0006

I_x (in^4) = 0.0026

I_y (in^4) = 0.8662

I_z (in^4) = 12.9683

Figure B.13 Measured Purlin Dimensions and Calculated Properties, Test P2/2-T-3

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.8130	0.7190
Lip angles	(degrees) :	81.0000	74.0000
Flange widths	(inches) :	2.9690	2.5940
Radii	(inches)		
Lip to flange	:	0.3125	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0630
Purlin thickness	(inches) :	0.0790

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3226
Gross moment of inertia	(in^4) :	11.27

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.8897	inches
Effective moment of inertia	: 10.31	in^4
Allowable flexural capacity	: 84.26	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.3227	inches		
Effective moment of inertia	: 11.27	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.40	ksi	(at flange : 35.20 ksi)	
Allowable flexural capacity	: 97.67	kip-in		

Figure B.14 Strength Calculations, Test P2/2-T-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8130	0.7190
Lip angles	(degrees) :		80.0000	74.0000
Flange widths	(inches) :		2.9690	2.5630
Radii	(inches)			
Lip to flange	:		0.3125	0.3440
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0630		
Purlin thickness	(inches) :	0.0785		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3294
Gross moment of inertia	(in^4) :	11.17

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.8930	inches
Effective moment of inertia	: 10.21	in^4
Allowable flexural capacity	: 83.67	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.3182	inches		
Effective moment of inertia	: 11.16	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.34	ksi	(at flange : 35.14 ksi)	
Allowable flexural capacity	: 96.88	kip-in		

Figure B.14 Strength Calculations, Test P2/2-T-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7500
Lip angles	(degrees) :		78.0000	77.0000
Flange widths	(inches) :		2.6250	2.9063
Radii	(inches)			
Lip to flange	:		0.3125	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0735		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0059
Gross moment of inertia	(in^4) :	10.52

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6806	inches
Effective moment of inertia	: 9.75	in^4
Allowable flexural capacity	: 77.12	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0059	inches		
Effective moment of inertia	: 10.52	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.74	ksi	(at flange : 34.31 ksi)	
Allowable flexural capacity	: 87.25	kip-in		

Figure B.14 Strength Calculations, Test P2/2-T-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7188
Lip angles	(degrees) :		77.0000	78.0000
Flange widths	(inches) :		2.6250	2.9375
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0124
Gross moment of inertia	(in^4) :	10.47

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6785	inches
Effective moment of inertia	: 9.69	in^4
Allowable flexural capacity	: 76.61	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0124	inches		
Effective moment of inertia	: 10.47	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.23 ksi)	
Allowable flexural capacity	: 86.86	kip-in		

Figure B.14 Strength Calculations, Test P2/2-T-3, Continued

(e) Purlin #1 South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.6875
Lip angles	(degrees) :		81.0000	75.0000
Flange widths	(inches) :		2.9375	2.5625
Radii	(inches)			
Lip to flange	:		0.3438	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0435		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2625
Gross moment of inertia	(in^4) :	11.21

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7129	inches
Effective moment of inertia	: 10.10	in^4
Allowable flexural capacity	: 82.29	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.2625	inches	
Effective moment of inertia	: 11.21	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 32.53	ksi	(at flange : 35.37 ksi)
Allowable flexural capacity	: 97.55	kip-in	

Figure B.14 Strength Calculations, Test P2/2-T-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.6875
Lip angles	(degrees) :		79.0000	75.0000
Flange widths	(inches) :		2.9375	2.5625
Radii	(inches)			
Lip to flange	:		0.3438	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2751
Gross moment of inertia	(in^4) :	11.29

1986 AISI PROCEDURE

Flange is not fully effective

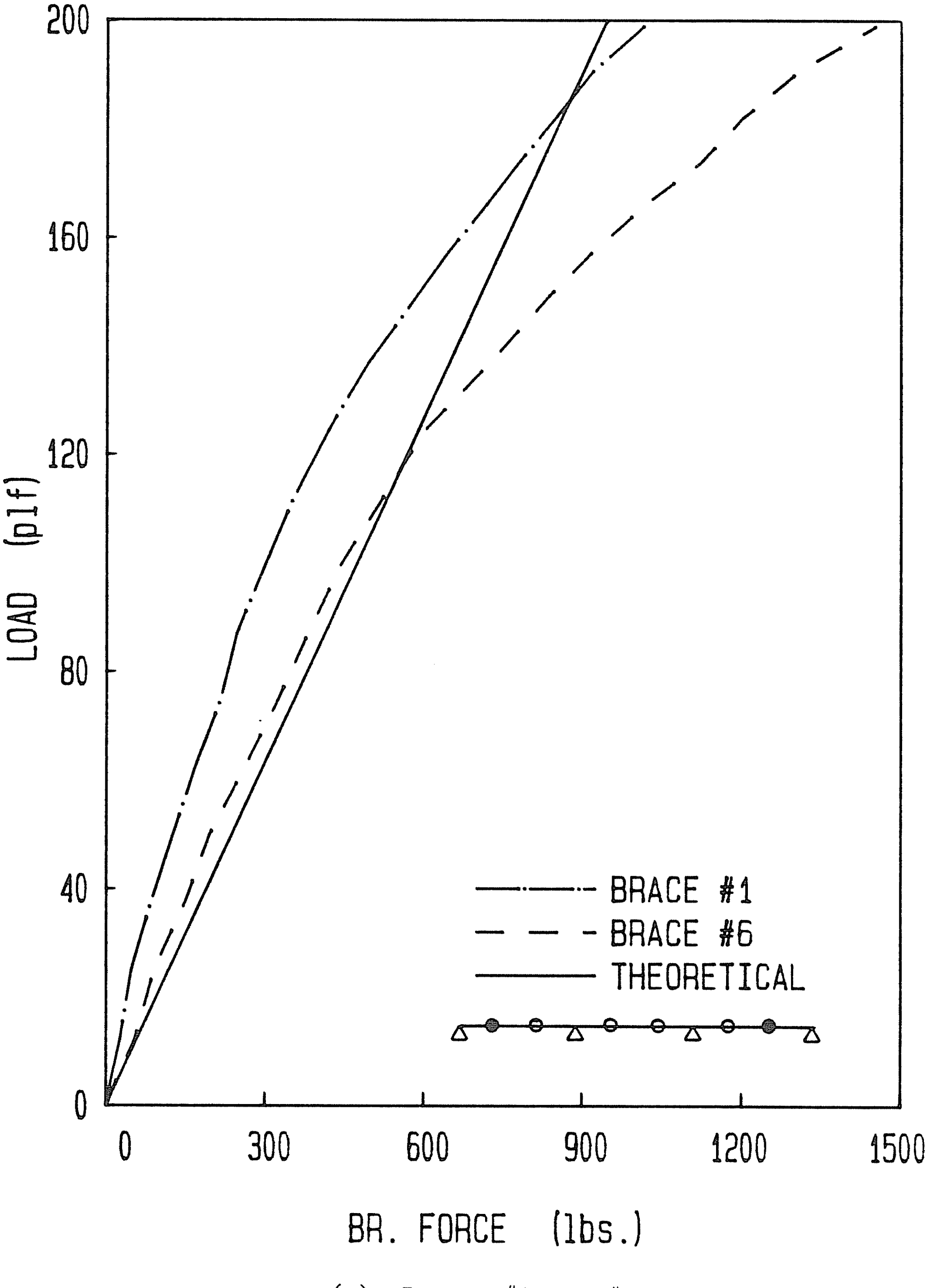
Effective flange width	: 1.7327	inches
Effective moment of inertia	: 10.18	in^4
Allowable flexural capacity	: 82.82	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

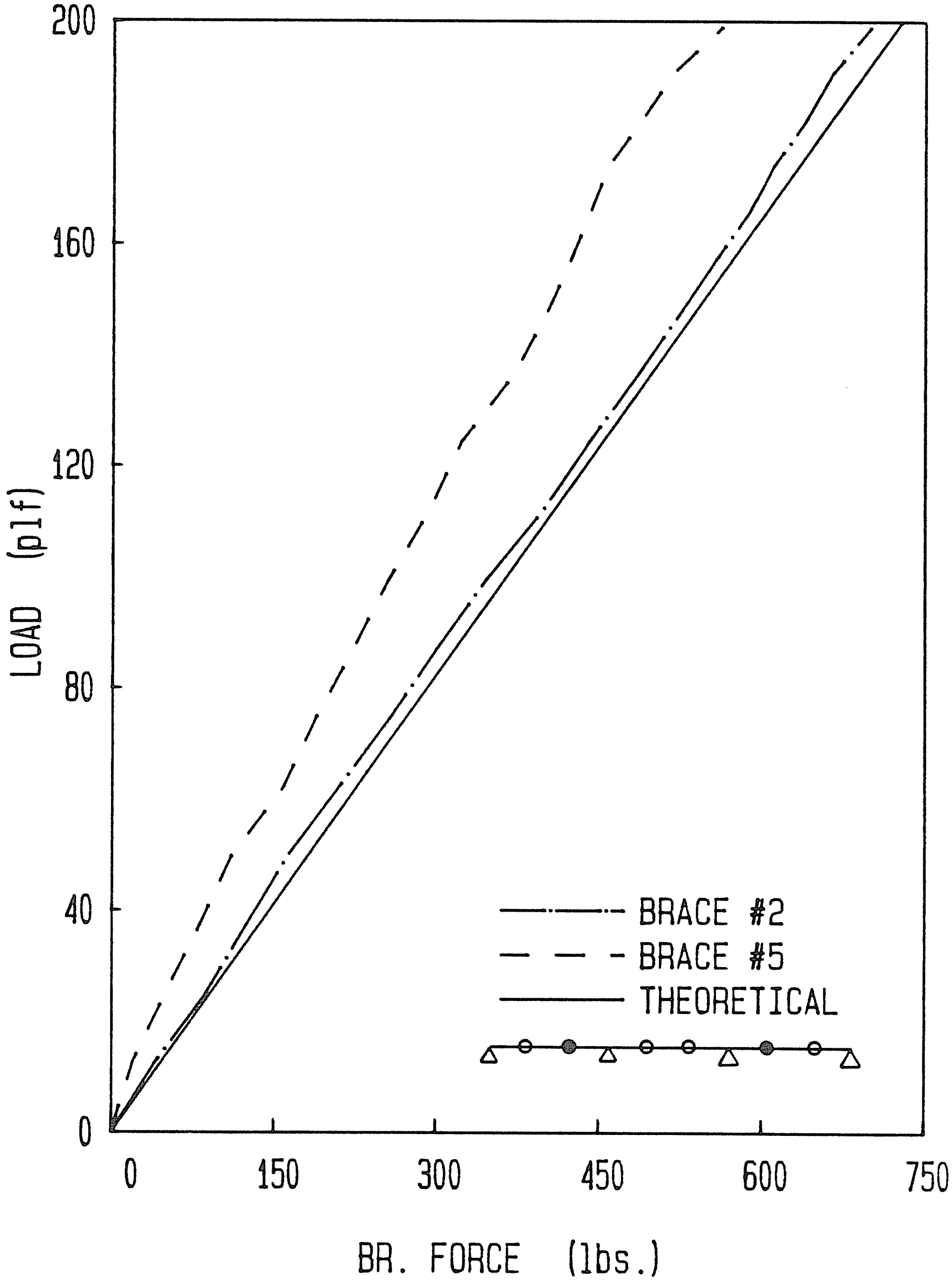
Effective flange width	: 2.2751	inches		
Effective moment of inertia	: 11.29	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.34 ksi)	
Allowable flexural capacity	: 98.14	kip-in		

