INVESTIGATION OF INFLECTION POINTS AS BRACE POINTS IN MULTI-SPAN PURLIN ROOF SYSTEMS

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(ABSTRACT)

An experimental and analytical investigation was conducted to evaluate the behavior of inflection points as brace points in multi-span purlin roof systems. Seven tests were conducted using "C" and "Z" purlins attached to standing seam and through fastened panels. These tests were subjected to uniform gravity loading by means of a vacuum chamber. The experimental results were compared with analytical predictions based on the 1996 AISI Specifications with and without the inflection point considered a brace point. Finite element modeling of through fastened "C" and "Z" purlin tests were conducted and compared to experimental through fastened results. Conclusions were drawn on the status of the inflection point and on the design of multi-span purlin roof systems with current AISI Specifications.

Acknowledgements

I would like to express my appreciation to my committee chairman, Dr. Thomas M. Murray. His guidance, advice, and patience over the course of this research was indispensable. I would also like to thank Dr. Samuel Easterling and Dr. Thomas Cousins for serving as committee members.

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I would like to thank the many friends I have made here in Blacksburg. They have helped add many fond memories during my time here. Finally, I would like to thank the people most responsible for my success: my Mom, my Dad, and my Sister. They have given me their full support during my undergraduate and graduate work. Their generosity was more than anyone could possibly ask for.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

Figure Page

LIST OF TABLES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Purlin supported metal roofs have become a very popular choice for commercial buildings. The major reason behind the popularity is the advent of the standing seam system. Standing seam roof systems are aesthetically pleasing and have eliminated much of the leakage problems associated with metal roofs. Conventional through-fastened panel systems are still used in construction but require more maintenance over the life of the building.

The majority of purlin supported roof systems employ the use of multi-span continuous purlins. The purlins may be continuous for only two spans or the purlins may be continuous across each span of the building. Purlins are rolled in many configurations, but the most widely used cross sections are stiffened “Z” and stiffened “C” shapes. These cross sections are shown in Figure 1.1. Continuity across the spans is achieved by lapping the purlins for a distance over each support. Typical lap configurations for Z- and C-purlins are shown in Figure 1.2. When considering simple spans subjected to uniform gravity loads, the entire purlin top flange is in compression and the entire bottom flange is in tension, this condition is called positive bending or positive moment. The top flange is fully braced when through fastened panel is used and partially braced with standing seam systems. When multiple continuous spans are subjected to uniform gravity loads, the conditions change. Regions near each internal

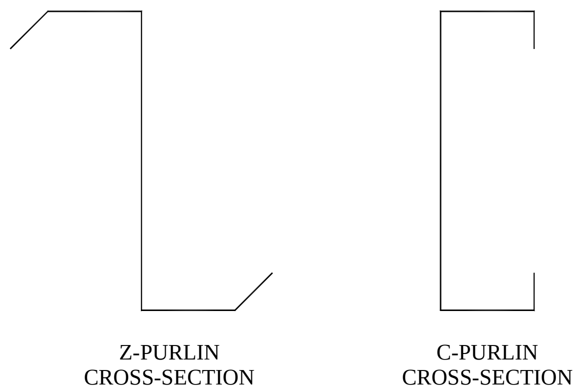

Figure 1.1 Purlin Cross-Sections

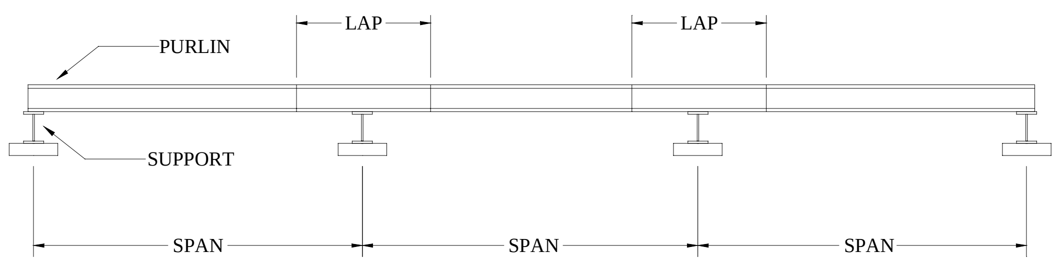

Figure 1.2 Typical Lap Configurations

support experience negative moment. This means that the unsupported purlin bottom flange is in compression between the support and the inflection point, while the top flange that is attached to the decking is in tension. The inflection point on a continuous beam is the point where the moment is zero (moment actually switches from negative to positive at this point). The beam cross-section is subjected to negative moment between the internal support and the inflection point. The cross-section is subjected to positive moment between an inflection point and an exterior support or between inflection points in an internal span. A typical moment diagram is shown in Figure 1.3.

A beam brace point is a location on the beam where the beam's tendency to twist and displace laterally is restrained. Inflection points have been assumed to act as brace points in continuous beams (Salmon and Johnson 1996) and in continuous purlin roof system design for some time (Murray and Elhouar 1994). Purlin supported roof systems are constructed of point-symmetric and singly-symmetric sections with their top flanges partially or fully braced by a sheeting diaphragm. Purlin roof systems are composed of beams that are considered continuous across multiple spans and subjected to uniform loads on all spans. This leads to inflection points that are much closer to the supports than at mid-span. Inflection points acting as brace points have been the subject of much discussion but little research has been conducted.

An experimental and analytical investigation was conducted to evaluate the behavior of inflection points as brace points in multi-span purlin roof systems. Seven tests were conducted using C- and Z-purlins attached to standing seam and through fastened panel. These tests were subjected to uniform gravity loading by means of a vacuum chamber. The experimental results were compared with analytical predictions based on the 1996 AISI specification for the Design of Cold-Formed Steel Structural Members (Specifications 1996), hereafter referred to as the 1996 AISI Specifications, with and without the inflection point considered a brace point.

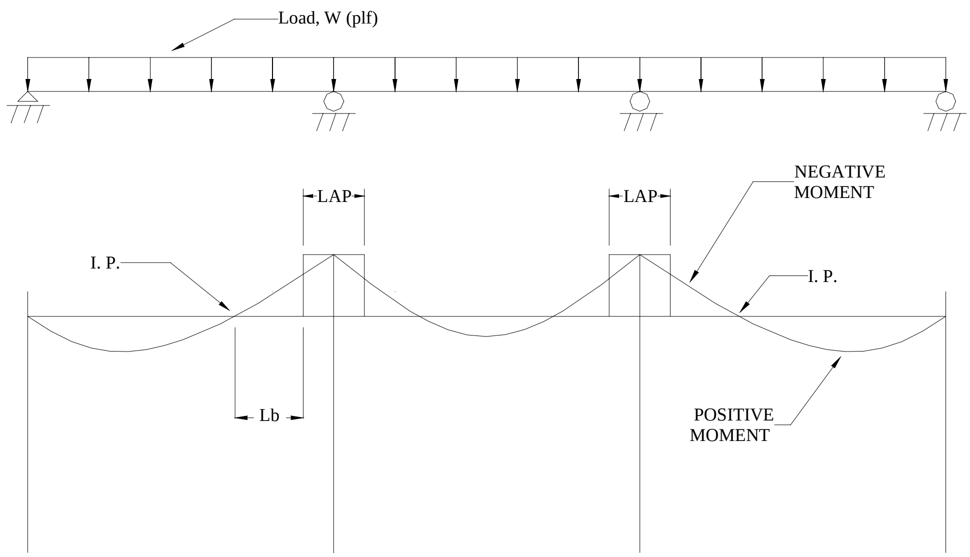

Figure 1.3 Typical Moment Diagram

1.2 Literature Review

Much research has been performed on metal roofs supported by cold-formed purlins. The majority of the most recent research was concerned with determining the strength of standing seam roof systems. Little or no research has been conducted on cold-formed purlin inflection points and their status as brace points. Considerable research has been conducted on doubly symmetric shapes. Some of this research addresses inflection points and brace points. This literature review first covers research findings on hot-rolled doubly symmetric sections, followed by research on cold-formed C- and Z-purlins.

1.2.1 Doubly Symmetric Sections

Beam and stability bracing has been studied by many over the years. Much of the most recent research has been conducted by Professor Joseph Yura at the University of Texas at Austin. Yura presents finite element and experimental results for various beam bracing conditions using hot rolled W-sections (W16X26) with span lengths of 20 ft. (Yura 1991, 1993). Yura concludes that restraining twist is the most critical component of beam bracing. Yura also considers the case of a beam bent in double curvature by subjecting a 20 ft. simple span to equal but opposite end moments as shown in Figure 1.4.

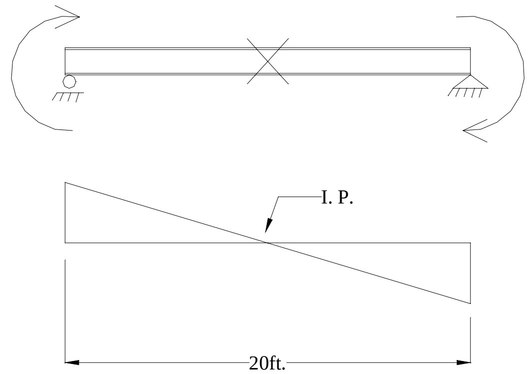

Figure 1.4 Yura Inflection Point Investigation

This causes an inflection point at mid-span and both flanges have portions that are in tension and in compression. Yura concluded that both top and bottom flanges must be braced (twist restrained) to gain more capacity over the unbraced case. If both flanges are braced at the midpoint, buckling moment increases nonlinearly as the brace stiffness increases up to the limit. Yura used a moment gradient factor of 1.75 to predict the critical moments for the W16X26 beam subjected to double curvature. The actual maximum moment was 25% higher than predicted, but brace stiffness must be increased by a factor of 4.3 to achieve the 25% capacity increase. The reason for the additional strength is because tension and compression exist in the same flange and this provides more warping resistance at mid-span. Yura points out that warping restraint isn't usually considered by design equations and this increased capacity should not be considered. Yura compares the double curvature case to a single point load applied at mid-span of an identical beam. The double curvature beam required a brace twice as stiff as the point load case in order to reach the same critical moment. Based on these observations Yura concludes that inflection points are not brace points and notes that bracing requirements at inflection points are greater than the bracing requirements for point loaded beams. Yura bases these conclusions on results from doubly symmetric sections and only considers simple spans with mid-span point loads or end moments.

The Guide to Stability Design Criteria for Metal Structures (Galambos 1998) addresses many topics related to beam buckling and beam bracing. Galambos sates that if a beam cross-section is subjected to a non-uniform moment, then the modifier known as C_b can account for the effect of moment gradient in design equations. Galambos also states that it may be necessary to provide bracing to the compression (bottom) flange in negative moment regions to prevent lateral-torsional buckling.

Johnson (1994) has published multiple papers on composite structures of steel and concrete. Information is provided on continuous beams and composite construction. The work presented is mainly for hot-rolled W sections shear connected to a concrete slab. Johnson states that near internal supports of continuous beams the bottom flange is compressed and the only lateral support for the bottom flange is provided by the flexible web. The concrete slab prevents twisting of the section as a whole. The bottom flange can only buckle if the web bends. This is referred to as distorstional lateral buckling. This type of buckle consists of one half-wave on each side of an internal support. This half-wave usually extends over most of the length of the negative moment region. Johnson states that this half-wave is not sinusoidal and the point of maximum lateral displacement is within two or three beam depths of the internal support. Johnson presents equations based on a U-frame model that can be used to predict critical moments for end span of a continuous beam. These equations apply to homogeneous doubly symmetric beam. The critical moment equations are also dependent on the torsional resistance provided by the concrete slab.

Salmon and Johnson (1996) present a discussion on lateral buckling and continuous beams. Salmon and Johnson state that continuous beams have lateral end restraint moments that develop as a result of continuity over several spans. Some lateral restraint moment may result when adjacent spans are shorter, braced at closer intervals, or less severely loaded than the span considered. This lateral restraint may develop but should not be relied on in design because opposite unbraced spans might buckle in opposite directions eliminating any restraint present.

The inflection point has often been treated as a braced point when design equations did not provide for the effect of moment gradient (Salmon and Johnson 1996). Current ASD and LRFD equations include the moment gradient except for those equations used to determine a compact section (equations for L_c and L_p). Salmon and Johnson state that one may wish to consider the inflection point as a possible braced point when determining L_c or L_p. The present opinion of Salmon and Johnson (1996) is that whenever moment gradient is included in a design equation, the inflection point should not be considered a brace point. However, when moment gradient is not included, in most cases the inflection point may be considered as a braced point. This is possible because of the torsional restraint provided by the floor or roof system attachments and the continuity at the support (point of maximum negative moment). The important factor in this assumption is the amount of torsional restraint provided by the floor system at the inflection point.

1.2.2 Singly- and Point Symmetric Sections

The Guide to Stability Design Criteria for Metal Structures (Galambos 1998) includes a chapter discussing thin-walled metal construction. The chapter does not present principles exclusive to continuous beam design, but several of the important points will be summarized. First, the increased use of cold-formed steel members is reflected by the existence of design specifications in Australia, China, Europe, Japan, and North America. Moment capacity of thin-walled flexural members is governed by one or more of the following: yielding of material, local buckling of compression flange or web, and lateral buckling. It is stated that lateral buckling equations derived for I-beams can be used for channels and other singly symmetric shapes with reasonable accuracy. However, a Z-section with similar ratios will buckle laterally at lower stresses. To account for this the AISI specifications have added a conservative factor of 0.5 to the critical moment equations for Z-sections.