Figure B.14 Strength Calculations, Test P2/2-T-3



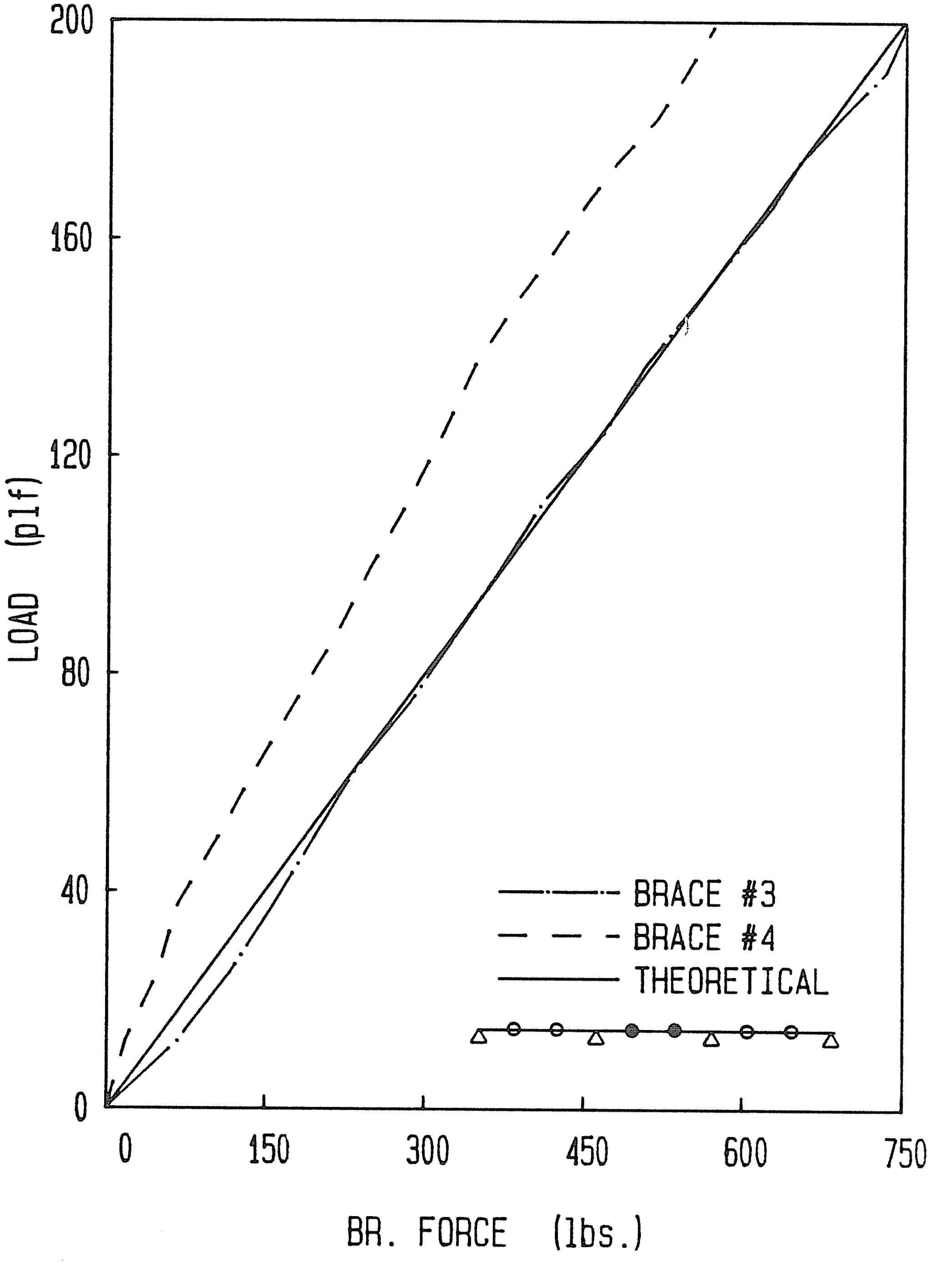
(a) Braces #1 and #6

Figure B.15 Load vs. External Brace Forces, Test P2/2-T-3, Continued



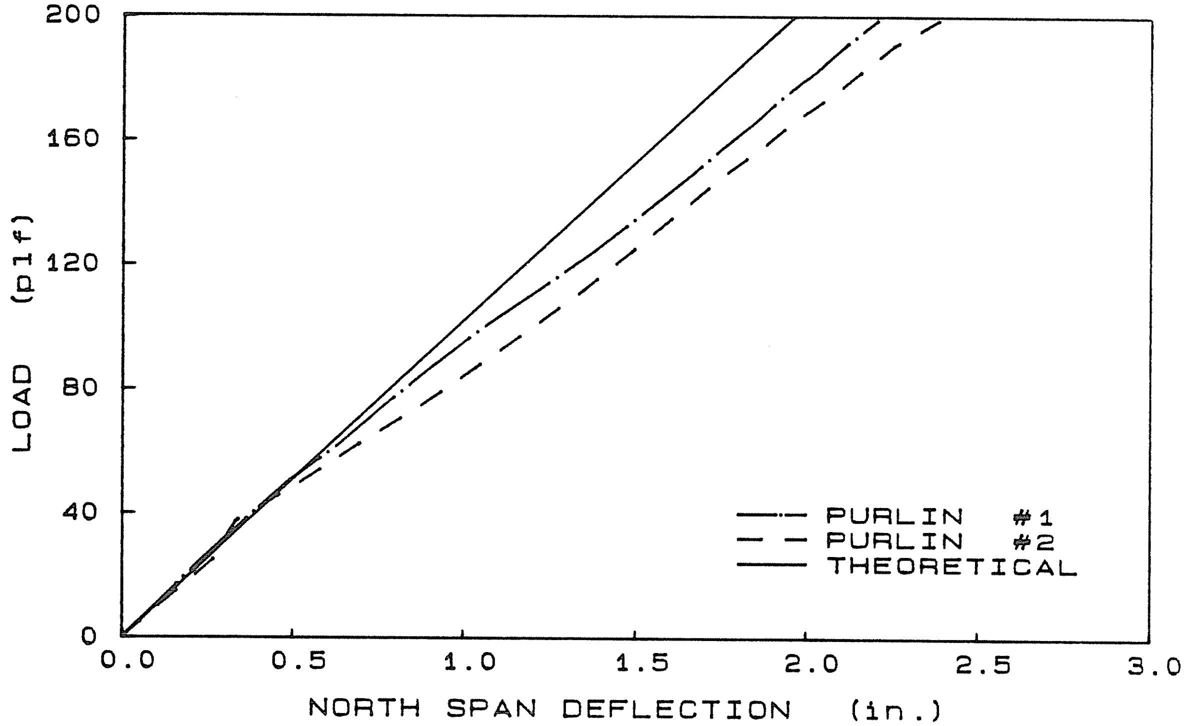
(b) Braces #2 and #5

Figure B.15 Load vs. External Brace Forces, Test P2/2-T-3, Continued

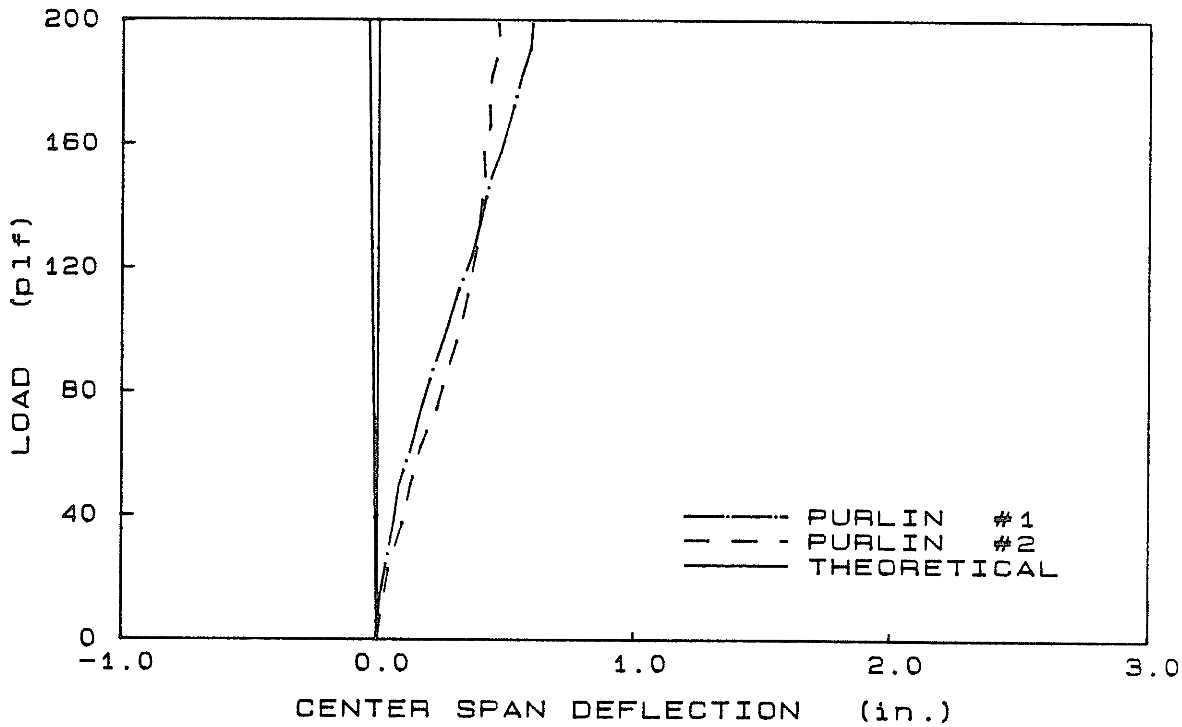


(c) Braces #3 and #4

Figure B.15 Load vs. External Brace Forces, Test P2/2-T-3

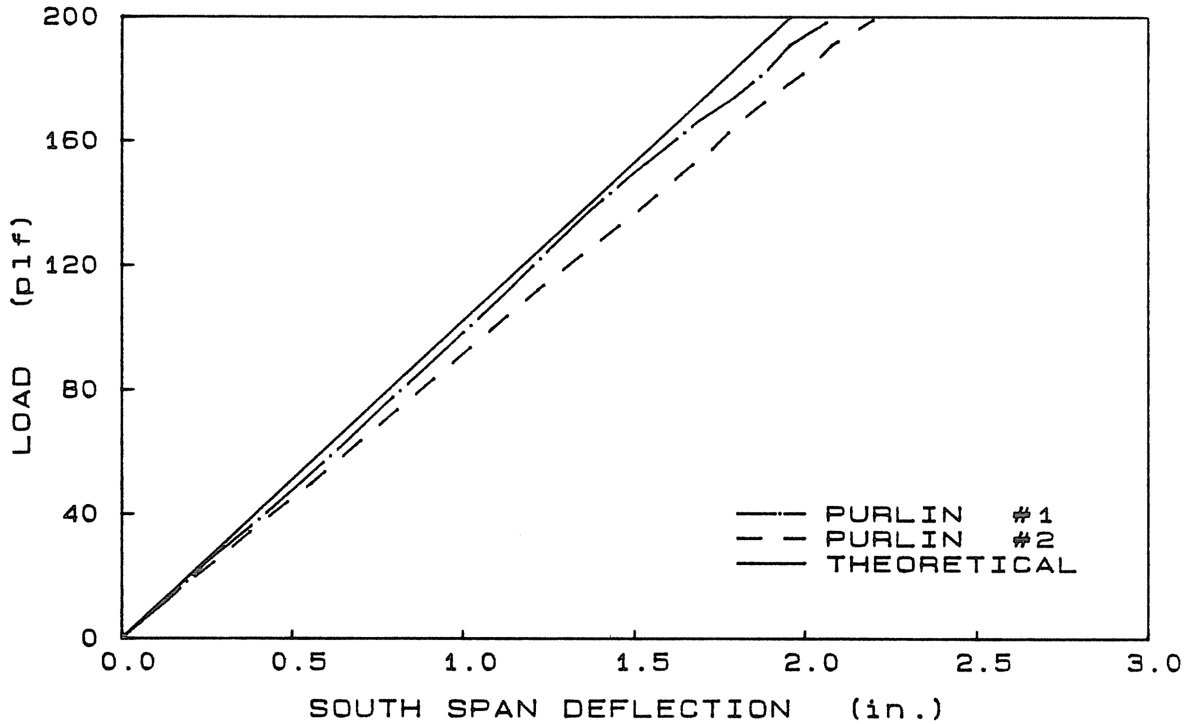


(a) Load vs. Deflection

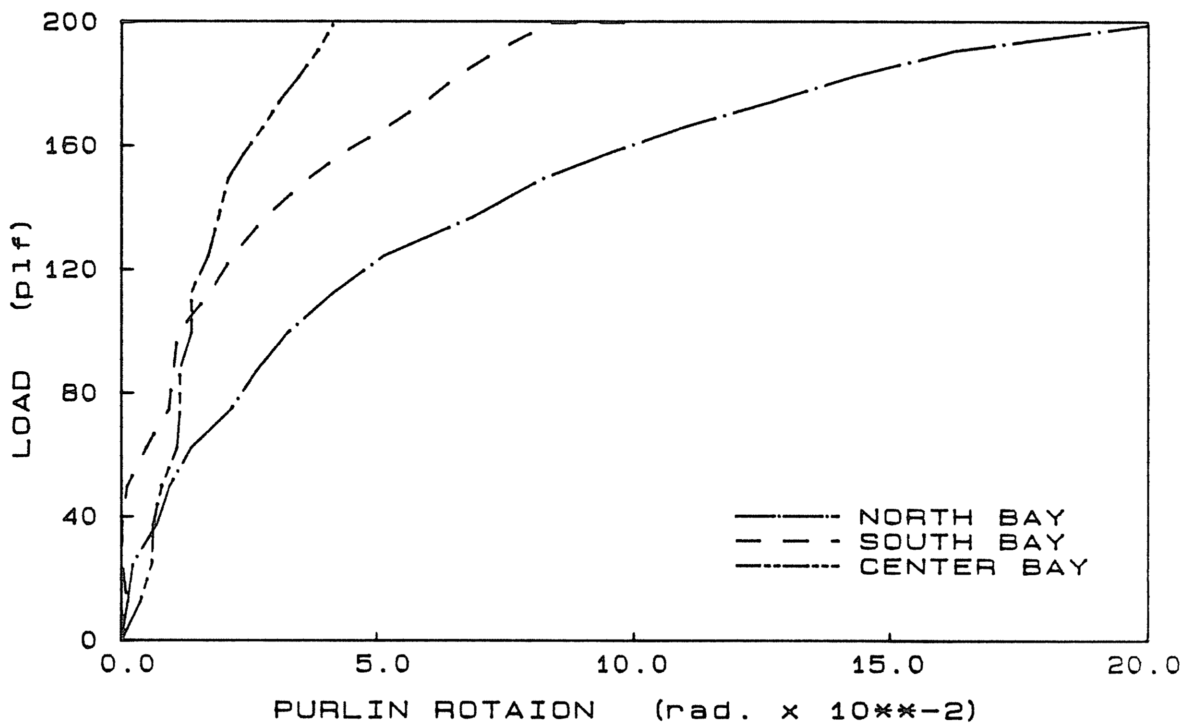


(b) Load vs. Deflection

Figure B.16 Load vs. Purlin Movement, Test P2/2-T-3, Continued



(d) Load vs. Deflection



(e) Load vs. Purlin Rotation

Figure B.16 Load vs. Purlin Movement, Test P2/2-T-3

STANDING SEAM ROOF SYSTEMS
THREE SPAN RESTRAINT
FORCE TESTS

TEST SUMMARY

Test No: R3/2-M-3 Test Date: 8-19-86
Three Spans @ 23.0 ft. Deck Type: Rib
Restraint Configuration: ____ Supports

X Midspan

____ Third Pts.

Purlin Data: Thickness 0.073 in.

Moment of Inertia 10.30 in^4 (Center & N. bays)

Thickness 0.080 in.

Moment of Inertia 11.24 in^4 (S. bay)

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

0.0 in. (Center Bay)

1.04 in. (N. Bay)

0.98 in. (S. Bay)

Predicted Failure Load 249.4 plf (1986 AISI)

290.7 plf (1980 AISI)

Brace Force @ 100 plf 727.6 lbs/brace (#1 & #3)

653.3 lbs/brace (#2)

Restraint: Bracing between purlins #1 and #2 at midspans.

Experimental Failure Load: 137.7 plf

Failure Mode: Due to lack of lateral restraint at the end support, Purlins #1 and #2, North Bay, rotated at ends and developed local buckling of the compression flange at approximately 7'-0" from the end support.