Salmon and Johnson (1996) present a section discussing lateral buckling of channels, zees, monosymmetric I-shaped sections and tees. It is stated that the equations for lateral-torsional buckling of symmetric I-shaped may be applied to channels for design purposes. Both the ASD and LRFD versions of the AISC Specifications have adopted this approach. It should be noted that an unconservative error of about 6 percent may exist in extreme cases when using this approach. Salmon and Johnson (1996) state that Z-sections are subject to unsymmetrical bending because the principle axis does not lie in the plane of loading. This leads to biaxial bending. The effect of biaxial bending on Z-sections was found to reduce the critical buckling moment by 5 to 10 percent. Unbraced Z-sections are rare and AISC does not address them. Salmon and Johnson recommend applying a factor of 0.5 to the critical moment equations for I-sections.

Murray and Elhouar (1994) conducted a study that examined the approach to designing continuous Z- and C-purlins for gravity loading based on the 1986 AISI cold-formed steel specifications. The paper begins by examining the assumptions commonly used when designing through fastened purlin roof systems. First constrained bending is assumed, this means that the purlin top flange is not free to rotate because it is directly fastened to sheeting. Purlins are lapped for a certain distance over the supports and the lapped portion is assumed to be fully continuous across the entire lap. The lapped region is assumed to have section properties and strengths equal to the sum of the section properties and strengths of the purlins that make up that lap. The region between the support and the end of the lap is assumed fully braced. The inflection point is considered a braced point. This is accounted for in design by considering the unbraced length for the negative moment region as the distance between the inflection point and the end of the lap. A moment gradient coefficient (C_b) is also incorporated into the moment capacity equations. Usually C_b is taken as 1.75.

Murray and Elhouar collected data on multi-span continuous through fastened purlin tests subjected to gravity loading. These tests were conducted at various testing facilities. Each test was analyzed using the 1986 AISI Specifications and the assumptions previously mentioned to determine a predicted failure load without applying the ASD factors of safety. These values were then compared to the actual experimental failure loads. It was concluded that the assumptions as well as the 1986 AISI specifications were adequate for design. However, it should be noted that several of the tests studied had experimental failure loads that were lower than the predicted values (unconservative predicted failure loads).

Willis and Wallace (1991) presented a paper on the behavior of cold-formed steel purlins under gravity loading in 1991. Their study dealt with two aspects of Z- and C-purlin construction. The first aspect was the effect of fastener location on purlin capacity. The second aspect dealt with the width of compression flange lip stiffeners. This study reported analytical and experimental results on several single and three span tests. Willis and Wallace used two purlin lines spaced 5 ft. on center for each test. The purlins used were oriented with their top flanges opposed. The panel used in all tests was a standard through fastened panel that was attached to the purlin top flange with self-tapping screws with rubber washers. The only bracing applied to the bottom flange was at the supports where the cross-section was attached to anti-roll clips. The parameter that was intentionally varied was fastener location on the purlin top flange.

The Willis and Wallace study presents predicted ultimate loads that were obtained by applying the provisions of the 1986 AISI Specifications to obtain an ASD allowable load and multiplying that value by 1.67 to remove the ASD factor of safety. The vertical deflection of each test is reported for a load that corresponds to the ASD allowable load. The other parameter that is reported is lateral movement or spread of the purlin bottom flange at the ASD allowable load. Spread and vertical deflection were both measured at the point of maximum vertical deflection for the corresponding test. Finally the predicted failure load is compared with the experimental failure load. The study concluded that Z-purlins were not noticeably affected by fastener location, but C-purlin capacity could be effected by as much as 10% by fastener location. The optimum fastener locations for C-purlins in near the stiffener lip. It is important to note that in this study, the capacities predicted by the 1986 AISI specification were near the experimental failure loads.

Epstein, et al (1998) presented a study on the design and analysis assumptions for continuous cold-formed purlins. This report questions the validity of considering the entire lapped region as laterally braced. This study also questions the use of the inflection point as a braced point for determining the unbraced length for the negative moment region. This study stresses that appropriate experimental testing is needed to verify or deny the assumptions used in continuous purlin design and that the suggestions presented by the authors should be verified experimentally. The only experimental research referenced by Epstein, et al was a study conducted by Murray and Elhouar (1994). Epstein, et al suggest that the Murray and Elhouar study did not support or verify the 1986 AISI Specifications.

1.3 Scope of Research

One of the most important aspects of multi-span purlin roof system design is the unbraced length of the compression flange in the negative moment region. The 1986 AISI Specifications considers the inflection point as a brace point, therefore the unbraced length would be the distance between the end of the lap (which is considered braced) and the inflection point. A moment gradient coefficient (C_b) is also used in this procedure and incorporated into the lateral buckling equations. The 1996 AISI Specifications and the AISI Guide for Designing with Standing Seam Roof Panels (Fisher and La Boube 1997), hereafter referred to as the AISI Guide, recommend that the unbraced length still be considered the distance between the end of the lap and the inflection point but the inflection point is not considered braced and C_b is taken as 1.0.

The primary purpose of this research is to evaluate the accuracy of assuming the inflection point as a brace point when using current AISI specification procedures to predict the failure load of multiple span, multiple purlin line Z- and C-purlin supported through fastened and standing seam roof systems. Experimental testing was conducted involving multiple span Z- and C-purlins attached to standing seam and through fastened panel. Limited finite element modeling was performed and compared to the experimental results.

1.4 Overview

Chapter II describes in detail the parameters of the experimental testing program. Purlin types and configurations as well as the types of panel and fasteners are discussed. Testing locations and measured parameters are also discussed.

Chapter III presents all of the experimental results. Important observations are discussed.

Chapter IV covers the finite element results. A simple model for both Z- and C-purlins is discussed. Results for a particular loading and boundary conditions are examined and compared to applicable experimental testing, as will be stresses at critical sections.

Chapter V compares experimental results with the finite element modeling discussed in Chapter IV. Next, experimental results were evaluated using three different methods. The first approach is to assume the inflection point is not a brace point and predict a failure load based on those assumptions from the 1996 AISI Specifications. The second approach assumes the inflection point as a brace point and predicts failure loads based on this assumption. The third approach assumes a fully braced cross-section.

Chapter VI presents conclusions based on all the information considered in this research. Recommendations are made concerning design procedures and possible further research. Appendices that contain summaries of all test data follow Chapter VI.

CHAPTER II

TEST DETAILS

2.1 Experimental Test Program

A series of seven tests were conducted. The first four tests were three span tests, whereas the last three were two span tests. The purpose was to determine if an inflection point is a brace point. Test components, procedures, and results are presented in the following sections.

The test designations for these experiments are identified as “Test # X-YY”. Where “#” notes the chronological order of the test, and X could be “Z” for a Z-purlin or “C” for a C-purlin. The YY is used to denote the type of decking used, TF for through fastened panel or SS for standing seam panel. Tests 1 to 4 were conducted at Virginia Tech and I. P. Tests 1, 2, and 3 were conducted at Ceco Building Systems, Columbus, Mississippi.

2.2 Components of the Test Assemblies

Manufacturers belonging to the Metal Building Manufactures Association (MBMA) supplied components used in the testing program. All standing seam tests used the same pan type panel and clips. Both three span through fastened tests used the same through fastened panel, whereas the two span test used a different through fastened panel. Table 2.1 shows the different test configurations used.

Purlins. Both Z– and C–purlins were used in the tests. Actual properties such as depth, thickness, flange and stiffener length varied with each test. Measured purlin dimensions can be found in Appendix A through Appendix G. Tensile coupon tests were conducted from material taken from the web of representative purlins for each test.

Table 2.1 Test Matrix

Test Designation	Purlin Type	Depth (in.)	Panel Type	Spans (ft.)	Purlin Orientation
Test 1 Z-TF	Z	8	Through Fastened	2 @ 25, 1 @ 23	Opposed
Test 2 Z-SS	Z	10	Standing Seam	2 @ 25, 1 @ 23	Opposed
Test 3 C-SS	C	10	Standing Seam	1 @ 24.5 1 @ 25 1 @ 23	Opposed
Test 4 C-TF	C	8	Through Fastened	1 @ 24.5 1 @ 25 1 @ 23	Opposed
I. P. Test 1 Z-SS	Z	8.5	Standing Seam	2 @ 30	Opposed
I. P. Test 2 Z-SS	Z	8.5	Standing Seam	2 @ 30	Opposed
I. P. Test 3 Z-TF	Z	8.5	Through Fastened	2 @ 30	Opposed

Panels. The panels used in the tests were of three basic configurations. The first is a standard through fastened panel shown in Figure 2.1. The second configuration is a standing seam pan type panel with sliding clips shown in Figure 2.2. Finally the third configuration uses the standing seam panel as a through-fastened panel with screws located near each seam or rib.

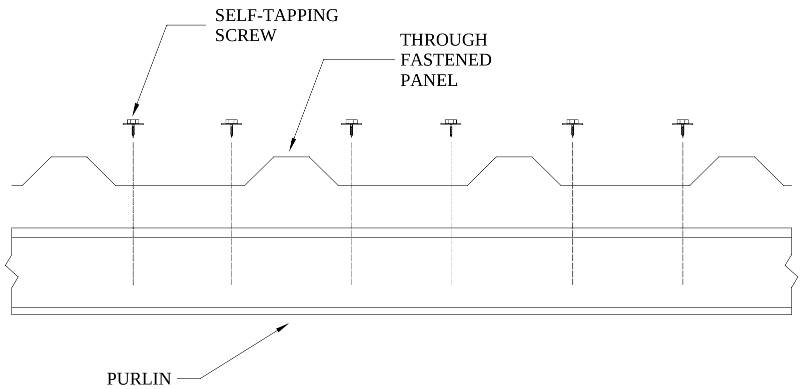

Figure 2.1 Through Fastened Panel

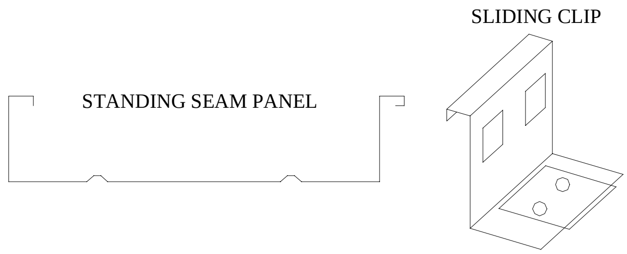

Figure 2.2 Standing Seam Panel and Sliding clip

Standing Seam Panel Clips. The standing seam clips used in testing were called "high clips". These clips required a Styrofoam block be used between the pan type panel and the purlin top flange. The clips were attached to the purlin top flange using standard self-tapping screws supplied by the metal building manufacturer.

Bracing. The rafters were the only location were bracing was provided. For the tests using Z-purlins, anti-roll clips were placed at each rafter support for both purlin lines. The bottom flanges of the purlins were also directly bolted to the rafters. For tests using C-purlins, anti-roll clips were placed only at the exterior support rafters. The bottom flanges of the purlins were also bolted directly to the rafters.

Tests I. P. Test 1, 2, and, 3 used anti-roll clips at each rafter support for both purlin lines. Test I. P. Test 2 Z-SS also had a brace attached between the purlin lines. The brace was attached at the theoretical inflection point.

2.3 Test Setups

All tests were subjected to gravity loading. The gravity load was simulated with the use of a vacuum chamber. The vacuum chamber provides an airtight space around the test setup. Air is pumped out of the chamber with one or more vacuum pumps. This causes a negative differential pressure in the chamber. In essence the surrounding atmospheric pressure loads the test specimens.

Tests were conducted in two locations, at the Virginia Tech Structures and Materials Research Laboratory, and at the Ceco Building Systems Research Laboratory in Columbus, Mississippi. The Virginia Tech vacuum chamber consisted of a box 8ft. x 78 ft. x 3 ft. The chamber is constructed from 3 ft. x 8 ft. galvanized steel panels. The joints between panels and between the panel and floor are sealed with caulk. Bulkhead panels can be inserted in the chamber to shorten the chamber when the entire length is not required. A plan view of the Virginia Tech vacuum chamber is shown in Figure 2.3.

The Ceco Building Systems chamber consisted of a box 10.58 ft. x 92 ft. x 3.83 ft. The Ceco chamber is constructed from two built-up I-sections stacked on each other and welded into place. The I-sections are sealed to the floor with caulk. Bulkhead panels can be inserted into the chamber to shorten the chamber to the required length. The Ceco chamber uses two additional purlin lines to reduce the width of the chamber to 8.5 ft. as shown in Figure 2.4 through Figure 2.6.

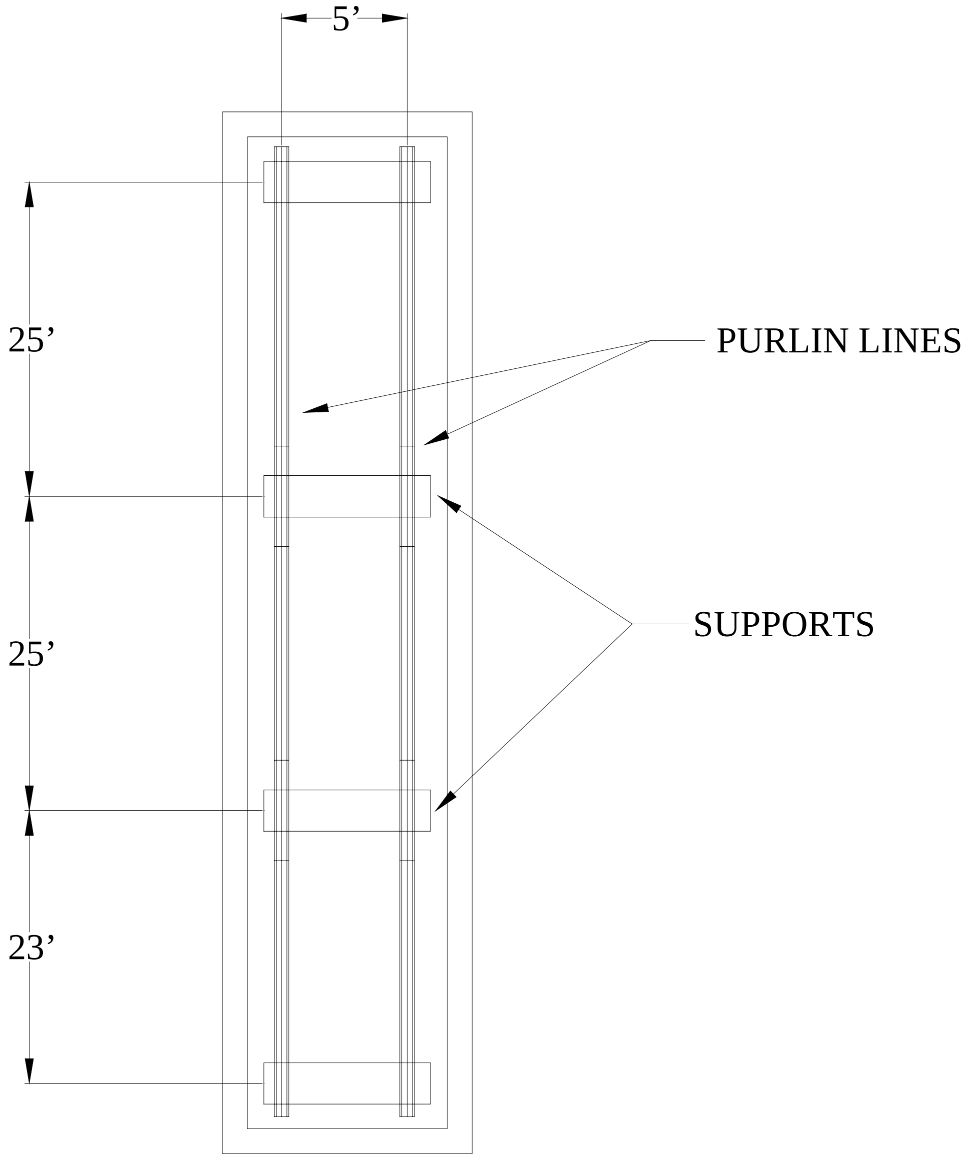

Figure 2.3 Virginia Tech Vacuum Chamber

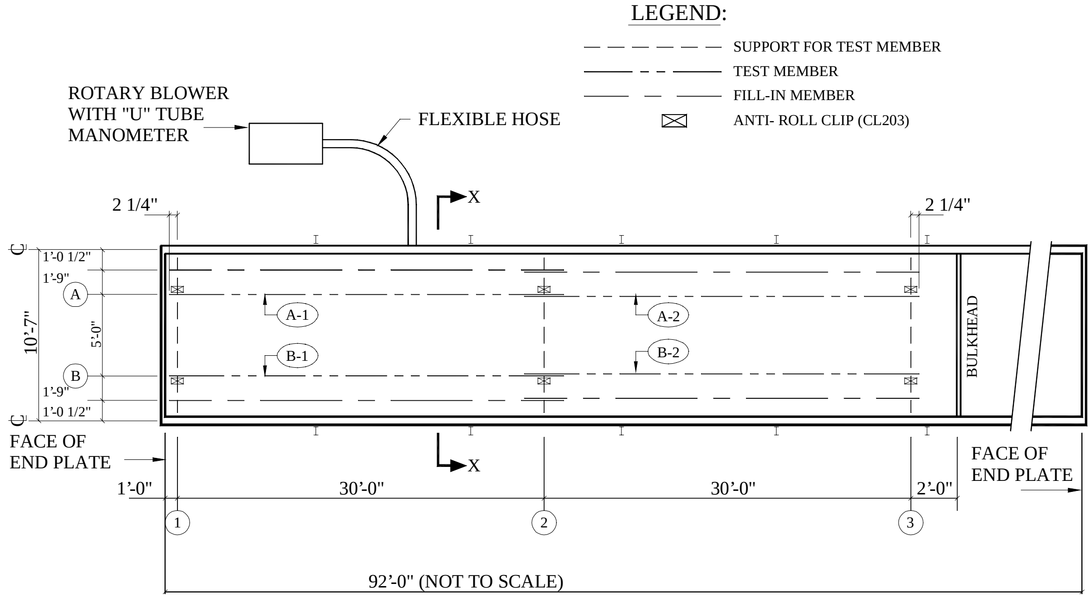

Figure 2.4 Ceco Vacuum Chamber

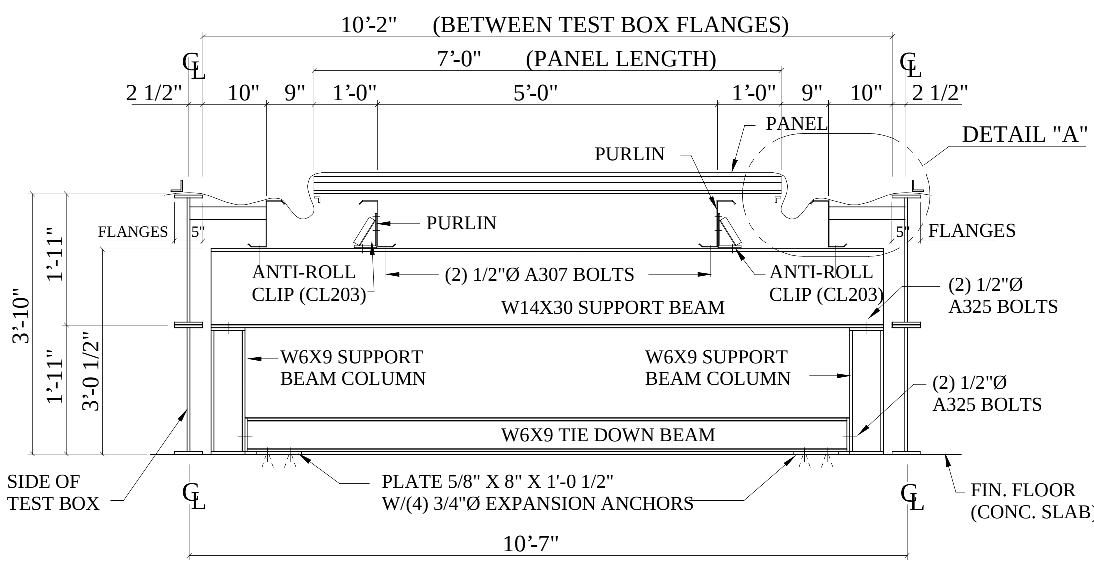

Figure 2.5 Ceco Chamber Cross-Section

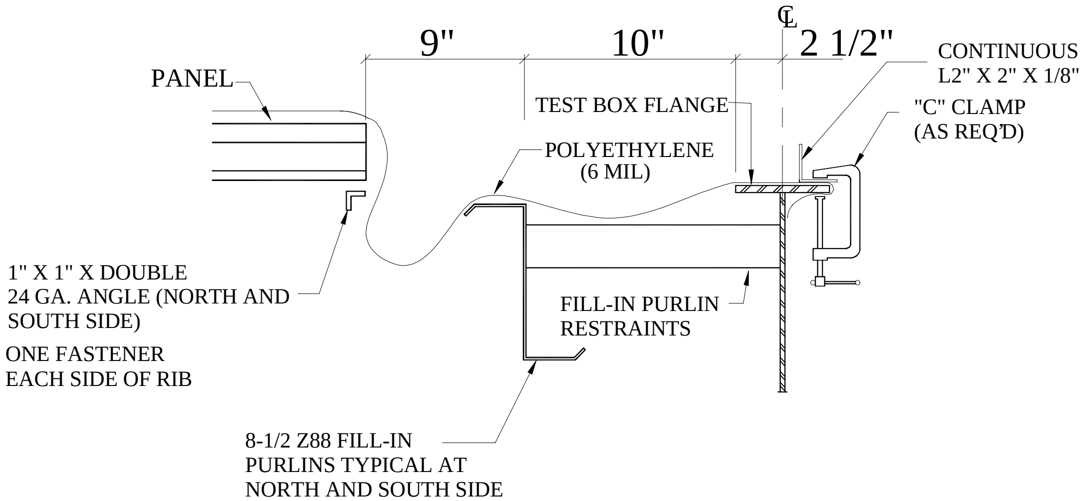

Figure 2.6 Ceco Chamber Edge Detail “A”

The configuration to be tested was then constructed inside the chamber. The top of the chamber was sealed with a sheet of polyethylene (6 mil thick). At Virginia Tech the air was removed from the chamber using a main vacuum pump and four auxiliary “shop-type” vacuum pumps. The Ceco tests used only one main vacuum pump to remove air from the chamber.

All tests consisted of two purlin lines spaced 5 ft. on center. The purlin flanges were facing in the opposite direction for all tests. The panel used for all testing was 7 ft. wide. This allowed for a 1-ft. overhang from the centerline of the web of each purlin. All standing seam tests used sliding clips that were attached to the purlin with self-drilling screws. The through-fastened panel was attached directly to the purlin with self-drilling screws.

The three span tests had varying parameters. The tests with Z-purlins had the span lengths of 25 ft., 25 ft., and 23 ft. The test bay with all instrumentation had a span length of 25 ft. while the opposite exterior bay was shortened to 23 ft. Lap splices at each interior support for the three span Z-purlin tests extended 1 ft. over each side of the support for a total lap length of 2 ft. The tests with C-purlins had a test span of 24.5 ft., a middle bay with a span of 25 ft., and an end span of 23 ft. This was done to help ensure that failure occurred in the test bay. The lap splices at each interior support for the three span C-purlin tests extended 1 ft. in the direction of the exterior support and 2 ft. into the middle bay for a total lap length of 3 ft.

Three two span tests were conducted. All span lengths were 30 ft. All two span tests used 8.5 in. deep Z-purlins. Two of the tests were conducted using standing seam panel, while the third used a through-fastened panel. The lap splice at the interior support of the two span tests extended 1.5 ft. beyond each support for a total lap length of 3 ft. Details of the test parameters are given in Table 2.2 and in Figure 2.7 through Figure 2.9.

Data was collected electronically at Virginia Tech for the three span tests using a personal computer based data acquisition system. The two span tests that were conducted at Ceco Building Systems used manual data collection.

The gravity loadings for tests at both locations were measured using U-tube manometers. The manometers have an accuracy of 0.1 in. of water. One inch of water is equivalent to about 5.2 psf.

Vertical displacement transducers were used at Virginia Tech to measure maximum vertical deflections in the test bay. Vertical deflection was measured at Ceco building systems using a surveyor's level to read a scale that was placed over the theoretical point of maximum deflection. Measurements were taken for both purlins in the test bay of each test. No Measurements were taken in non-test bays.

Lateral displacement of the test bay was measured for the three span standing seam tests. A vertical displacement transducer was used with a pulley system that allows the actual lateral movement to be calculated. This value was small because of the opposite orientation of the purlins.

Spread of the test purlins was measured using potentiometers. Spread refers to the roll or lateral displacement measured approximately two inches above the purlin bottom flange with respect to the purlin top flange. The potentiometers were placed at the location of maximum moment and 1 ft. away from the calculated inflection point on both sides. The potentiometers were suspended from cold-formed angles that span across the purlin lines in such a manner that they did not provided any additional bracing between the purlin lines as shown in Figure 2.10 and Figure 2.11. The potentiometers measured the spread of the purlin at about two inches above the purlin bottom flange.

Finally, tests conducted at Virginia Tech had strain gages placed on the top and bottom surface of the purlin bottom flange. This was done to find the location of the true inflection point. Ten gages were placed on each test purlin. They were located at the calculated inflection point, and 6 in., and 12 in. on each side of the calculated inflection point. The location of the inflection point was calculated using a non-prismatic stiffness analysis. Figure 2.12 and Figure 2.13 show typical strain gage locations.