Discussion:

- North bay purlin #2 rotation @ 133.9 plf = 0.073 rad. at the midspan.

- Horizontal deflection of north bay purlin #2 = 0.076 in. at the midspan.

- Good correlation was found between theoretical and experimental predictions for both deflections and brace forces.

- Experimental failure load was 55.2% of 1986 AISI/constrained bending/full lateral restraint predictions.

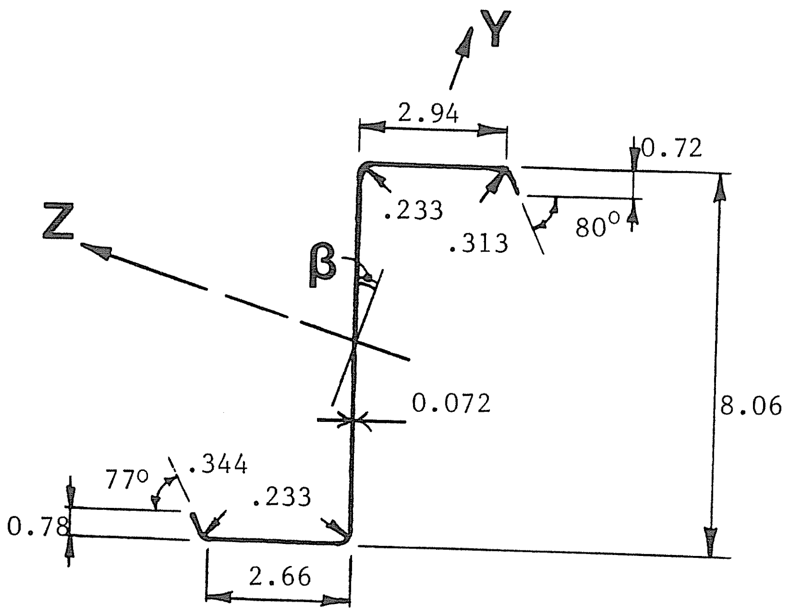
- Very little clip movement was observed.

Initial purlin readings:

	Purlin #1	Purlin #2
North span	Sweep 3/8"	1/4"
	Camber 1/8"	1/4"
Center span	Sweep 3/16"	0.0"
	Camber -1/8"	-1/8" (upward)
South span	Sweep 1/8"	-1/2"
	Camber 0.0"	1/8"

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0669

β(deg) = 18.2531

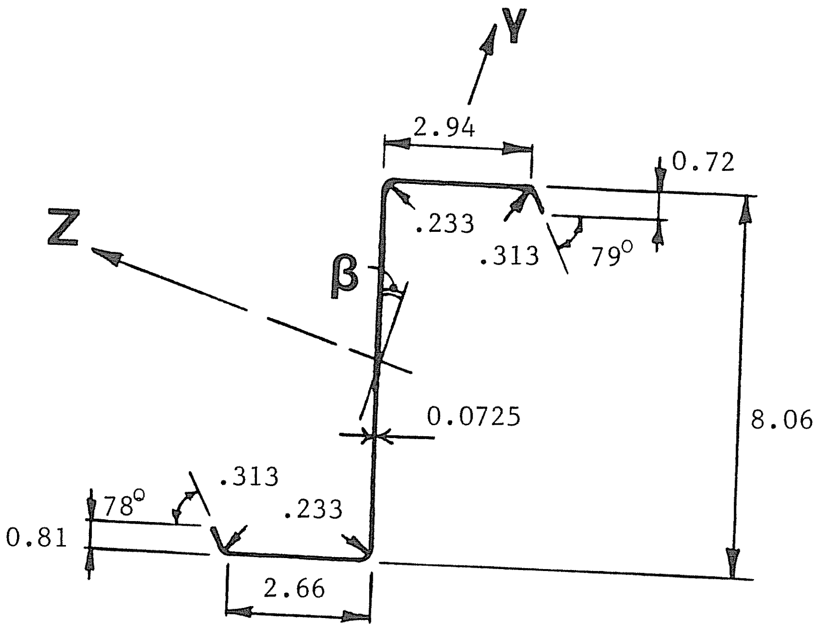
I_x (in^4) = 0.0019

I_y (in^4) = 0.7950

I_z (in^4) = 11.8301

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0772

β(deg) = 18.3530

I_x (in^4) = 0.0019

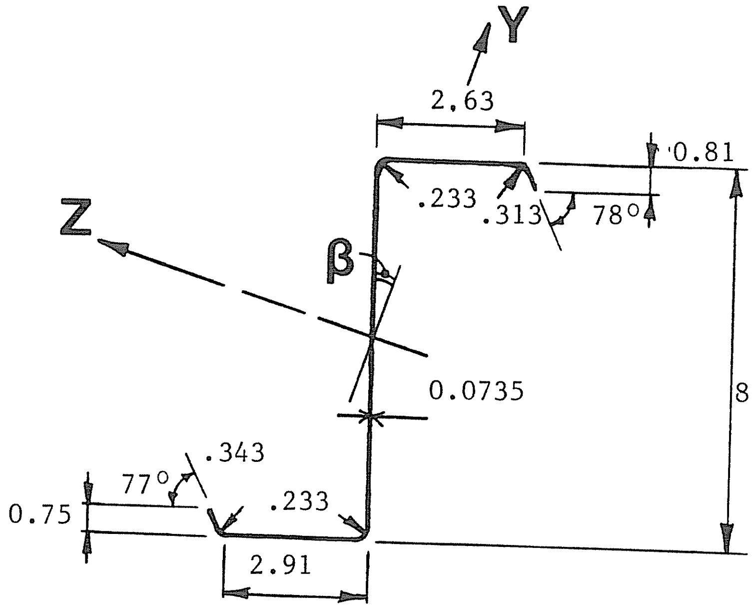
I_y (in^4) = 0.8065

I_z (in^4) = 11.9653

Figure B.17 Measured Purlin Dimensions and Calculated Properties, Test R3/2-M-3, Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0901

β(deg) = 18.2603

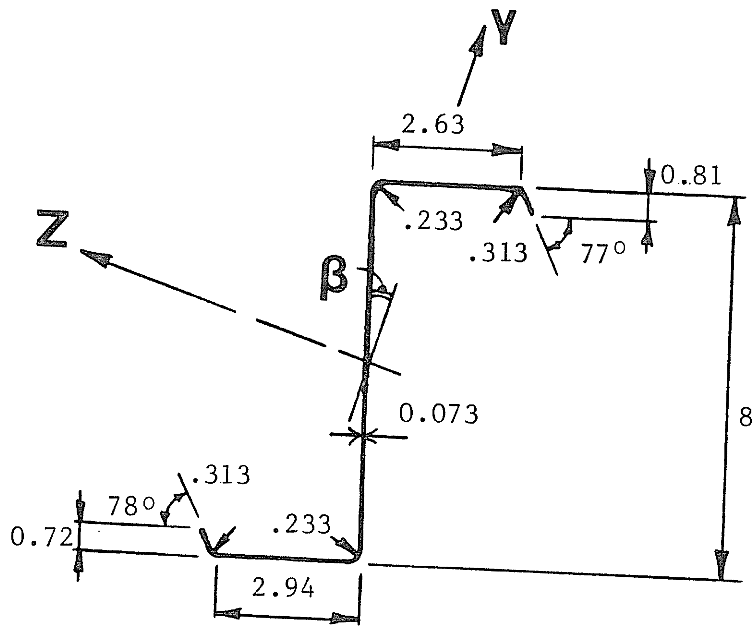
I_x (in^4) = 0.0020

I_y (in^4) = 0.8146

I_z (in^4) = 12.0635

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0833

β(deg) = 18.2974

I_x (in^4) = 0.0020

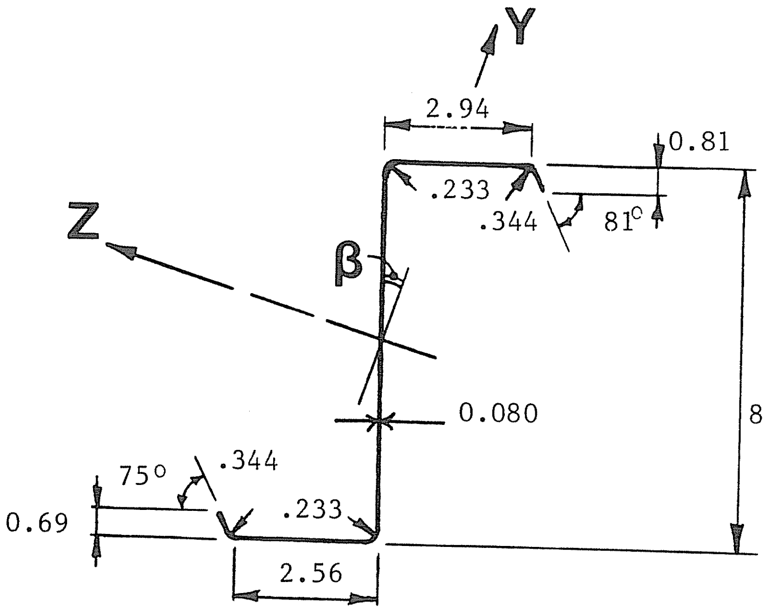
I_y (in^4) = 0.8076

I_z (in^4) = 12.0150

Figure B.17 Measured Purlin Dimensions and Calculated Properties, Test R3/2-M-3, Continued