Table 2.2 Test Details

TEST #	PURLIN TYPE	SPANS	TOTAL LAP	LAP LENGTH INTO TEST BAY	PANEL TYPE
Test 1 Z-TF	8 in. Z	Test Bay: 25 ft. Middle Bay: 25 ft. End Bay: 23 ft.	2 ft.	1 ft.	Through Fastened
Test 2 Z-SS	10 in. Z	Test Bay: 25 ft. Middle Bay: 25 ft. End Bay: 23 ft.	2 ft.	1 ft.	Standing Seam
Test 3 C-SS	10 in. C	Test Bay: 24.5 ft. Middle Bay: 25 ft. End Bay: 23 ft.	3 ft.	1 ft.	Standing Seam
Test 4 C-TF	8 in. C	Test Bay: 24.5 ft. Middle Bay: 25 ft. End Bay: 23 ft.	3 ft.	1 ft.	Through Fastened
I. P. Test 1 Z-SS	8.5 in. Z	Test Bay: 30 ft. End Bay: 30 ft.	3 ft.	1.5 ft.	Standing Seam
I. P. Test 2 Z-SS	8.5 in. Z	Test Bay: 30 ft. End Bay: 30 ft.	3 ft.	1.5 ft.	Standing Seam
I. P. Test 3 Z-TF	8.5 in. Z	Test Bay: 30 ft. End Bay: 30 ft.	3 ft.	1.5 ft.	Through Fastened

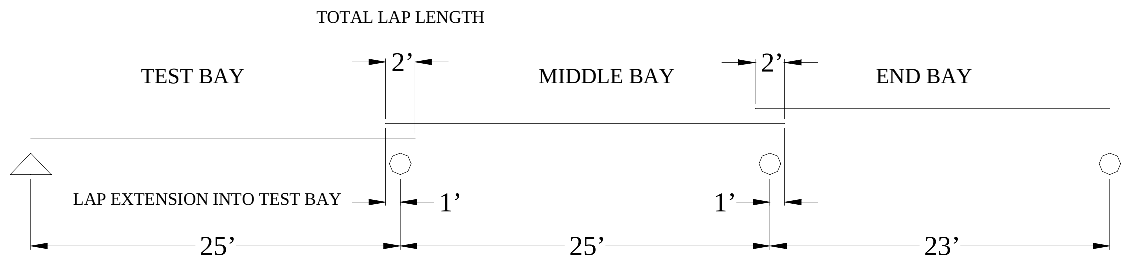

Figure 2.7 Test 1 Z–TF & Test 2 Z–SS

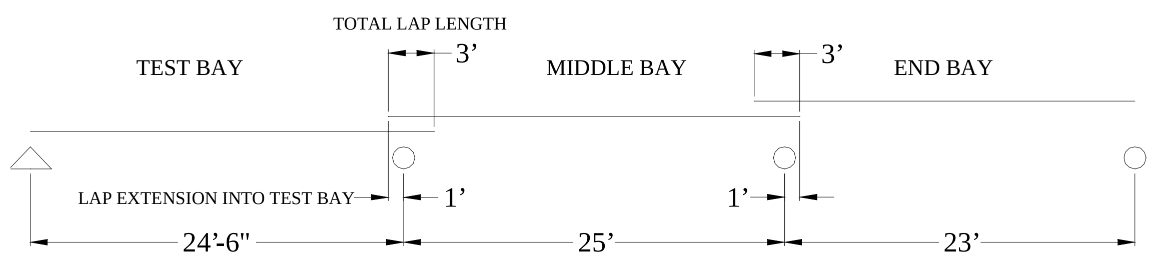

Figure 2.8 Test 3 C–SS & Test 4 C–TF

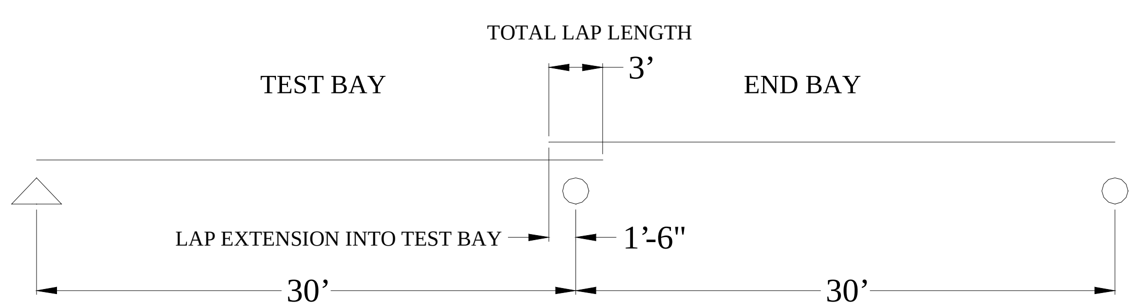

Figure 2.9 I. P. Test 1, 2, and 3

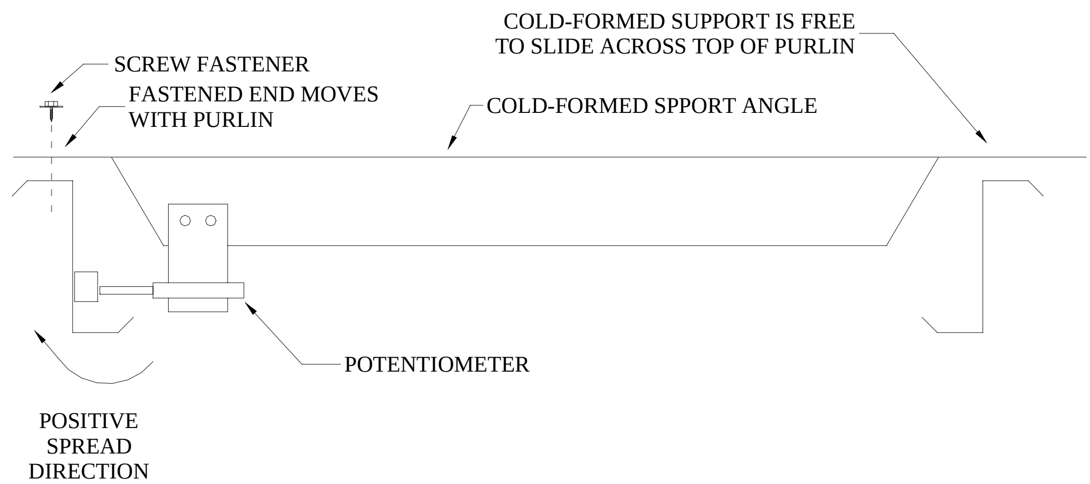

Figure 2.10 Potentiometer Support Configuration

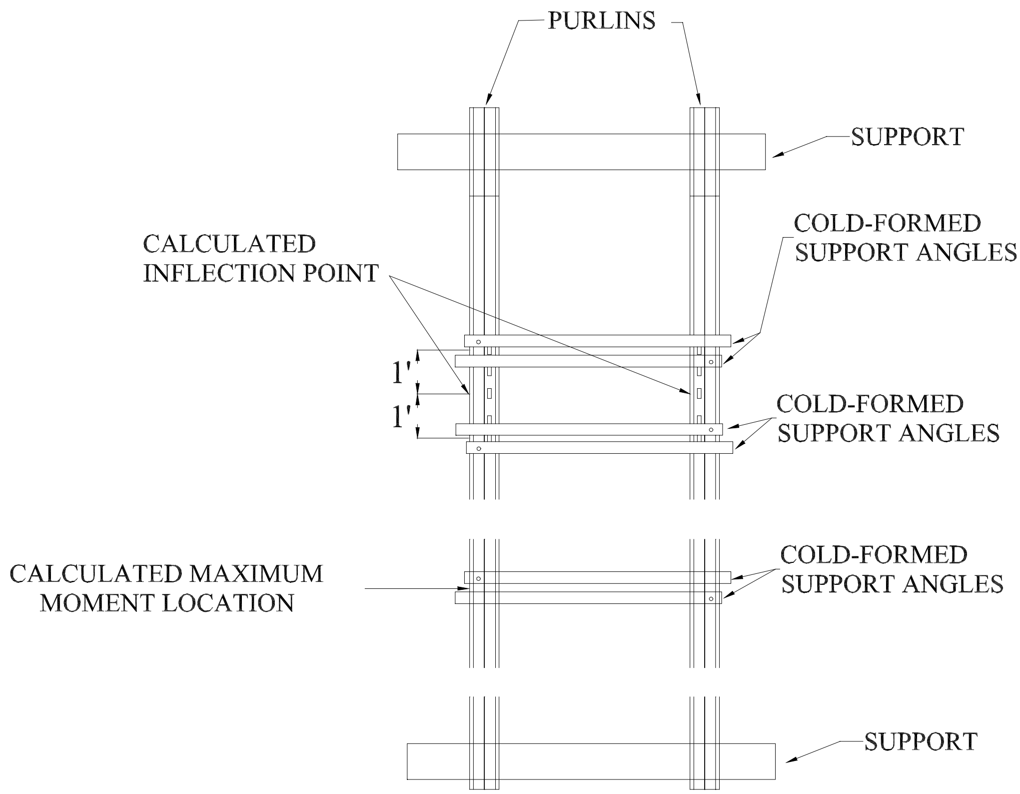

Figure 2.11 Spread Potentiometer Support Locations in Test Bay

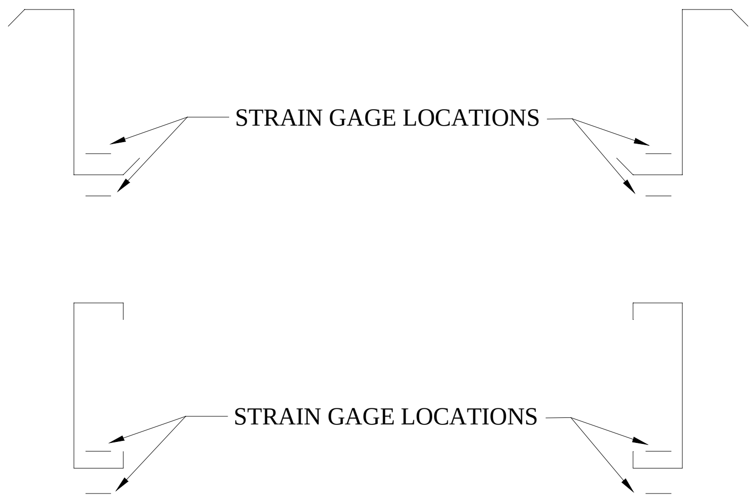

Figure 2.12 Z- and C-Purlin Strain Gage Locations

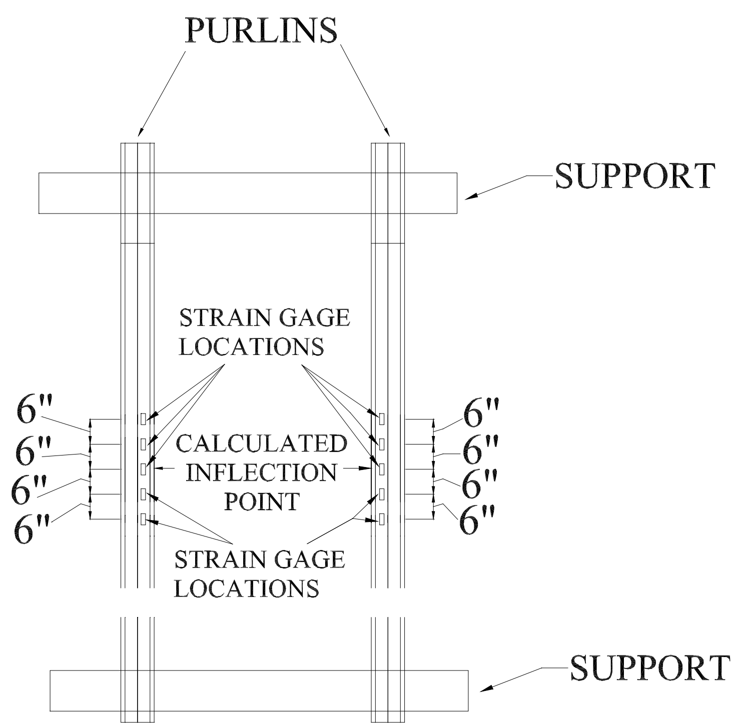

Figure 2.13 Strain Gage Locations in Test Bay

CHAPTER III

EXPERIMENTAL RESULTS

3.1 General Comments

Individual results for each test are found in Appendices A through G. Each set of results includes a test summary sheet, measured purlin dimensions, section properties, flexural strength, purlin arrangement within each test, tensile coupon results, and results from a stiffness analysis. Each test appendix also includes individual data, plots of load versus deflection, load versus strain, load versus purlin spread, and flexural strength based on the assumption that the inflection point is a brace point and based on the assumption that the inflection point is not a brace point.

A commercial software program was used to perform a non-prismatic stiffness analysis of the each test configuration. A non-prismatic analysis is needed because of the overlap of the purlins. The lapped region is stiffer and therefore attracts more moment. The models were built with actual section properties and loaded with a uniform load of 100 pounds per foot. Moments and shears from critical locations were then recorded for this loading, and were later scaled for other loadings. The stiffness models were also used to calculate locations of maximum moment, maximum deflection, and to calculate the location of the inflection point about which measurements were made.

3.2 Tensile Test Results

At least one standard ASTM coupon was cut and machined from the undamaged web of a failed purlin from each test. The coupons were then tested according to ASTM loading procedures; where more than one coupon was tested, average values are reported. A summary of tensile test results is in Table 3.1.

Table 3.1 Summary of Tensile Test Results

Identification	Thickness (in.)	Width (in.)	Yield Stress (ksi)	Tensile Strength (ksi)	Elongation %
Test 1 Z-TF	0.104	1.504	55.5	76.7	37
Test 2 Z-SS	0.076	1.501	50.0	76.5	22
Test 3 C-SS	0.078	1.506	87.7	101.6	10
Test 4 C-TF	0.079	1.506	75.2	88.7	15
I.P. Test 1 Z-SS	0.077	1.502	69.5	78.3	20
I.P. Test 2 Z-SS	0.078	1.501	69.5	78.2	21
I.P. Test 3 Z-TF	0.077	2.050	69.5		

3.3 Summary of Testing Results

A summary of the failure loads and failure locations is given in Table 3.2. Two types of failure were observed in these tests. First was inelastic and local buckling near the face of the lap in the negative moment region of the test bay. The second type was local buckling of the compression flange, stiffener, and web near the location of maximum positive moment in the test bay. The failure load shown in Table 3.2 is the applied load in pounds per linear foot; the self-weight of the system was added later for analysis and comparison purposes.

TABLE 3.2 Summary of Failure Loads and Locations

Identification	Number of Spans	Applied Load at Failure (plf)	Failure Location
Test 1 Z-TF	3	320.8	Negative Region*
Test 2 Z-SS	3	142.4	Positive Region
Test 3 C-SS	3	219.0	Positive Region
Test 4 C-TF	3	280.3	Negative Region*
I. P. Test 1 Z-SS	2	104.8	Positive Region
I. P. Test 2 Z-SS	2	102.8	Positive Region
I. P. Test 3 Z-TF	2	161.2	Negative Region*

***** Local buckling immediately outside of the lapped portion of the purlin in the exterior span.

As shown in Figure 3.1, the strain gage at position 8 is located at the calculated inflection point, Figure 3.2 shows that the strain at this location remains very low throughout the test demonstrating that the method used to calculate the inflection point is adequate. Figure 3.2 is typical for all tests that were strain gaged. Other plots of load versus strain can be found in the appendices.

Figure 3.3 again shows the potentiometer locations for measuring purlin spread. Spread was measured at 1 ft. inside the calculated inflection point (negative moment region) and 1 ft. outside the inflection point (positive moment region). The spread was also measured at the location of maximum moment for all tests except Test 1 Z-TF. Figure 3.4 shows a plot of load versus spread for a typical through-fastened Z-purlin test. Figure 3.5 shows typical spread of a standing seam Z-purlin test. Figure 3.6 shows the typical behavior of a through-fastened C-purlin test and Figure 3.7 shows a typical standing seam C-purlin test.

It was expected that very little movement would occur at an inflection point. It was hypothesized that out-of-plane double curvature might be exhibited near the inflection point, especially in the Z-purlin tests. The major reason for expecting this behavior was because of the conditions at the inflection point and the properties of the purlin cross-section. Negative moment is present between the interior support and the inflection point, while positive moment is present between the inflection point and the exterior support. The principle axis of a Z cross-section is inclined to the plane of loading This would seem to lead to the section wanting to rotate in one direction on one

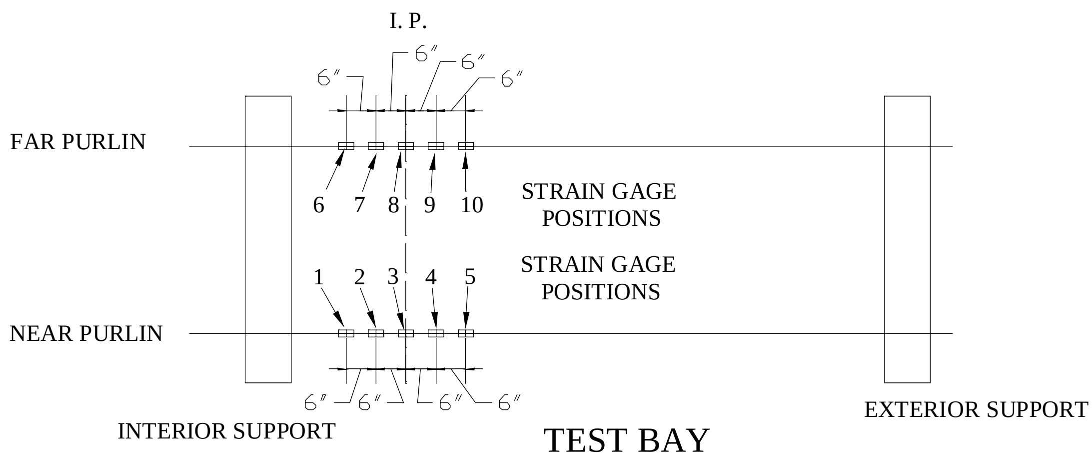

Figure 3.1 Strain Gage Locations

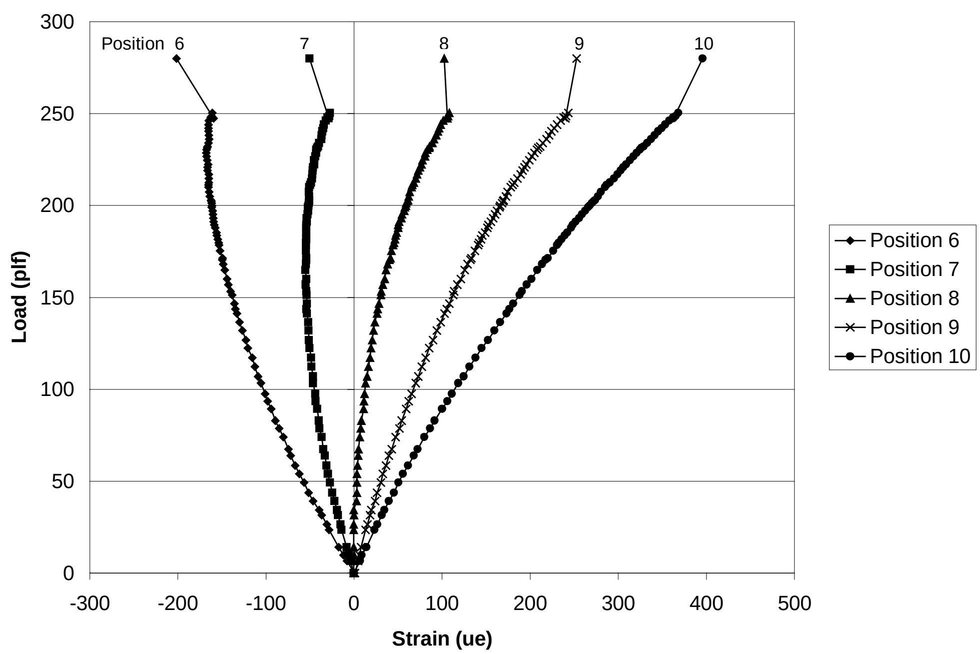

Figure 3.2 Load vs. Strain Far Purlin Line

side of the inflection point and another direction on the other side of the inflection point. The actual behavior was somewhat different.

As shown in the figures of this chapter and in the appendices, the inflection point did not remain stationary in any test conducted. In general, the inflection point rolled inward for the tests using Z-purlins and outward for tests using C-purlins. The values of spread were small in all cases compared to the spread at maximum moment. It should be noted that the spreads of the Z-purlins were much less that the C-purlin spread. Test data and plots for each test can be found in appendices A through G.