Purlin #1

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1762

β(deg) = 17.9974

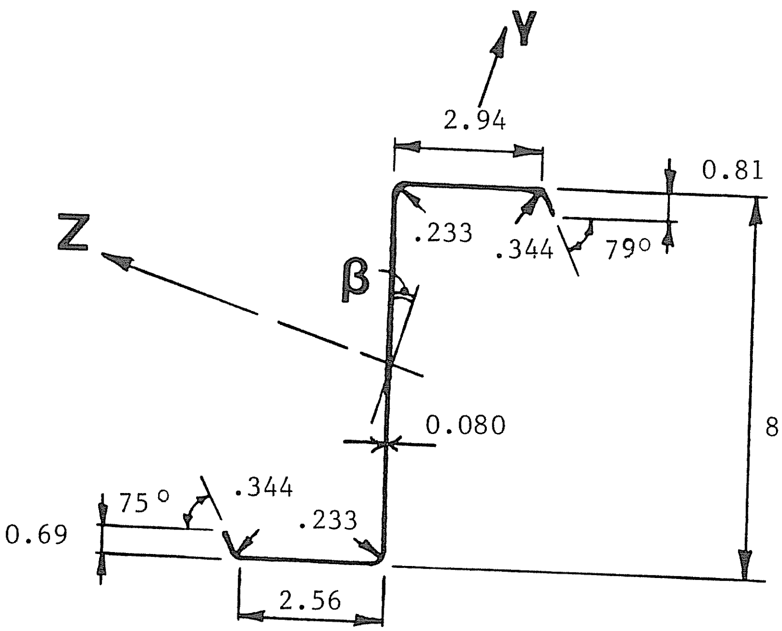
$I_x(in^4)$ = 0.0025

$I_y(in^4)$ = 0.8597

$I_z(in^4)$ = 12.8797

Purlin #2

South Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1788

β(deg) = 18.0006

I (in^4) = 0.0026

I (in^4) = 0.8662

I (in^4) = 12.9683

Figure B.17 Measured Purlin Dimensions and Calculated Properties, Test R3/2-M-3, Continued

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7188	0.7813
Lip angles	(degrees) :	80.0000	77.0000
Flange widths	(inches) :	2.9380	2.6560
Radii	(inches)		
Lip to flange	:	0.3125	0.3438
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0720

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3104
Gross moment of inertia	(in^4) :	10.32

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7369	inches
Effective moment of inertia	: 9.27	in^4
Allowable flexural capacity	: 74.21	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2015	inches		
Effective moment of inertia	: 10.19	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.54	ksi	(at flange : 34.14 ksi)	
Allowable flexural capacity	: 86.48	kip-in		

Figure B.18 Strength Calculations, Test R3/2-M-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7188	0.8125
Lip angles	(degrees) :		79.0000	78.0000
Flange widths	(inches) :		2.9375	2.6563
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0725		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3146
Gross moment of inertia	(in^4) :	10.42

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7519	inches
Effective moment of inertia	: 9.38	in^4
Allowable flexural capacity	: 74.96	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.2120	inches		
Effective moment of inertia	: 10.30	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 31.61	ksi	(at flange : 34.21 ksi)	
Allowable flexural capacity	: 87.33	kip-in		

Figure B.18 Strength Calculations, Test R3/2-M-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.8125	0.7500
Lip angles	(degrees) :	78.0000	77.0000
Flange widths	(inches) :	2.6250	2.9063
Radii	(inches)		
Lip to flange	:	0.3125	0.3438
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0735

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0059
Gross moment of inertia	(in^4) :	10.52

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.6806	inches
Effective moment of inertia	:	9.75	in^4
Allowable flexural capacity	:	77.12	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	:	2.0059	inches	
Effective moment of inertia	:	10.52	in^4	
Allowable stress at flange	:	33.96	ksi	controls
Allowable stress at web	:	31.74	ksi	(at flange : 34.31 ksi)
Allowable flexural capacity	:	87.25	kip-in	

Figure B.18 Strength Calculations, Test R3/2-M-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.7188
Lip angles	(degrees) :		77.0000	78.0000
Flange widths	(inches) :		2.6250	2.9375
Radii	(inches)			
Lip to flange	:		0.3125	0.3125
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0730		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.0124
Gross moment of inertia	(in^4) :	10.47

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.6785	inches
Effective moment of inertia	: 9.69	in^4
Allowable flexural capacity	: 76.61	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.0124	inches	
Effective moment of inertia	: 10.47	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.67	ksi	(at flange : 34.23 ksi)
Allowable flexural capacity	: 86.86	kip-in	

Figure B.18 Strength Calculations, Test R3/2-M-3, Continued

(e) Purlin #1, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.6875
Lip angles	(degrees) :		81.0000	75.0000
Flange widths	(inches) :		2.9375	2.5625
Radii	(inches)			
Lip to flange	:		0.3438	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0435		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2625
Gross moment of inertia	(in^4) :	11.21

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7129	inches
Effective moment of inertia	: 10.10	in^4
Allowable flexural capacity	: 82.29	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 2.2625	inches	
Effective moment of inertia	: 11.21	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 32.53	ksi	(at flange : 35.37 ksi)
Allowable flexural capacity	: 97.55	kip-in	

Figure B.18 Strength Calculations, Test R3/2-M-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.8125	0.6875
Lip angles	(degrees) :		79.0000	75.0000
Flange widths	(inches) :		2.9375	2.5625
Radii	(inches)			
Lip to flange	:		0.3438	0.3438
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2751
Gross moment of inertia	(in^4) :	11.29

1986 AISI PROCEDURE

Flange is not fully effective

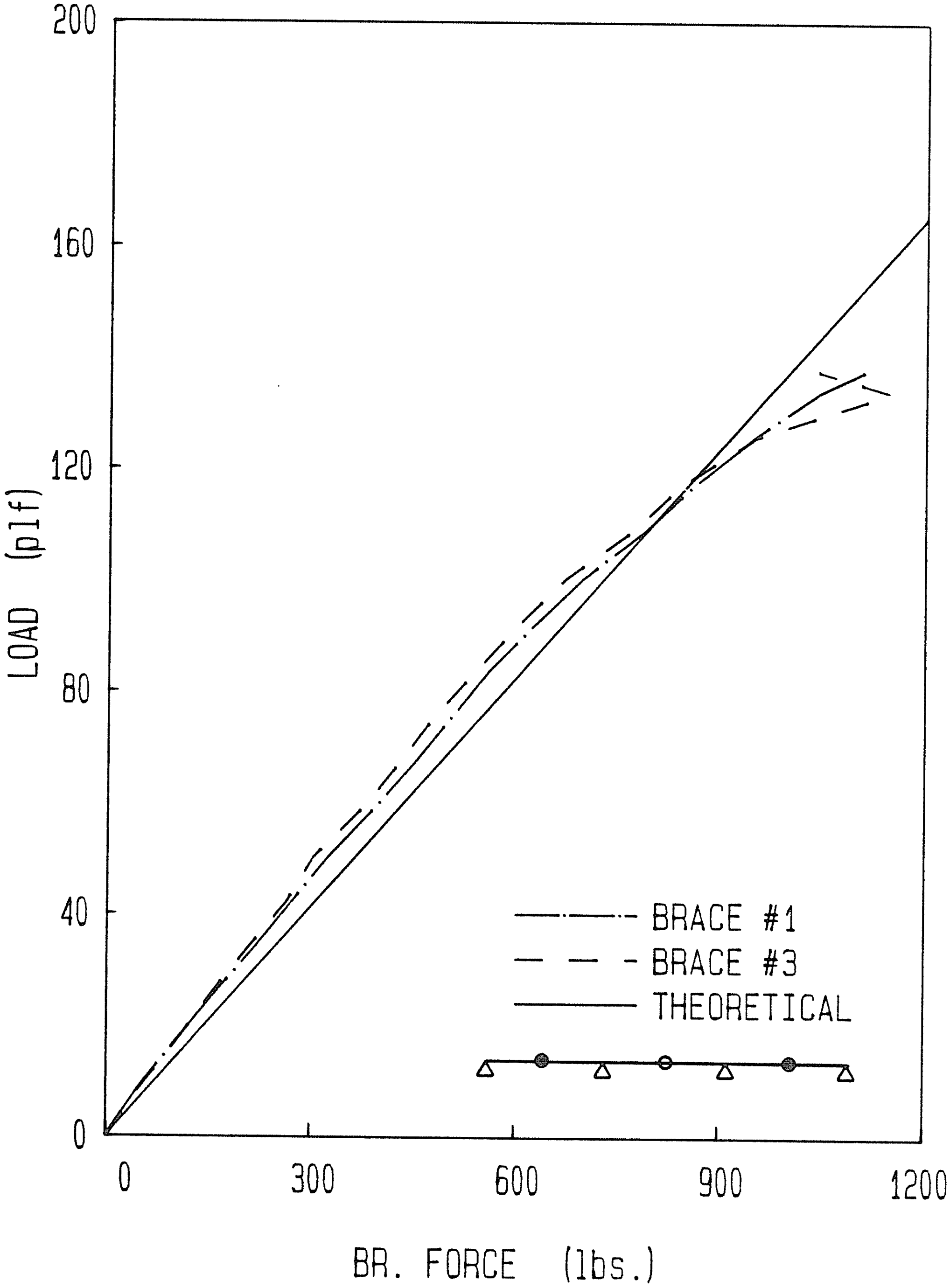
Effective flange width	:	1.7327	inches
Effective moment of inertia	:	10.18	in^4
Allowable flexural capacity	:	82.82	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

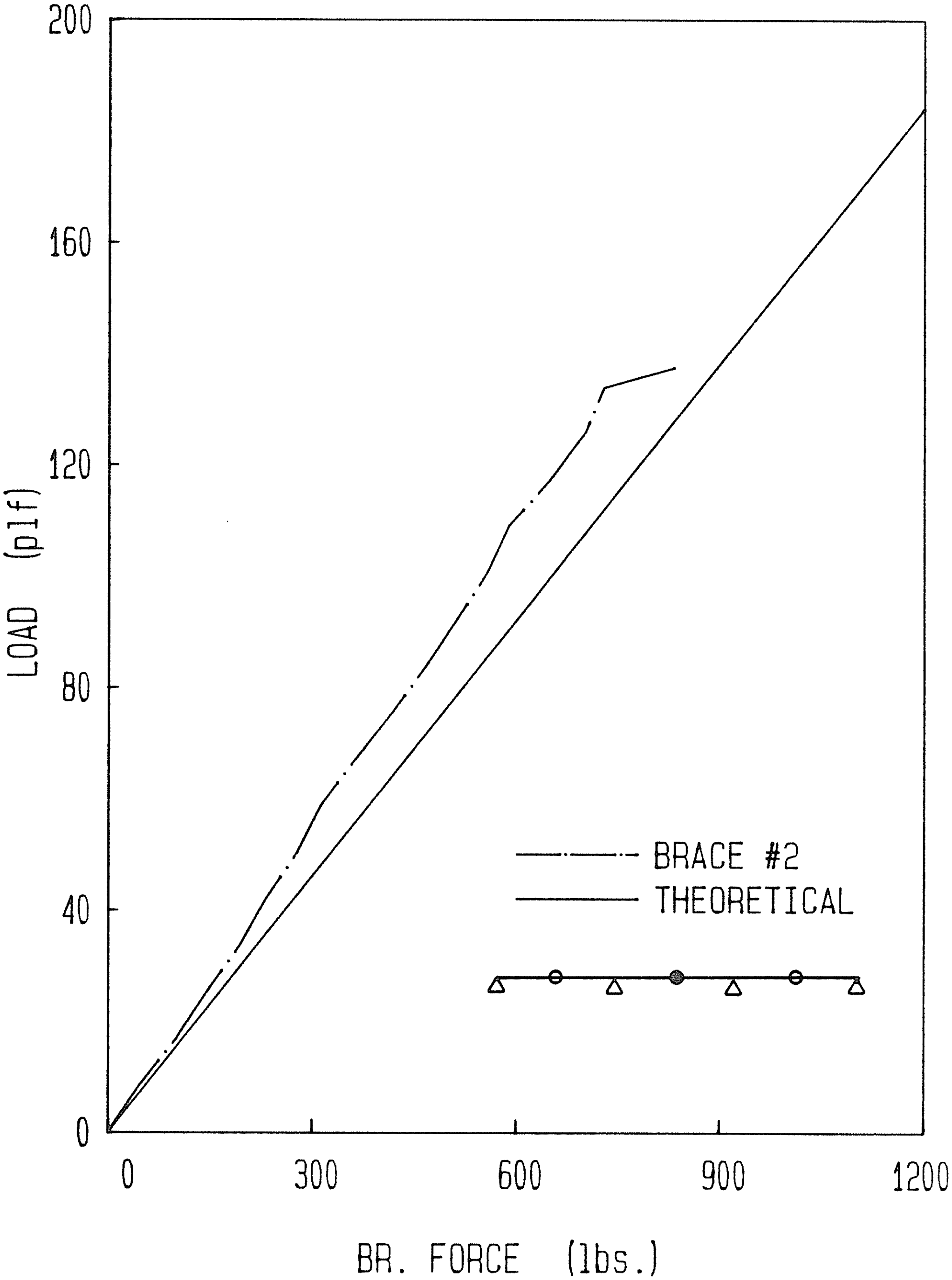
Effective flange width	:	2.2751	inches		
Effective moment of inertia	:	11.29	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	32.51	ksi	(at flange : 35.34 ksi)	
Allowable flexural capacity	:	98.14	kip-in		

Figure B.18 Strength Calculations, Test R3/2-M-3



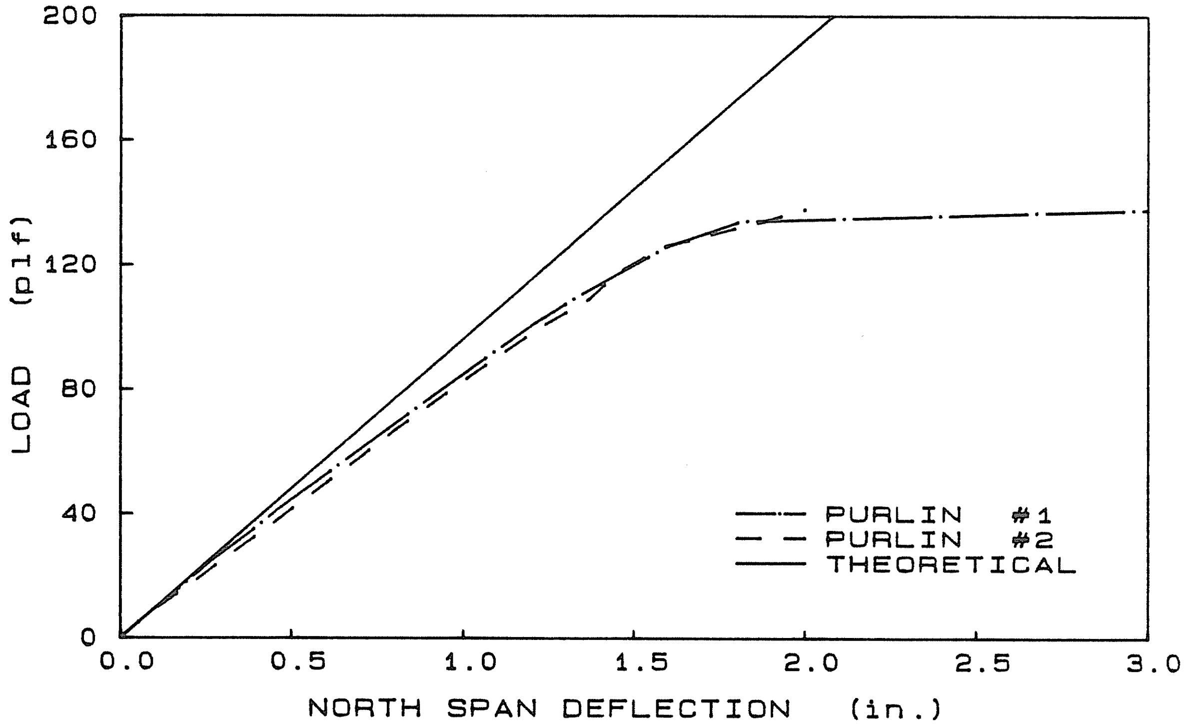
(a) Braces #1 and #3

Figure B.19 Load vs. External Brace Forces, Test R3/2-M-3, Continued

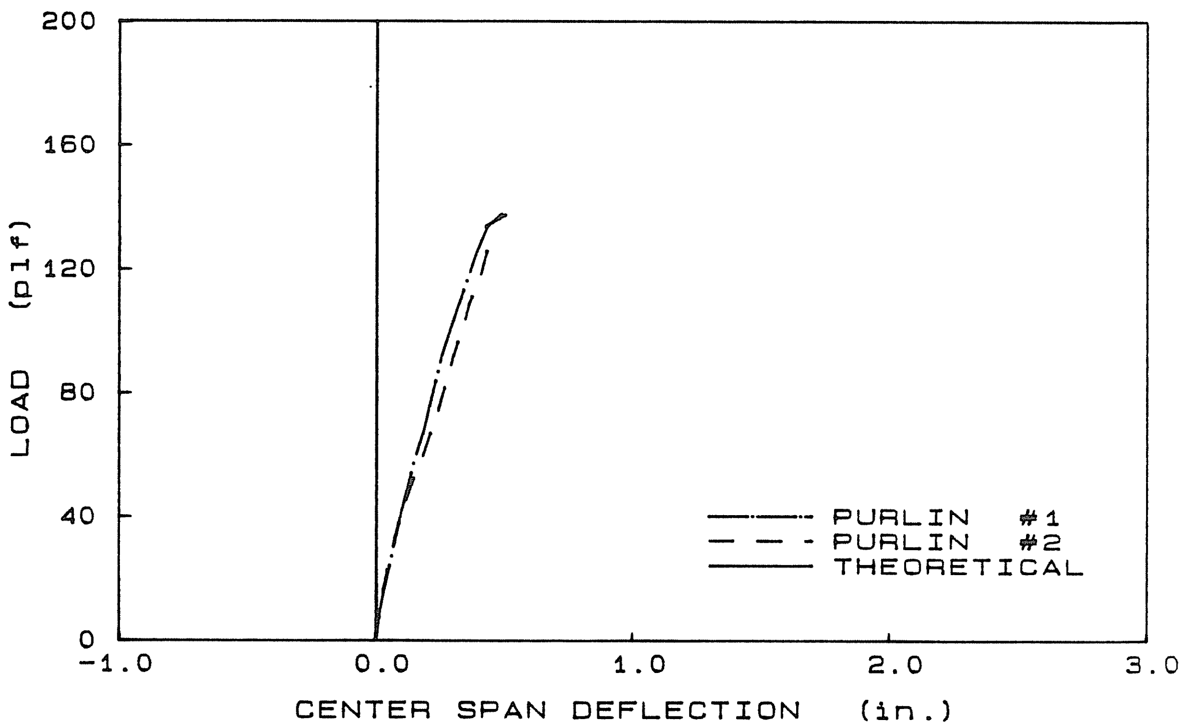


(b) Brace #2

Figure B.19 Load vs. External Brace Forces, Test R3/2-M-3

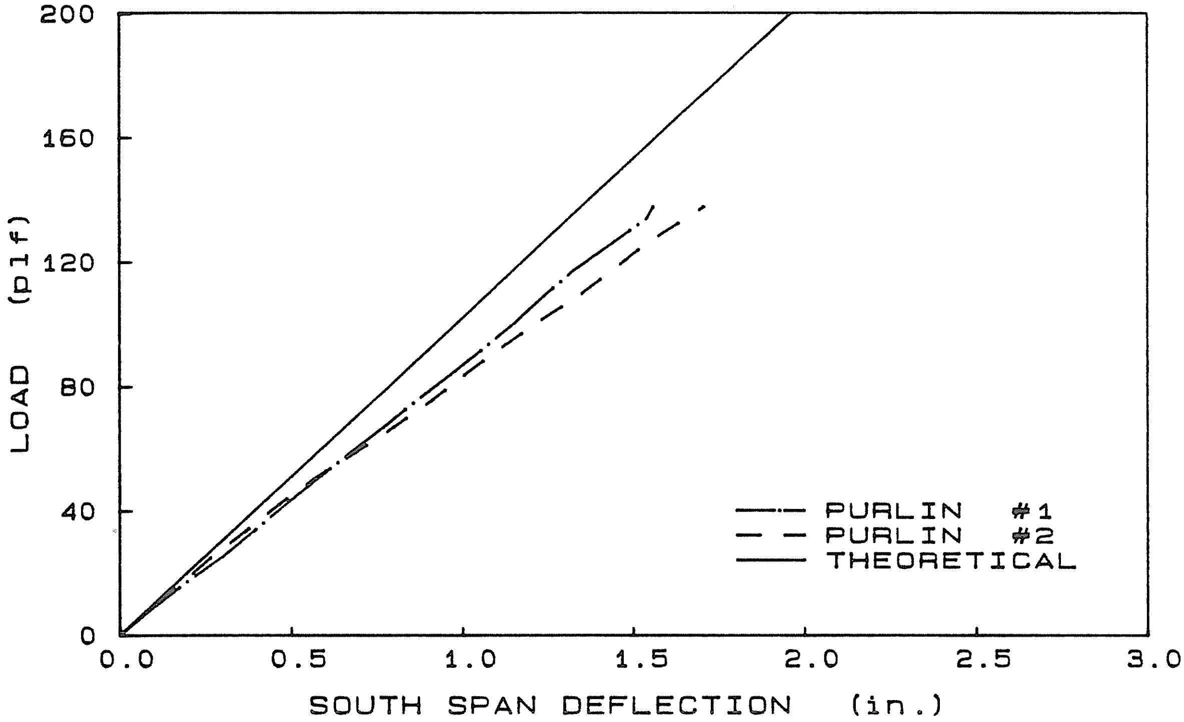


(a) Load vs. Deflection

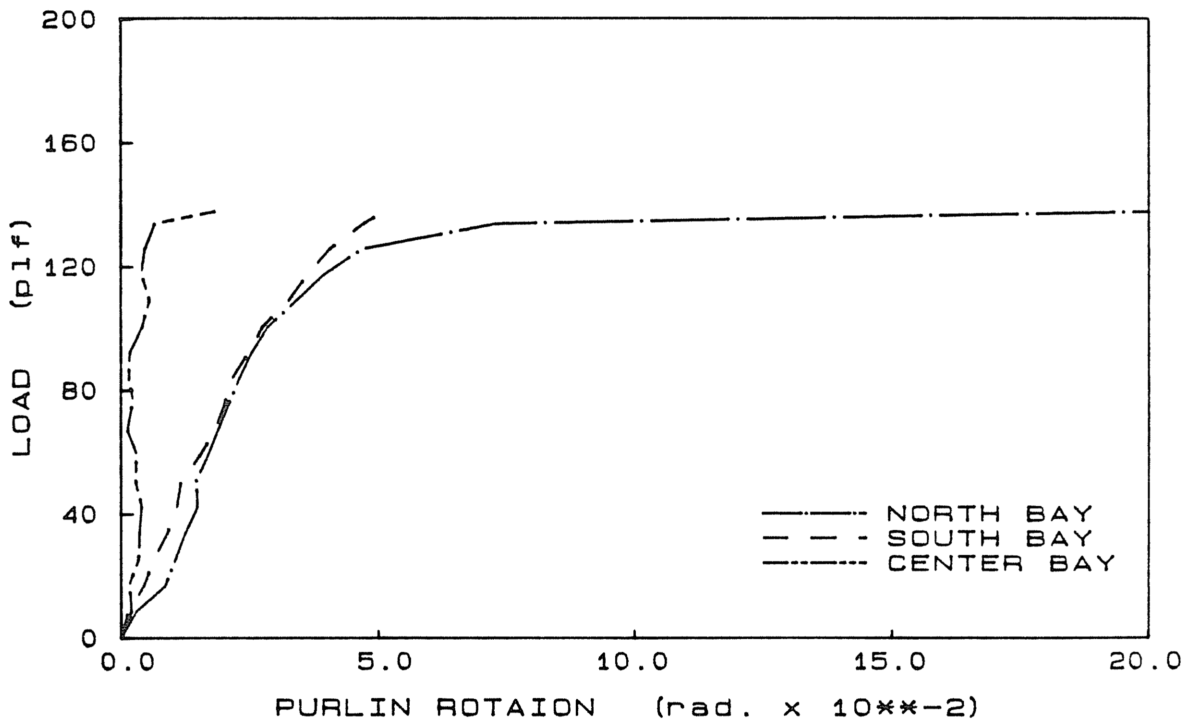


(b) Load vs. Deflection

Figure B.20 Load vs. Purlin Movement, Test R3/2- M-3, Continued



(c) Load vs. Deflection



(d) Load vs. Purlin Rotation

Figure B.20 Load vs. Purlin Movement, Test R3/2-M-3

STANDING SEAM ROOF SYSTEMS THREE SPAN RESTRAINT FORCE TESTS

TEST SUMMARY

Test No: P2/2-M-3 Test Date: 9/22/86

Three Spans @: 23.0 ft. Deck Type: Pan

Restraint Configuration: ______ Supports

X Midspan

______ Third Pts.

Purlin Data: Thickness 0.072 in.