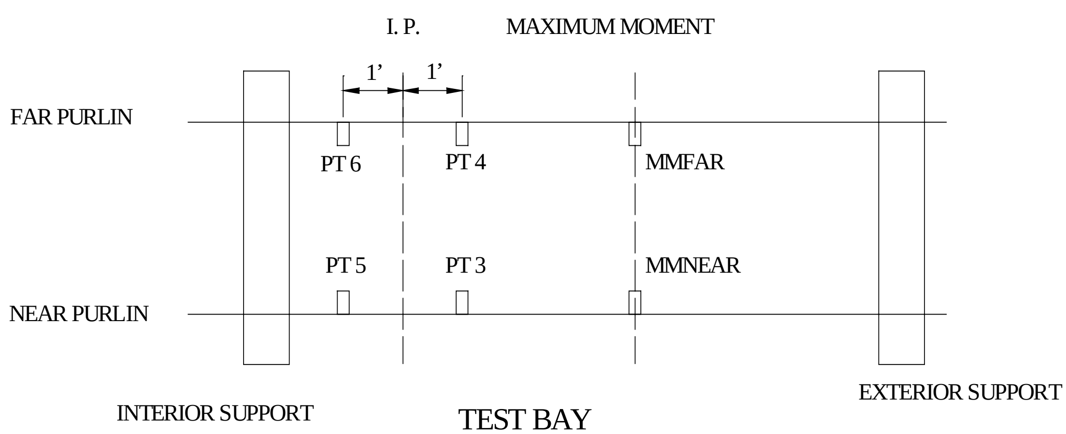

Figure 3.3 Potentiometer Locations

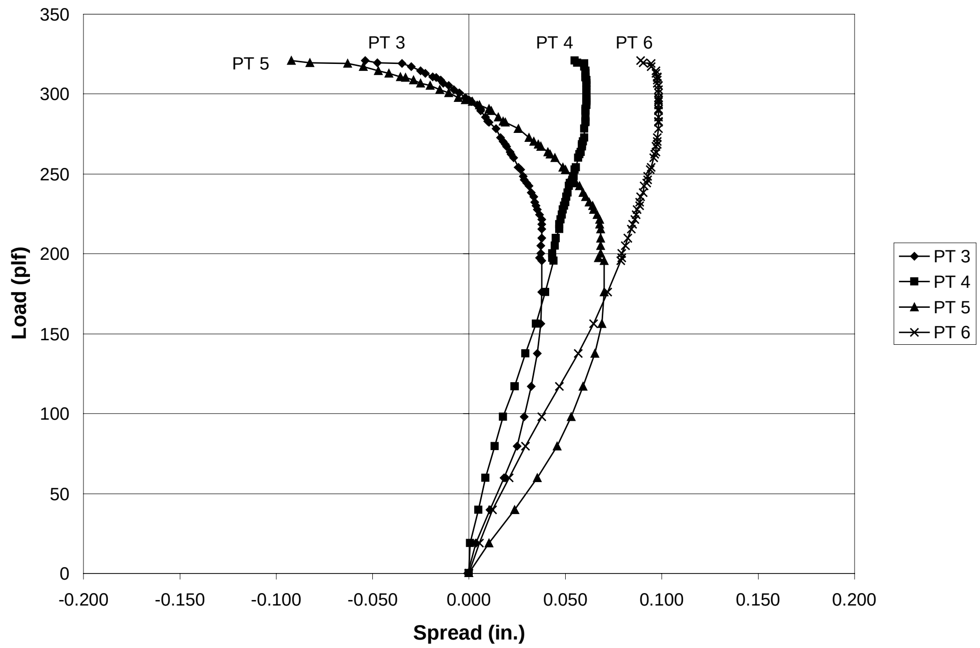

Figure 3.4 Z-TF Load vs. Spread

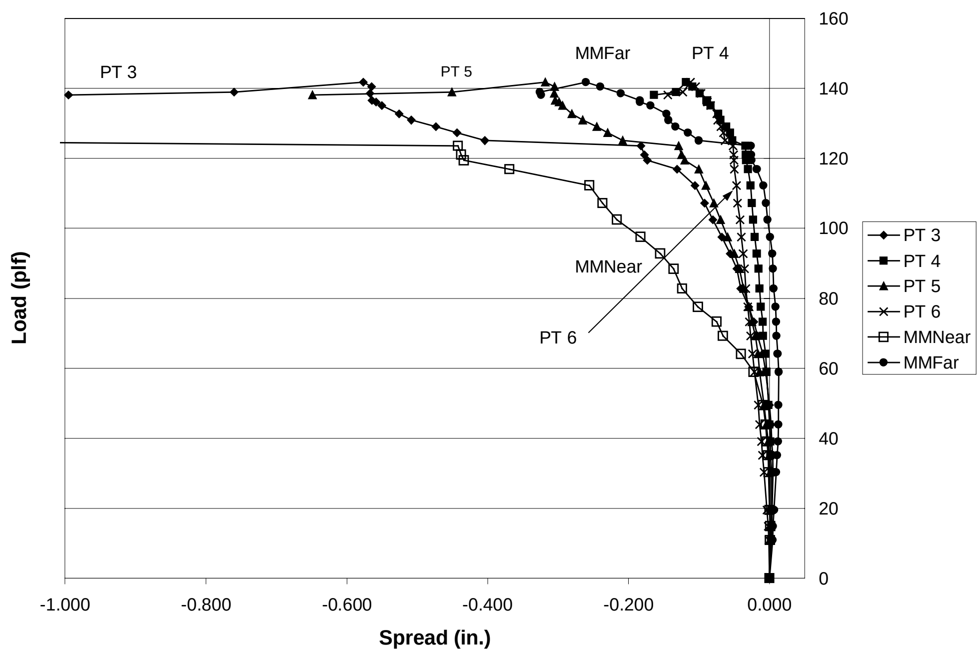

Figure 3.5 Z–SS Load vs. Spread

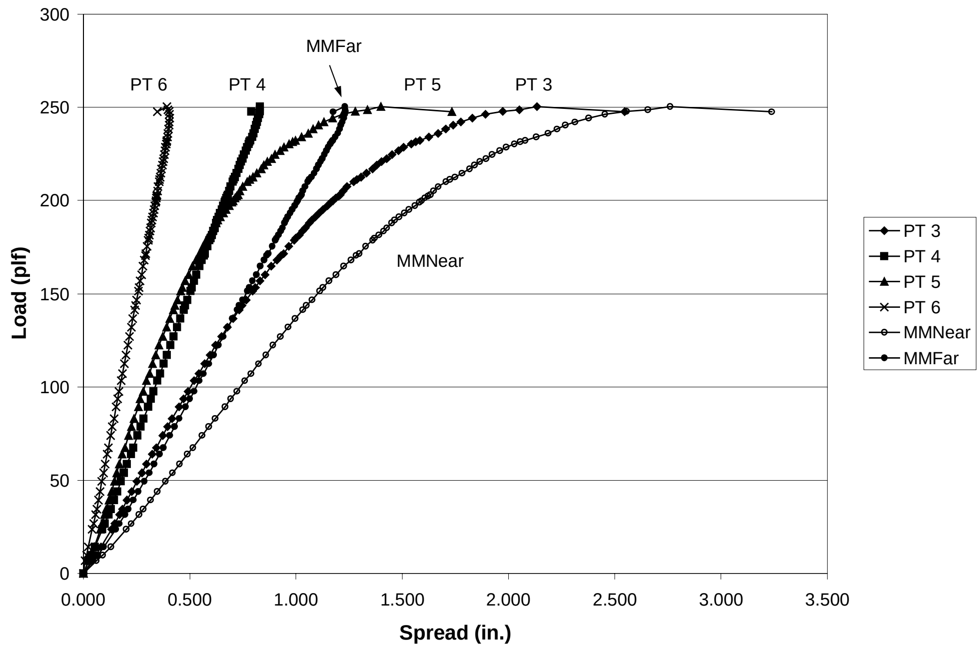

Figure 3.6 C–TF Load vs. Spread

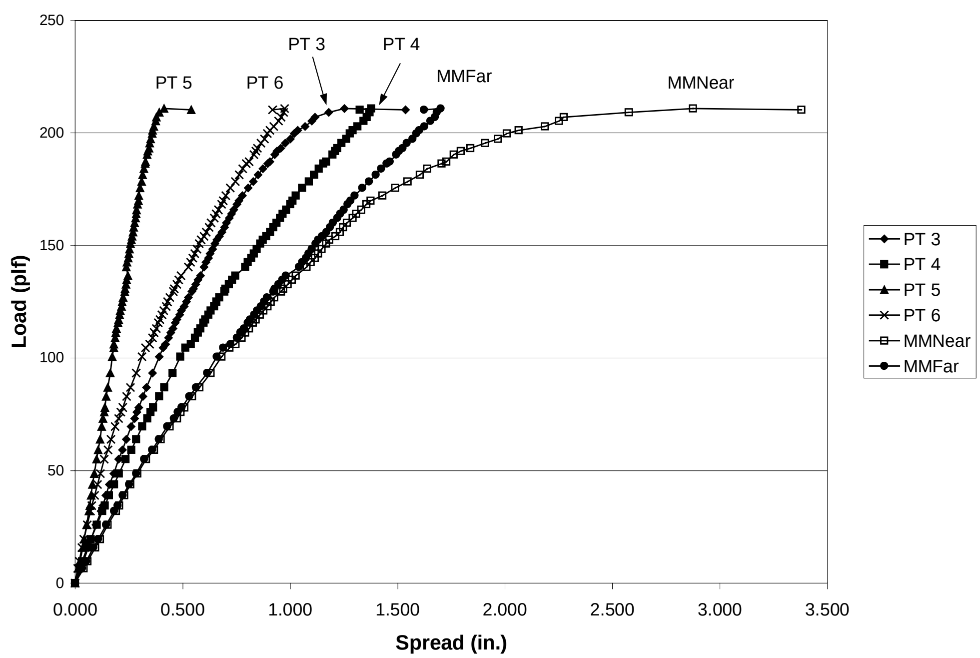

Figure 3.7 C–SS Load vs. Spread

CHAPTER IV

ANALYTICAL RESULTS

4.1 Background

Analytical studies were made of Z- and C-purlins lines using the finite element method. The purpose of the modeling was to determine if the experimental behavior of the purlin cross-section could be adequately modeled using simple procedures, therefore, the modeling is restricted to through fastened panel. It is possible to model the conditions of standing seam panel, but the uncertainty in the boundary conditions present at the panel/clip/purlin interface are beyond the scope of this research.

Finite element modeling was done using the commercial finite element program Ansys 5.4 (Ansys 1996). The program has complete three-dimensional capabilities and is capable of modeling much more complex problems than required by this study. All modeling used four node shell elements with six degrees of freedom at each node. The shell elements were capable of transmitting flexural forces. These elements basically behaved like actual plates. These elements were chosen because of their ability to model three-dimensional behavior as well as their ability to properly model the large aspect ratios needed with modeling purlin lines. The aspect ratio is large because typical purlin cross-sections have depths of 8 to 10 in., flanges that are 2 to 4 in. wide with a thickness of 0.1 in. or less. The length of the purlin may be 20 to 40 ft. Certain types of elements require aspect ratios that leave the elements nearly square, this would required 2 to 3 times more elements than with the shell elements.

4.2 Z-Purlin Model

The Z-purlin model was created to model the conditions of Test 1 Z-TF. When viewing the end of the purlin cross-section, the Y-axis is vertical, the X-axis is horizontal, and the Z-axis is into the page. The purlin cross-section is shown in Figure 4.1 with node locations and global axes shown. Figure 4.2 shows the length of the purlin in the Z direction. The Z-purlin model contains 2,800 elements and 17,700 degrees of freedom.

The modeling of the purlin lap required special consideration. The lap region has a thickness equal to the thickness of both purlins that are a part of the lap. In the case of Test 1 Z-TF a thickness of 0.2 inches was used. This translates to twice the thickness and twice the stiffness if the lap acts together as a unit. In actuality, the lap is connected by a specified number of bolts. The most accurate model would model the lap as two separate purlins bolted together at specified locations. However, the AISI Guide design models assume that the lap acts as one unit. Therefore, the lap was modeled as one continuous cross-section with twice the stiffness of one purlin. The lap region stiffness can be increased by increasing the thickness of the elements or by increasing the modulus of elasticity. Both properties were easy to modify and produced nearly identical results. The results presented in this study were obtained by doubling the thickness of the elements in the lapped region of the model.

The required boundary conditions also required special considerations. At the supports, translations in the X and Y directions were restricted at locations that corresponded to the anti-roll clips as shown in Figure 4.3. These locations were allowed to rotate about the X-axis to simulate a pinned support condition. One end of the model

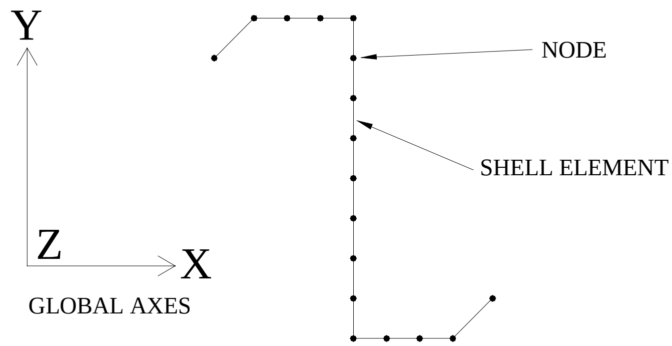

Figure 4.1 Z Model Cross-Section

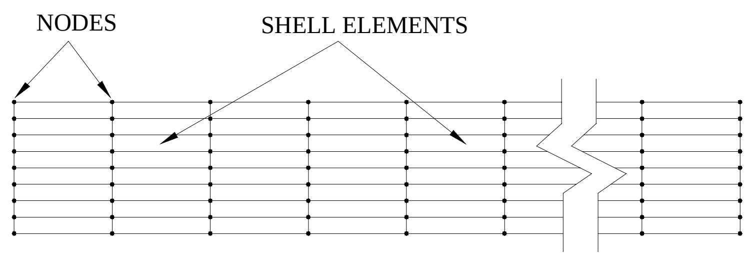

Figure 4.2 Z Model Side View

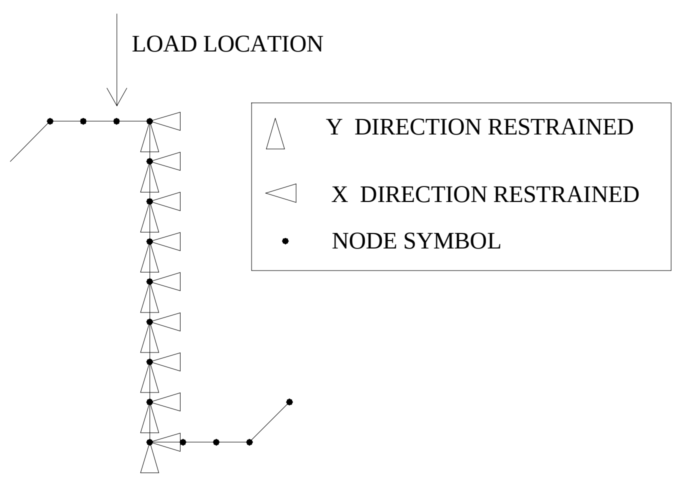

Figure 4.3 Boundary Conditions at Supports

needed to have translation restricted in the Z direction to make the model stable. The boundary conditions of the purlin top flange required special consideration. The purlin top flange was fixed in the X direction at the intersection of the purlin top flange and web. These are the conditions provided by through-fastened panel. The purlin lateral movement or spread could be greatly effected by the location of load application. The uniform line load was placed one-third of the flange width away from the purlin web. Note that if load were transferred to the purlin top flange based on stiffness, the resultant of that distribution would coincide with the load location used in this model. Figure 4.3 shows the final boundary conditions and load location used for the model.

Lateral or spread movement of the purlins at the locations shown in Figure 4.4 is plotted in Figure 4.5. The negative values imply movement of the purlin bottom flange to the left for the orientation shown in Figure 4.1. As with the experimental results, movement is greatest in the positive moment side of the inflection point and the entire area moves to the left.

Loads versus strain at the locations shown in Figure 4.6 are plotted in Figure 4.7. Finally, Figure 4.8 shows the deflected shape of the bottom flange of the Z-purlin model. The values plotted in Figure 4.8 represent the lateral movement of the bottom flange at the intersection with the purlin web as you move along the length of the purlin.