Moment of Inertia 10.11 in^4 (N.& S. Bays)

Thickness 0.080 in.

Moment of Inertia 11.25 in^4 (Center Bay)

Yield Stress 56.6 ksi

Predictions: Vertical Deflection @ 100 plf

-0.03 in. (Center Bay)

0.08 in. (South Bay)

1.04 in. (North Bay)

Failure Load 248.5 plf (1986 AISI)

284.9 plf (1980 AISI)

Brace Force @ 100 plf

726.2 lbs/brace (#1 & #3)

651.8 lbs/brace (#2)

Restraint: Bracing between purlin #1 and #2 at midspan.

Experimental Failure Load: 154.0 plf

Failure Mode: Local buckling of south bay purlin #2 at midspan brace location

Discussion:

- South bay purlin #2 rotatin @ 149.2 plf = 0.156 rad. at the midspan.

- Excellent correlation was found between theoretical and experimental brace force predictions.

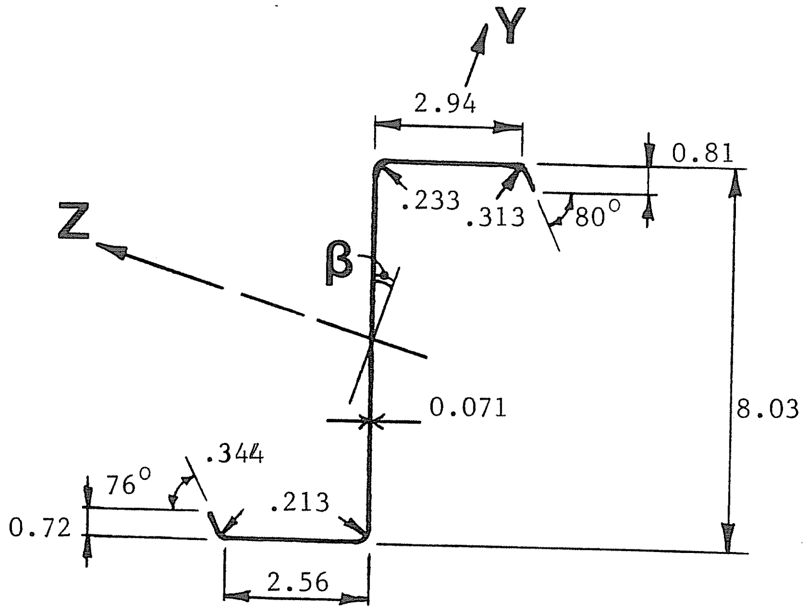
- Clip movement at ends and midspans was observed up to 0.15" at 100 plf.

- Initial camber was less than 1/8" for all purlins.

- Experimental failure load was 62.0% of 1986 AISI/constrained bending/full lateral restraint predictions.

Purlin #1

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0459

β(deg) = 18.1421

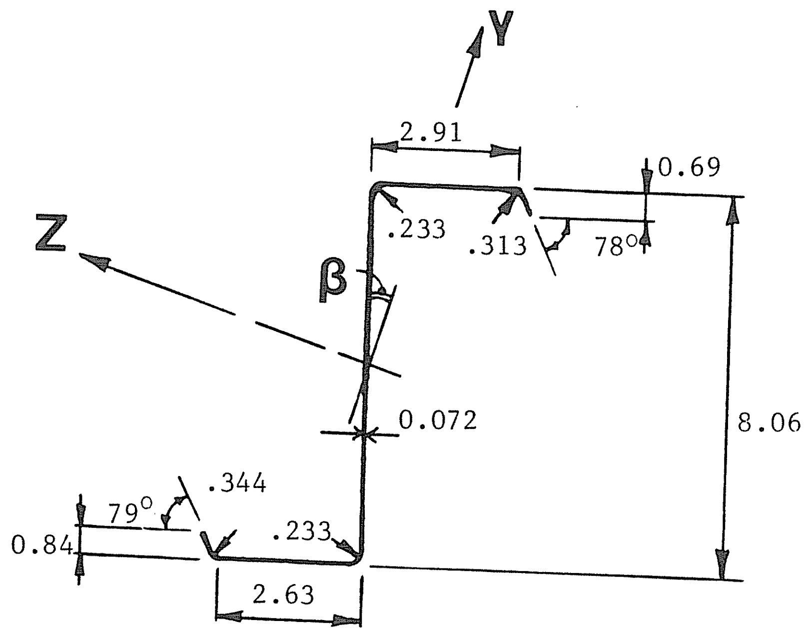
$I_x(in^4)$ = 0.0018

$I_y(in^4)$ = 0.7713

$I_z(in^4)$ = 11.4534

Purlin #2

North Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.0646

β(deg) = 18.0915

$I_x(in^4)$ = 0.0019

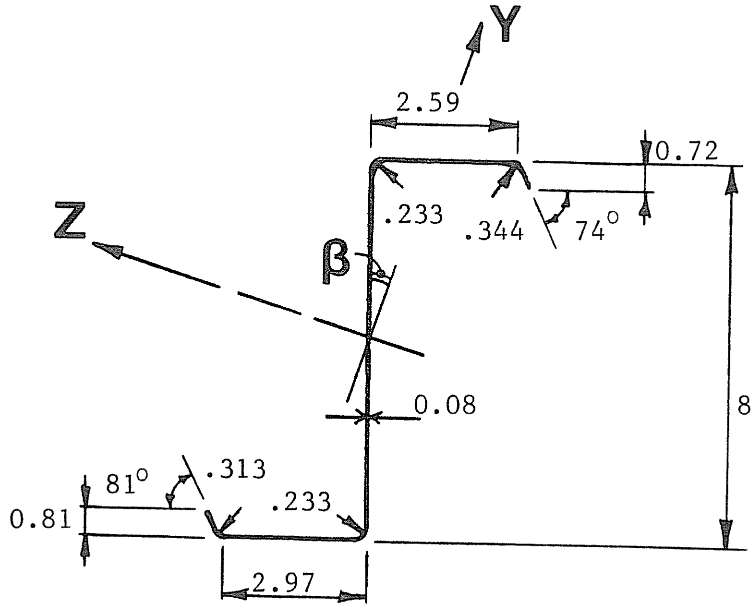
$I_y(in^4)$ = 0.7822

$I_z(in^4)$ = 11.7572

Figure B.21 Measured Purlin Dimensions and Calculated Properties, Test P2/2-M-3, Continued

Purlin #1

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1866

β (deg) = 18.3066

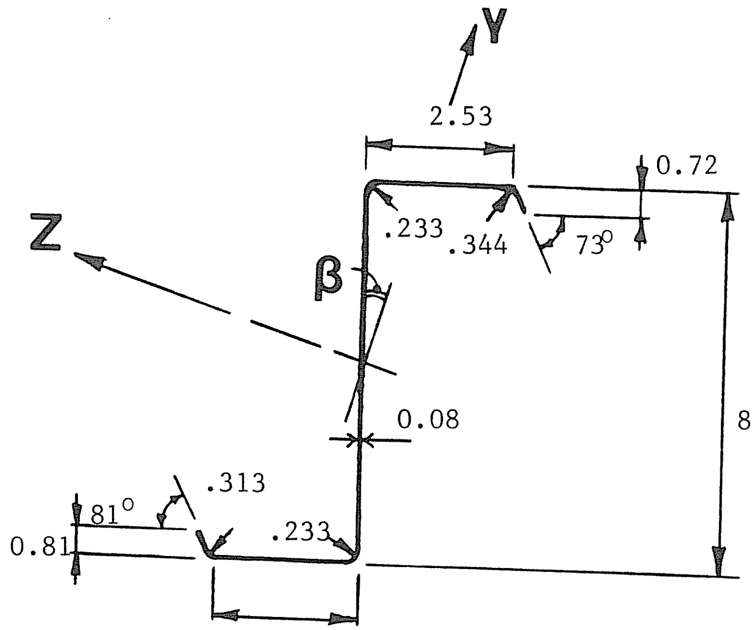
I_x (in^4) = 0.0026

I_y (in^4) = 0.8901

I_z (in^4) = 13.1412

Purlin #2

Center Span



Properties: Span (ft) = 23.0

Area (in^2) = 1.1822

β(deg) = 18.1213

I_x (in^4) = 0.0026

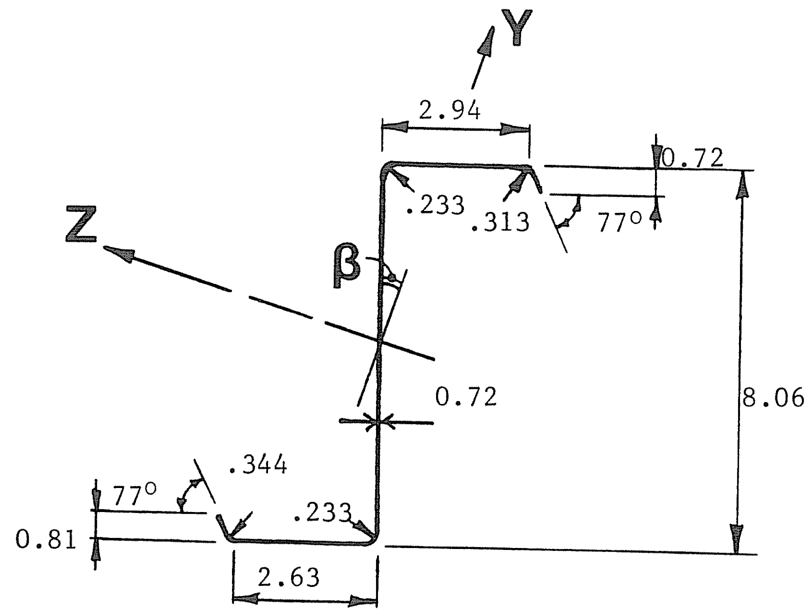
I_y (in^4) = 0.8751

I_z (in^4) = 13.0318

Figure B.21 Measured Purlin Dimensions and Calculated Properties, Test P2/2-M-3, Continued

Purlin #1

South Span



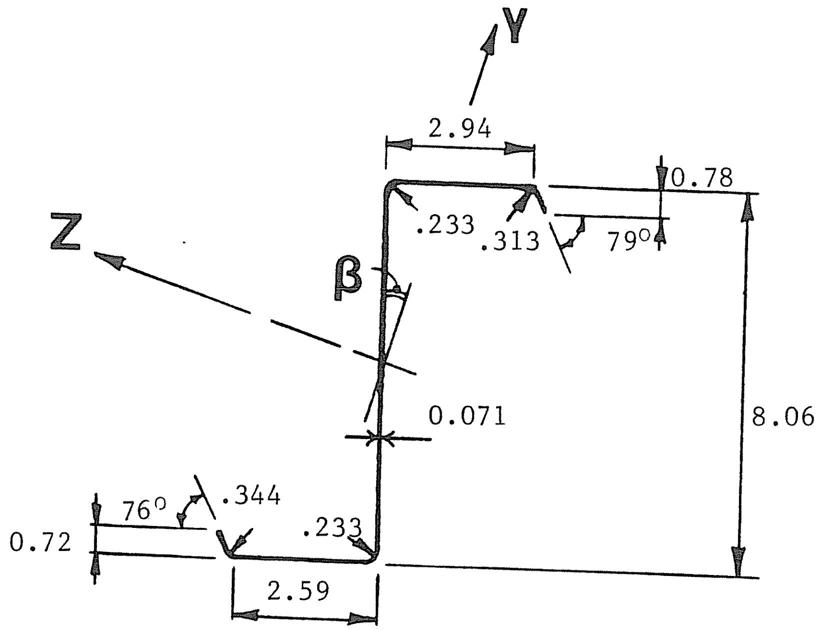
Properties: Span (ft) = 23.0 $\quad I_x(in^4) = 0.0019$