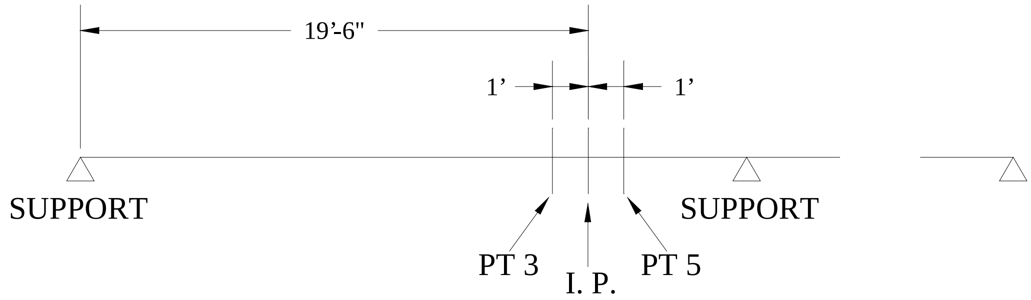

Figure 4.4 Spread Measurement Locations

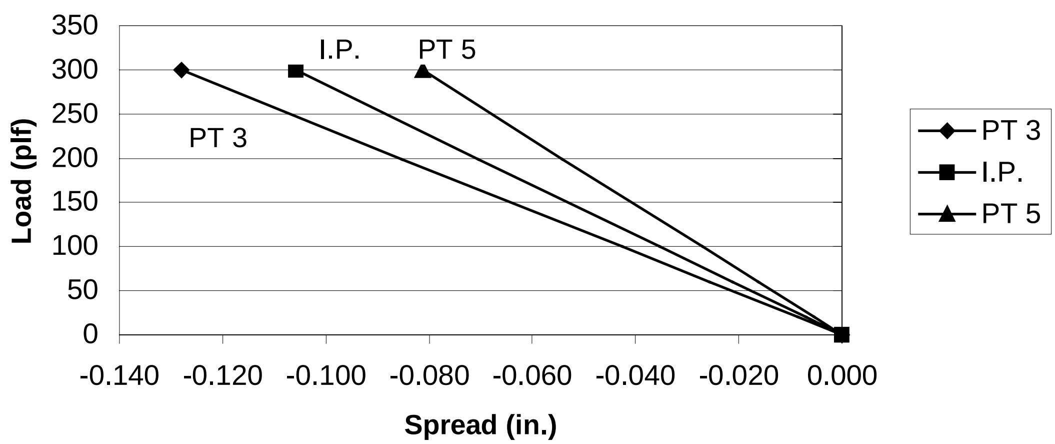

Figure 4.5 Z-Model Load vs. Spread

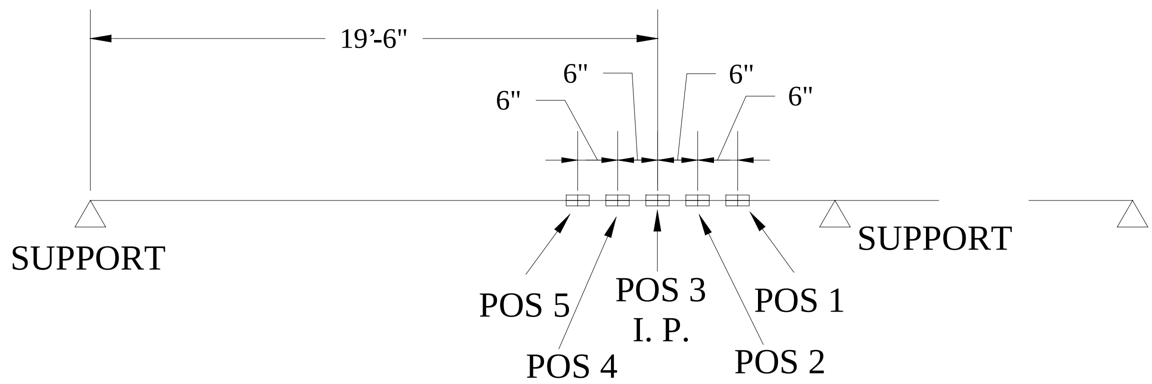

Figure 4.6 Strain Measurement Locations

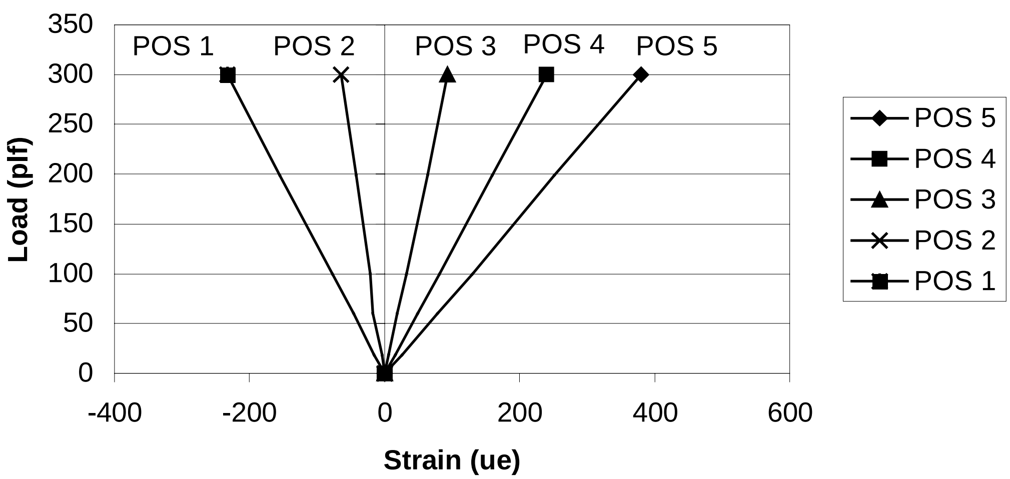

Figure 4.7 Z-Model Load vs. Strain

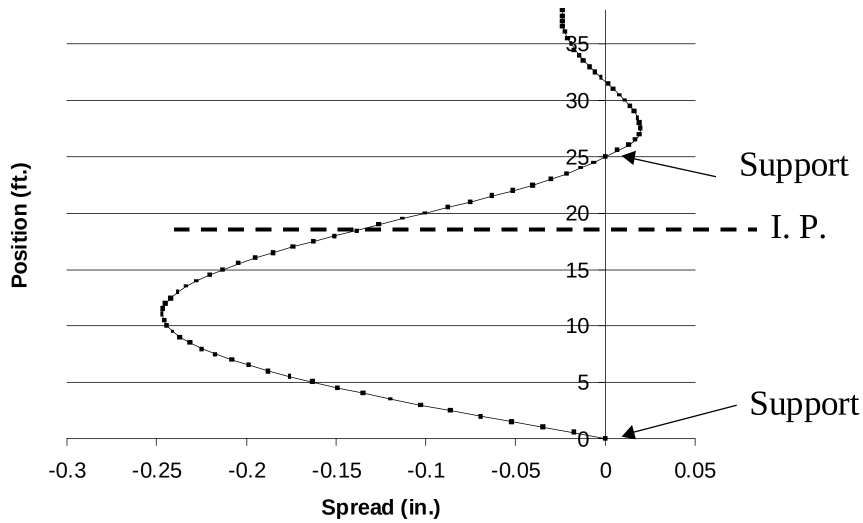

Figure 4.8 Spread of Bottom Flange for Z-Purlin Model

4.3 C-Purlin Model

The C-purlin model was created to model the conditions of Test 4 C-TF. When viewing the end of the purlin cross-section, the Y-axis is vertical, the X-axis is horizontal, and the Z-axis is into the page. The purlin cross-section is shown in Figure 4.9 with node locations and global axis shown. Figure 4.10 shows the length of the purlin in the Z direction. The C-purlin model contains 2,500 elements and 15,000 degrees of freedom.

The lap region consists of two C-purlins with their webs back-to-back and connected with bolts. The AISI Guide Design models and assumptions treat the lapped region as if the lapped purlins are continuously connected. For this reason, the lap was modeled by using one web with double the thickness of the purlins used in Test 4 C-TF. The flanges of both purlins are attached to the double thickness web as was shown in Figure 4.9. The single purlin web thickness is 0.08 in. and the lapped web thickness is 0.160 inches. In actuality, the lap is connected by a specified number of bolts. A more accurate model would be to model the lap as two separate purlins bolted together at specified locations.

The required boundary conditions needed special considerations. At the supports, translations in the X and Y directions were restricted at locations that corresponded to the anti-roll clips as shown in Figure 4.11. These locations were allowed to rotate about the X-axis to simulate a pinned support condition. One end of the model needed to have translation restricted in the Z direction to make the model stable. The boundary conditions of the Purlin top flange required special attention. The purlin top flange was fixed in the X direction at the intersection of the purlin top flange and web. These are the conditions provided by through-fastened panel. The purlin lateral movement or spread could be greatly effected by the location of the load application. The uniform line load was placed at the intersection of the purlin web and top flange. Figure 4.11 shows the final boundary conditions used for the model.

Lateral or spread movement of the purlins at the locations shown in Figure 4.12 is plotted in Figure 4.13. The positive values imply movement of the purlin bottom flange to the right for the orientation shown in Figure 4.8. As with the experimental results, movement is greatest in the positive moment side of the inflection point and the entire area moves to the right.

Loads versus strain at the locations shown in Figure 4.14 are plotted in Figure 4.15.

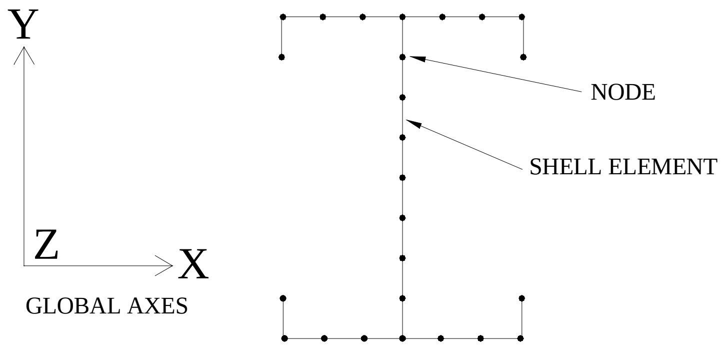

Figure 4.9 C-Model Cross-Section

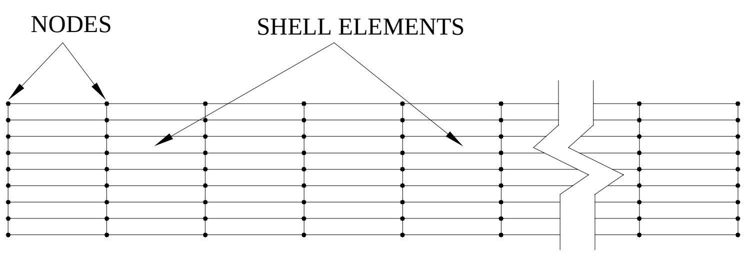

Figure 4.10 C-Model Side View

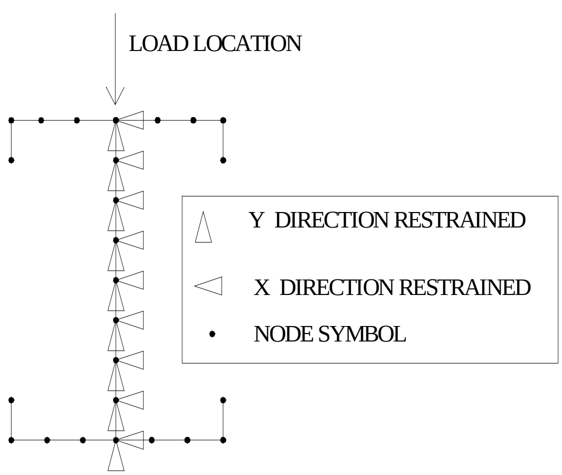

Figure 4.11 C - Model Boundary Conditions at Supports

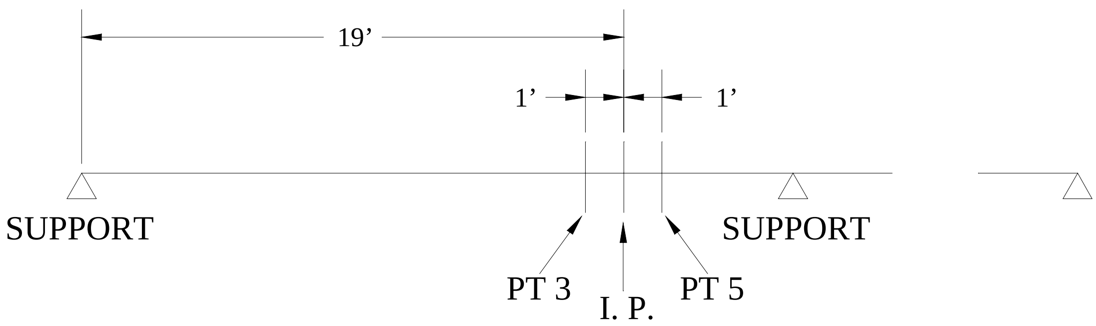

Figure 4.12 Spread Measurement Locations

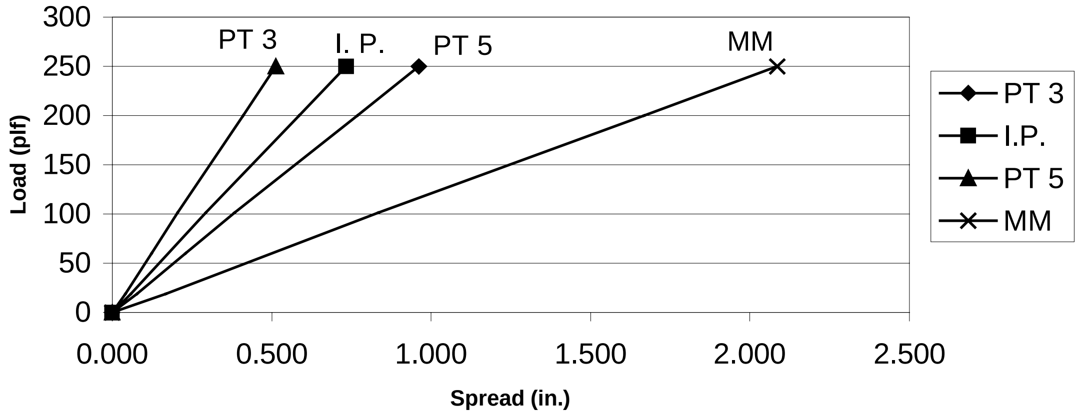

Figure 4.13 C-Model Load vs. Spread

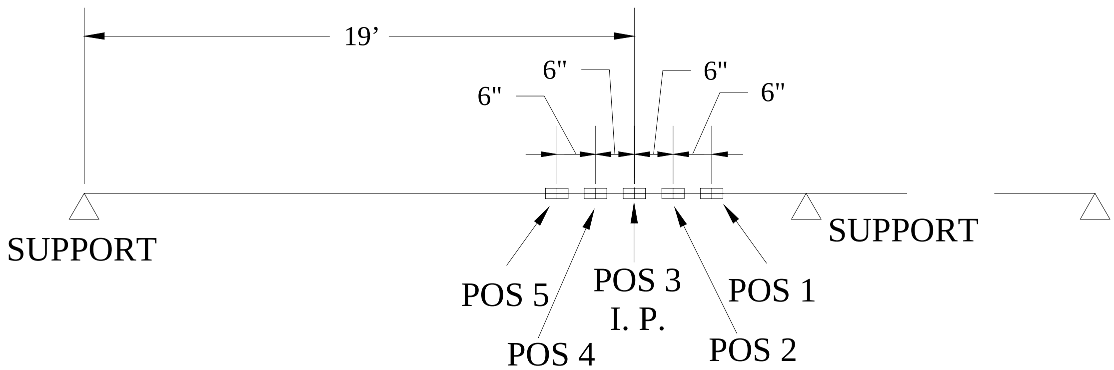

Figure 4.14 Strain Measurement Locations

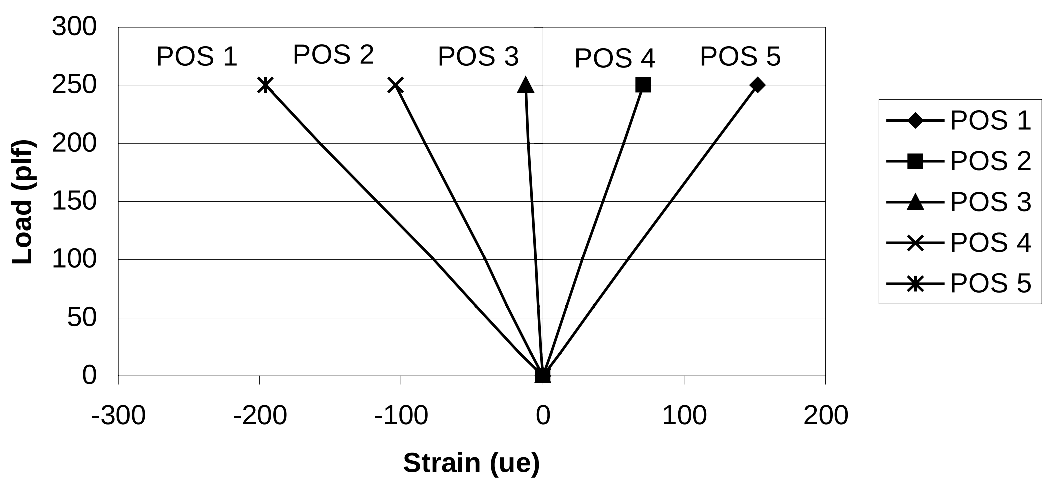

Figure 4.15 C - Model Load vs. Strain

CHAPTER V

EVALUATION OF RESULTS

5.1 Introduction

The following sections include comparisons of Finite Element (FE) and experimental strain values near the purlin line inflection point and purlin spread values at the experimentally measured locations, as well as strength comparisons. The predicted strengths of the test assemblies are based on the 1996 AISI Specifications and the design suggestions in the AISI Guide for Designing with Standing Seam Roof Panels.