Area (in^2) = 1.0683 $\quad I_y(in^4) = 0.7995$

β(deg) = 18.3028 $\quad I_z(in^4) = 11.8466$

Purlin #2

South Span



Properties: Span (ft) = 23.0 $\quad I_x(in^4) = 0.0018$

Area (in^2) = 1.0485 $\quad I_y(in^4) = 0.7749$

β(deg) = 18.0981 $\quad I_z(in^4) = 11.5748$

Figure B.21 Measured Purlin Dimensions and Calculated Properties, Test P2/2-M-3

(a) Purlin #1, North Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.8125	0.7188
Lip angles	(degrees) :	80.0000	76.0000
Flange widths	(inches) :	2.9375	2.5625
Radii	(inches)		
Lip to flange	:	0.3130	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0313
Purlin thickness	(inches) :	0.0710

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3113
Gross moment of inertia	(in^4) :	9.92

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.8028	inches
Effective moment of inertia	: 9.03	in^4
Allowable flexural capacity	: 73.98	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.1839	inches	
Effective moment of inertia	: 9.78	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.44	ksi	(at flange : 34.07 ksi)
Allowable flexural capacity	: 84.49	kip-in	

Figure B.22 Calculated Properties, Test P2/2-M-3, Continued

(b) Purlin #2, North Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.6875	0.8438
Lip angles	(degrees) :	78.0000	79.0000
Flange widths	(inches) :	2.9063	2.8438
Radii	(inches)		
Lip to flange	:	0.3130	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0720

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.2895
Gross moment of inertia	(in^4) :	10.43

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7230	inches
Effective moment of inertia	: 9.40	in^4
Allowable flexural capacity	: 74.13	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	: 2.1930	inches	
Effective moment of inertia	: 10.32	in^4	
Allowable stress at flange	: 33.96	ksi	controls
Allowable stress at web	: 31.54	ksi	(at flange : 34.09 ksi)
Allowable flexural capacity	: 86.06	kip-in	

Figure B.22 Calculated Properties, Test P2/2-M-3, Continued

(c) Purlin #1, Center Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7190	0.8130
Lip angles	(degrees) :	74.0000	81.0000
Flange widths	(inches) :	2.5940	2.9690
Radii	(inches)		
Lip to flange	:	0.3130	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0630
Purlin thickness	(inches) :	0.0800

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	1.9849
Gross moment of inertia	(in^4) :	11.30

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7565	inches
Effective moment of inertia	: 10.63	in^4
Allowable flexural capacity	: 83.95	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 1.9849	inches		
Effective moment of inertia	: 11.30	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.17 ksi)	
Allowable flexural capacity	: 92.69	kip-in		

Figure B.22 Calculated Properties, Test P2/2-M-3, Continued

(d) Purlin #2, Center Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7190	0.8130
Lip angles	(degrees) :		73.0000	81.0000
Flange widths	(inches) :		2.5310	2.9690
Radii	(inches)			
Lip to flange	:		0.3440	0.3130
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0630		
Purlin thickness	(inches) :	0.0800		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	1.9043
Gross moment of inertia	(in^4) :	11.23

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	: 1.7383	inches
Effective moment of inertia	: 10.67	in^4
Allowable flexural capacity	: 84.33	kip-in

1980 AISI PROCEDURE

Flange is fully effective
Lip is adequate

Effective flange width	: 1.9043	inches		
Effective moment of inertia	: 11.23	in^4		
Allowable stress at flange	: 33.96	ksi		controls
Allowable stress at web	: 32.51	ksi	(at flange : 35.16 ksi)	
Allowable flexural capacity	: 91.64	kip-in		

Figure B.22 Calculated Properties, Test P2/2-M-3, Continued

(c) Purlin #1, South Span

GEOMETRY OF CROSS-SECTION

		TOP	BOTTOM
Vertical lip dimensions	(inches) :	0.7188	0.8125
Lip angles	(degrees) :	77.0000	77.0000
Flange widths	(inches) :	2.9375	2.6250
Radii	(inches)		
Lip to flange	:	0.3130	0.3440
Flange to web	:	0.2330	0.2330

Total purlin depth	(inches) :	8.0625
Purlin thickness	(inches) :	0.0720

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3263
Gross moment of inertia	(in^4) :	10.24

1986 AISI PROCEDURE

Flange is not fully effective

Effective flange width	:	1.7681	inches
Effective moment of inertia	:	9.24	in^4
Allowable flexural capacity	:	74.27	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

Effective flange width	:	2.2078	inches		
Effective moment of inertia	:	10.11	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.54	ksi	(at flange : 34.14 ksi)	
Allowable flexural capacity	:	85.86	kip-in		

Figure B.22 Calculated Properties, Test P2/2-M-3, Continued

(f) Purlin #2, South Span

GEOMETRY OF CROSS-SECTION

			TOP	BOTTOM
Vertical lip dimensions	(inches) :		0.7813	0.7188
Lip angles	(degrees) :		79.0000	76.0000
Flange widths	(inches) :		2.9375	2.5938
Radii	(inches)			
Lip to flange	:		0.3130	0.3440
Flange to web	:		0.2330	0.2330
Total purlin depth	(inches) :	8.0625		
Purlin thickness	(inches) :	0.0710		

MATERIAL PROPERTIES

Material yield stress	(ksi) :	56.6
Modulus of elasticity	(ksi) :	29500.0

GENERAL

Flat width of compression flange	(inches) :	2.3170
Gross moment of inertia	(in^4) :	10.03

1986 AISI PROCEDURE

Flange is not fully effective

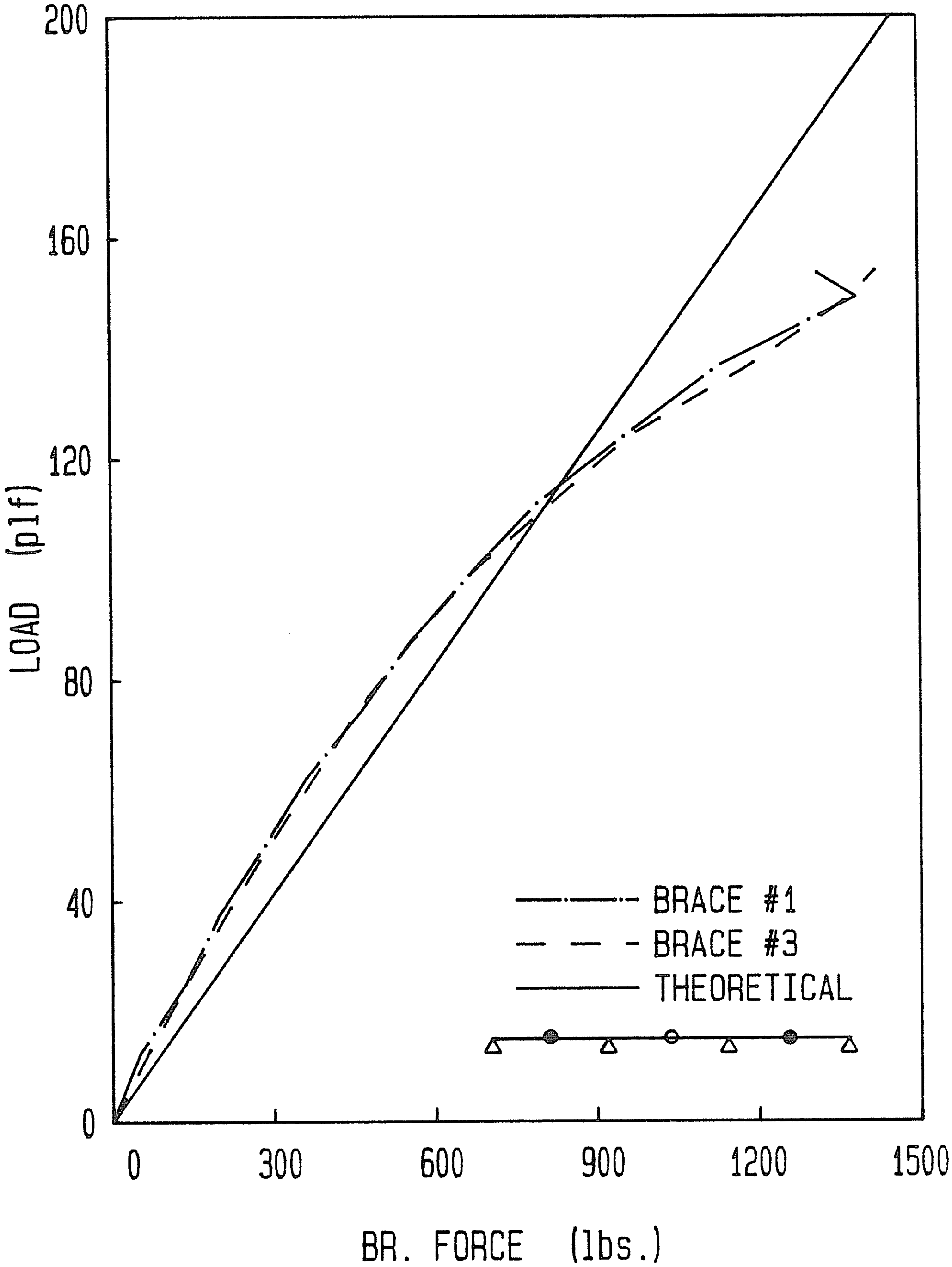
Effective flange width	:	1.7890	inches
Effective moment of inertia	:	9.10	in^4
Allowable flexural capacity	:	73.94	kip-in

1980 AISI PROCEDURE

Flange is not fully effective
Lip is adequate

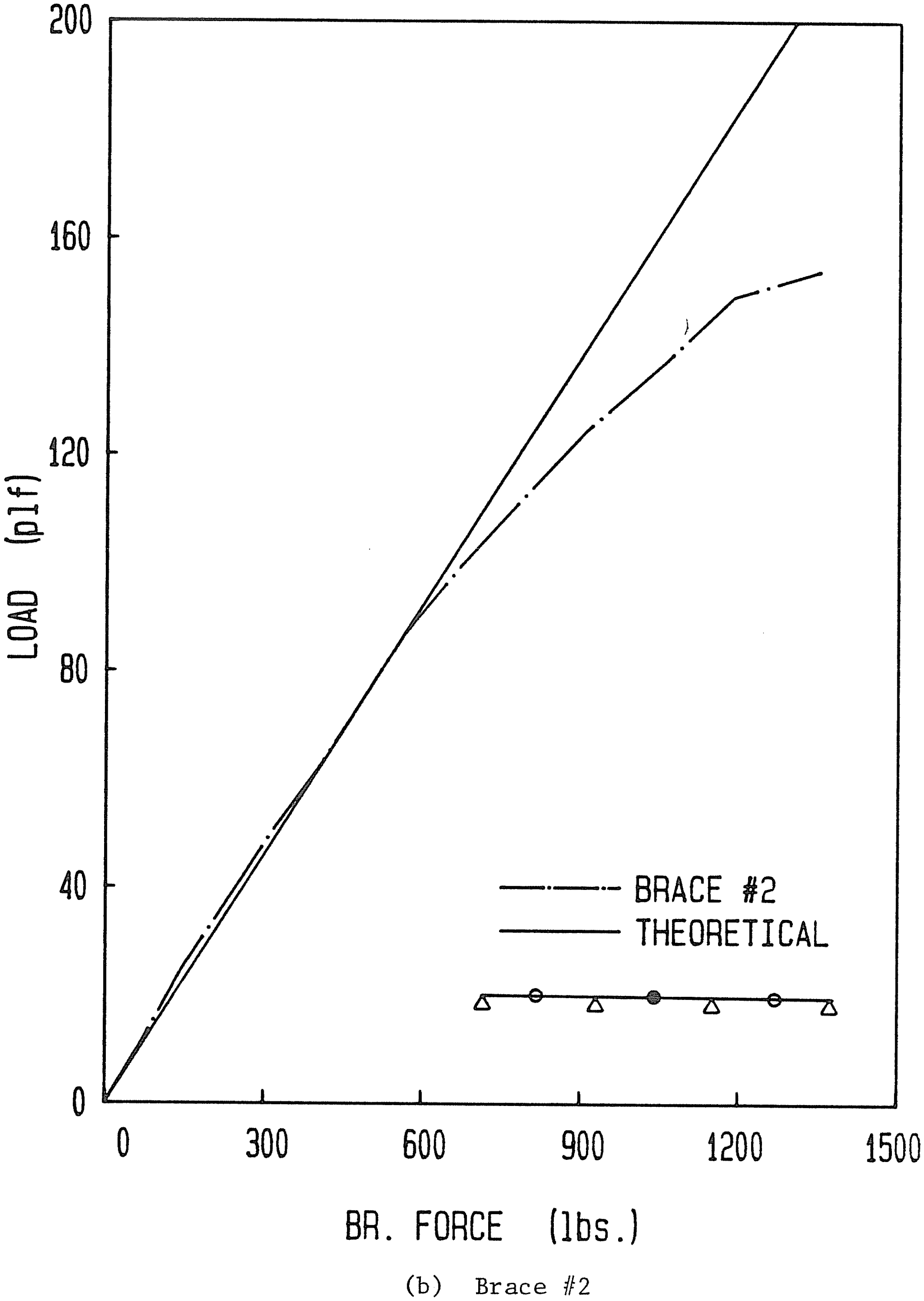
Effective flange width	:	2.1861	inches		
Effective moment of inertia	:	9.89	in^4		
Allowable stress at flange	:	33.96	ksi		controls
Allowable stress at web	:	31.40	ksi	(at flange : 34.01 ksi)	
Allowable flexural capacity	:	84.77	kip-in		

Figure B.22 Calculated Properties, Test P2/2-M-3



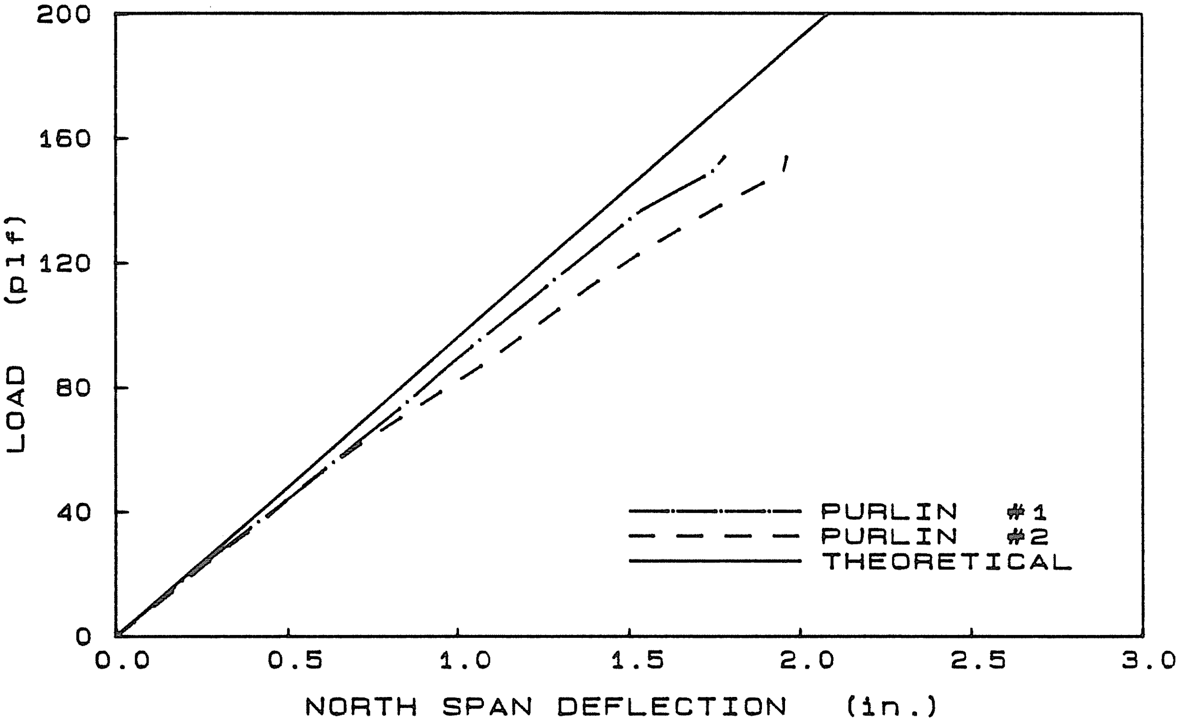
(a) Braces #1 and #3

Figure B.23 Load vs. External Brace Forces, Test P2/2-M-3, Continued

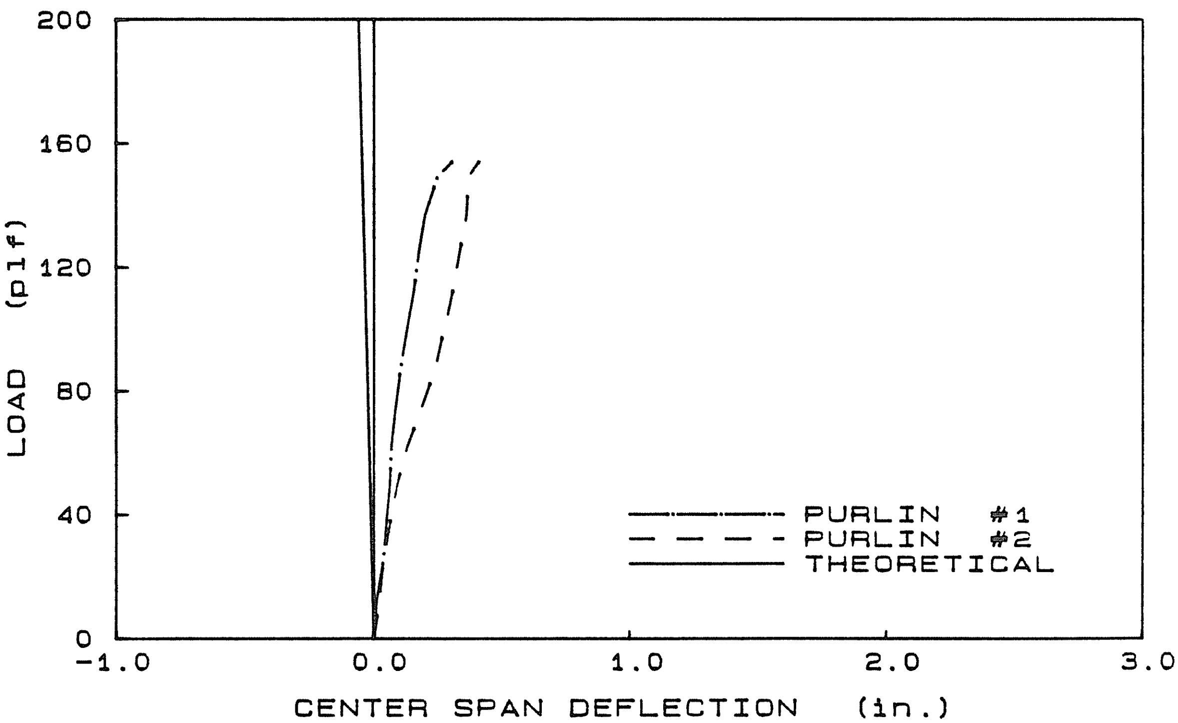


(b) Brace #2

Figure B.23 Load vs. External Brace Forces, Test P2/2-M-3

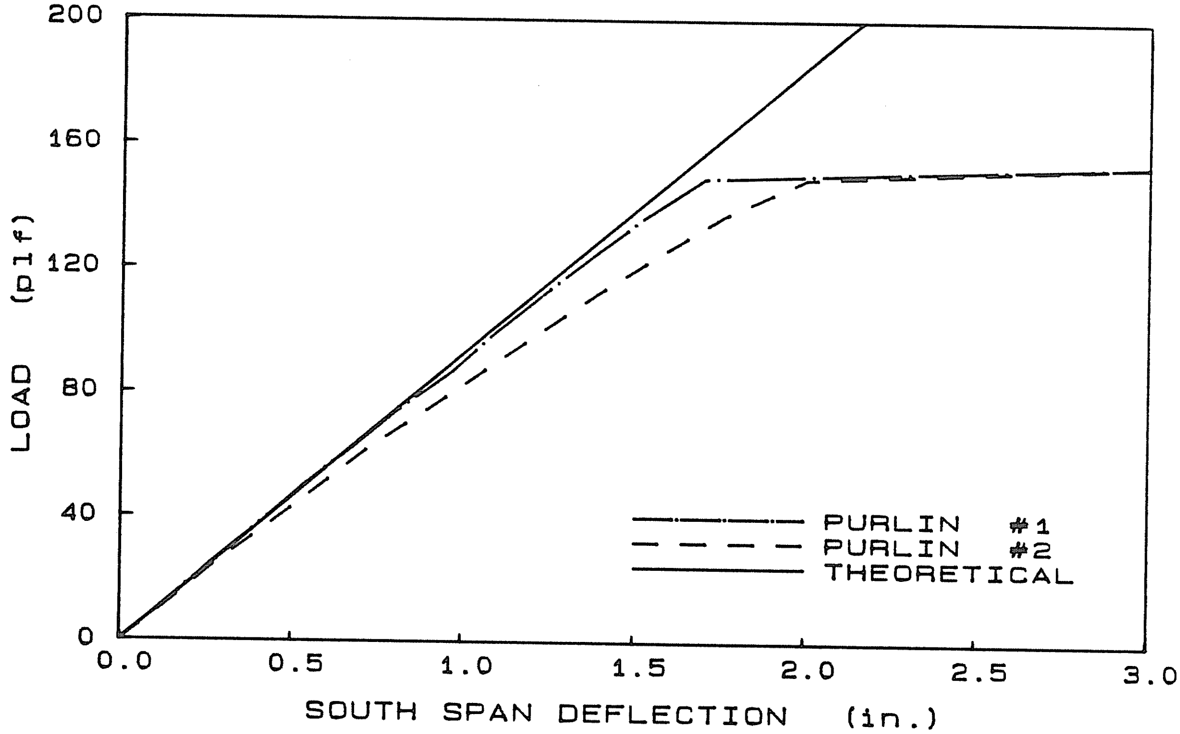


(a) Load vs. Deflection

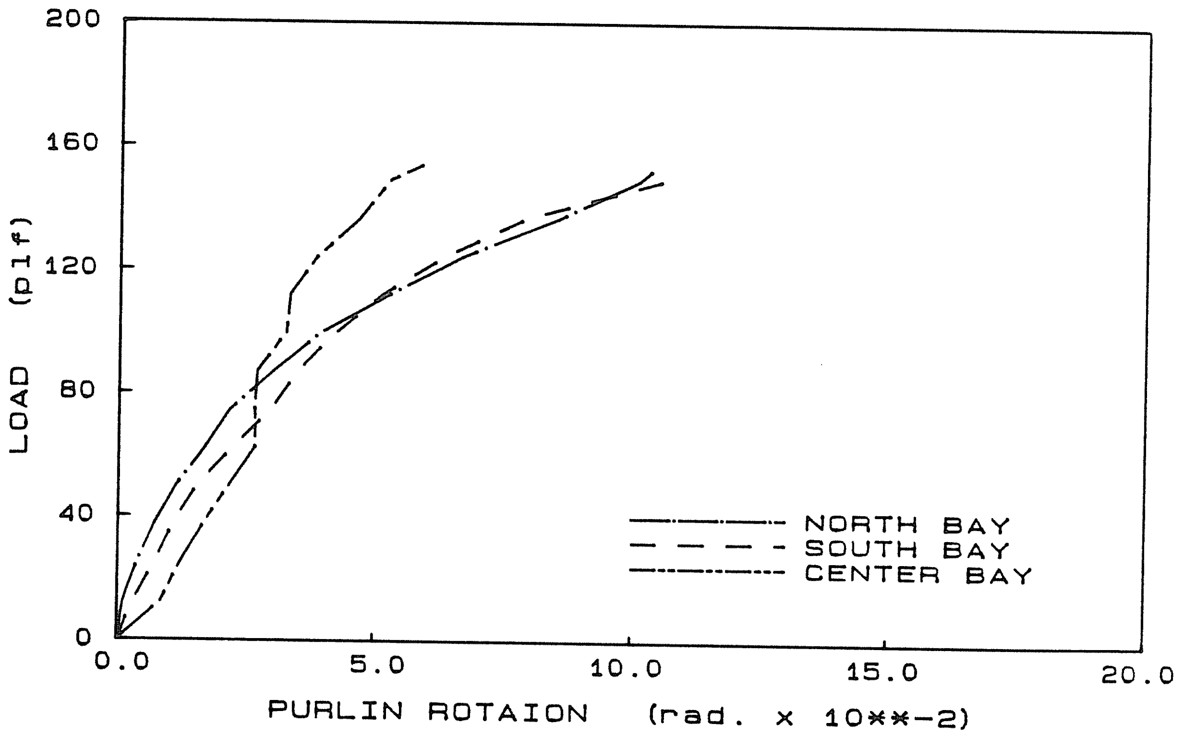


(b) Load vs. Deflection

Figure B.24 Load vs. Purlin Movement, Test P2/2-M-3, Continued



(c) Load vs. Deflection



(d) Load vs. Purlin Rotation

Figure B.24 Load vs. Purlin Movement, Test P2/2-M-3