5.2 Predicted and Measured Strains

Strain values from the Z- and C-purlin FE models were compared with strain gage data. The Z-purlin model strain comparison is shown in Figure 5.1. Figure 5.2 shows strain comparisons for the C-purlin model. In general, the finite element stains are shifted to the right as compared to the experimental strains. This may indicate that the finite element inflection point was shifted closer to the internal supports as compared to the experimental data. Another possible explanation could be that the strain values are effected by the cross-section twist. This is included in the finite element strains, but might not be measured by the uniaxial strain gages used in the experimental testing.

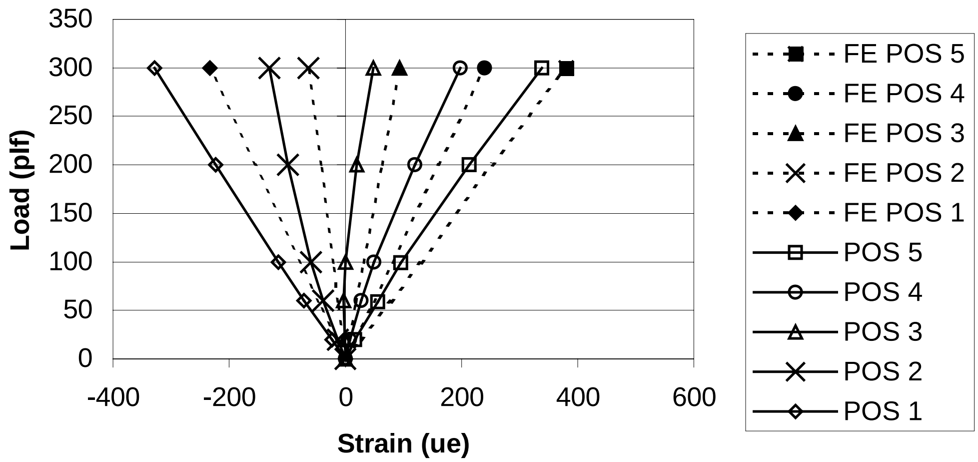

Figure 5.1 Finite Element and Experimental Strain Results for Test 1 Z–TF

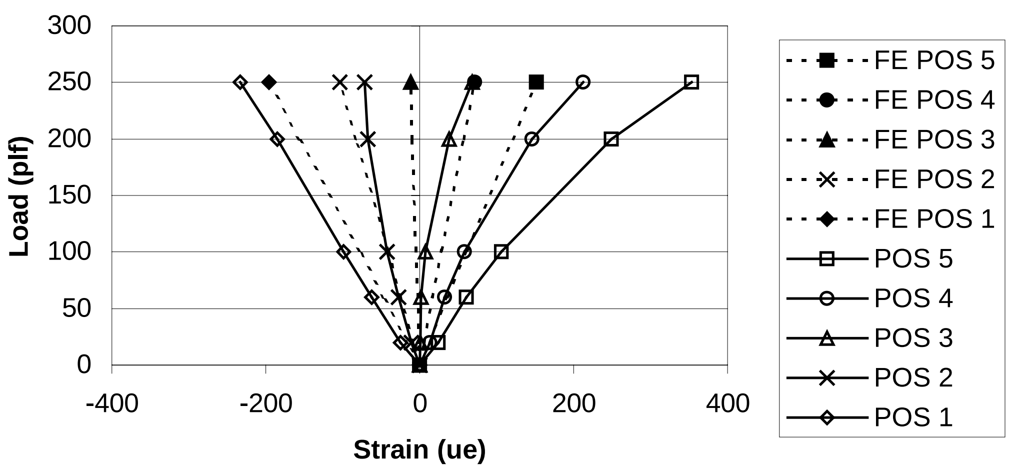

Figure 5.2 Finite Element and Experimental Strain Results for Test 4 C–TF

5.3 Predicted and Measured Purlin Spread

The analytical model consisted of finite element modeling of the three span through fastened tests. Both Z- and C-purlin models were developed. The spread of the Z- and C-purlin models were recorded for three locations that were 2 in. above the purlin bottom flange. The locations are 1 ft. each side of the inflection point (FE PT 3 on the positive moment side and FE PT 5 on the negative moment side and at the inflection point FE I.P.). The experimental measurements were taken at approximately the same locations on each side of the inflection points (PT 3 and PT 5). The finite element and experimental purlin spreads for Test 1 Z–TF are shown in Figure 5.3 as a function of uniform load on the purlin. The finite element and experimental purlin spreads for Test 4 C–TF are shown in Figure 5.4 as a function of uniform load on the purlin. Considering the magnitude of the spread, excellent agreement between the analytical and experimental results is apparent.

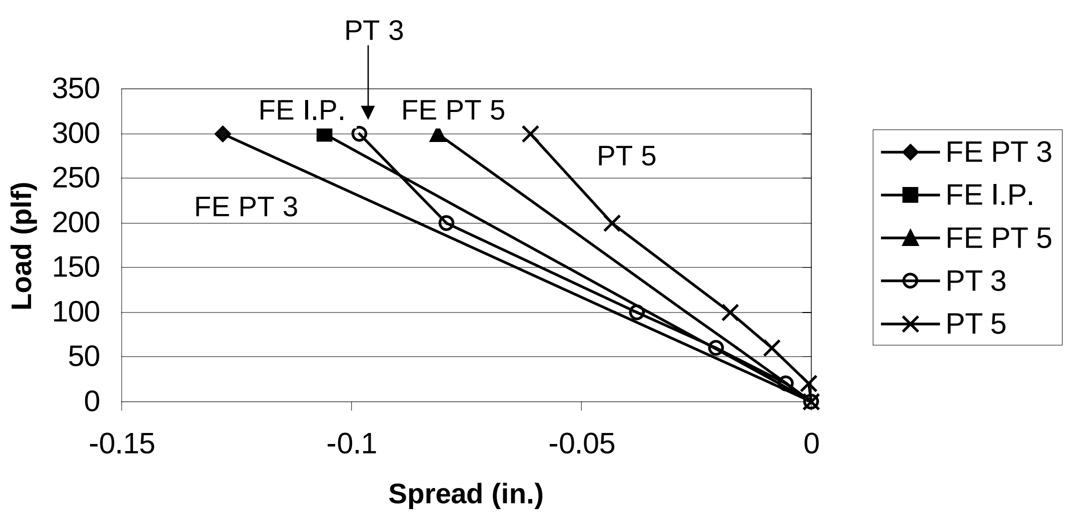

Figure 5.3 Finite Element and Experimental Purlin Spread for Test 1 Z–TF

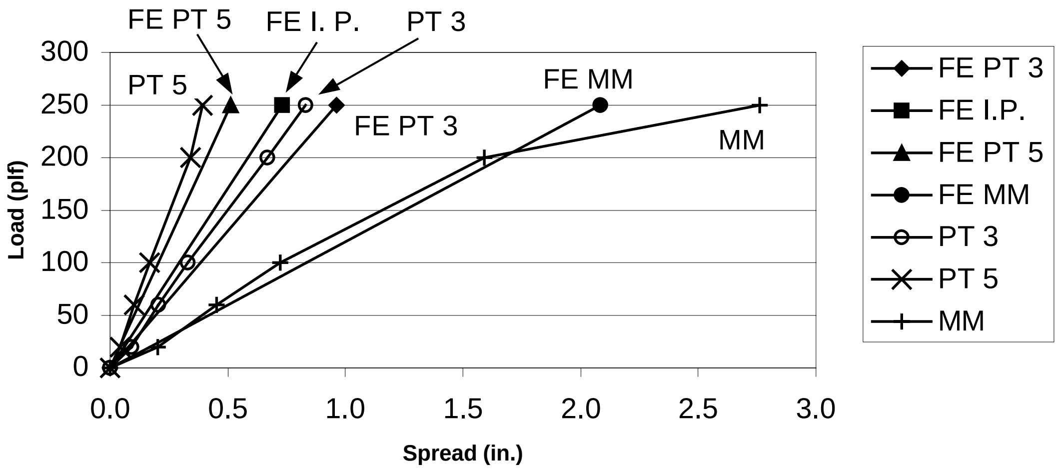

Figure 5.4 Finite Element and Experimental Purlin Spread for Test 4 C–TF

5.4 Strength Evaluation

5.4.1 Evaluation Assumptions

The 1986 edition of the AISI Specifications permitted the assumption that the inflection point of an unbraced member is a brace point resulting in a moment gradient factor, $C_{b,}$ value of 1.75. The 1996 AISI Specifications states that an inflection point of an unbraced member is not a brace point and the AISI Design Guide suggests that the length of purlin between the end of the lap and the inflection point be designed as if the section is a cantilever. The latter provision implies that C_b be taken as 1.0. Also, the 1986 and 1996 AISI Specifications have different provisions for the calculation of C_b.

Both the 1986 and 1996 AISI Specifications have the following sentence in Section C3.1.2 Lateral Buckling Strength: "The provisions of this section do not apply to laterally unbraced compression flanges of otherwise laterally stable sections." This sentence is a bit ambiguous but can be interpreted to apply to the distance between the end of the lap and the inflection point for, at least through fastened roof systems. The roof deck prevents lateral movement of the cross-section, but the compression flange is free to move laterally in the negative moment region. Thus, both conditions are satisfied.

For standing seam roof systems, the restraint provided by the clips and deck is not as great as for through fastened systems but may be sufficient to restrain the purlin in the negative moment region.

Strength predictions for the seven tests conducted in this study were calculated using the 1996 AISI Specifications nominal strength provisions assuming: (1) the inflection point is not a brace point and with C_b equal to 1.0, (2) the inflection point is a brace point and with C_b determined using the 1996 AISI Specifications Equation (Eq. C3.1.2-11), and (3) the negative moment region of the purlin is fully braced. It is noted that the second method is equivalent to that of the 1986 Specification method except for the C_b relationship.

5.4.2 1996 AISI Specification Provisions

The 1996 AISI Specification provisions for determining Z- and C-purlin flexural, shear, and combined bending and shear nominal strengths follow.

Positive Moment Region: Section C3.1.1 Nominal Section Strength

(a) Procedure I - Based on Initiation of Yielding
Effective yield moment based on section strength
shall be determined as follows:

$$M_n = R \cdot S_e \cdot F_y \qquad \text{(Eq. C3.1.4-1)}$$

Where:

R = Reduction factor determined by the Bast Test Method for Standing Seam Roofs
S_e = Elastic section modulus of the effective section calculated at F_y
F_y = Yield Stress of the purlin material

Note: R is taken as 1.0 for Through Fastened Panel

Negative Moment Region: Section C3.1.2 Lateral Buckling Strength

The nominal Strength of the laterally unbraced segments of singly-, doubly-, and point-symmetric sections* subject to lateral buckling shall be calculated as follows:

$$M_n = S_c \cdot \frac{M_c}{S_f} \qquad \text{(Eq. C3.1.2-1)}$$

Where:

M_c = Critical Moment
S_c = Elastic section modulus of the effective section calculated at M_c / S_f
S_f = Elastic section modulus of the full section for the extreme compression fiber

***** The provisions of this Section apply to I-, Z-, C-, and other singly-symmetric section flexural members (not including multiple-web deck, U- and closed box-type members, and curved or arch members). The provisions of this section do not apply to laterally unbraced compression flanges of otherwise laterally stable sections. Refer to C3.1.3 for C- and Z-purlins in which the tension flange is attached to sheathing.

Note: Section C3.1.3 Beams having one Flange Through-Fastened to Deck or Sheathing does not apply to continuous beams for the region between inflection points adjacent to a support, or to a cantilever beam.

Method (a) for singly-, doubly-, and point symmetric sections:

$$M_e = C_b \cdot r_o \cdot A \cdot \sqrt{\sigma_{ey} \cdot \sigma_t} \qquad \text{(Eq. C3.1.2-6)}$$

Where:

M_e = Elastic Critical Moment

C_b = Bending Coefficient (Moment Gradient Factor)

$$C_b = \frac{12.5 \cdot M_{max}}{2.5 \cdot M_{max} + 3 \cdot M_A + 4 \cdot M_B + 3 \cdot M_C} \qquad \text{(Eq. C3.1.2-11)}$$

M_{max} = absolute value of maximum moment in unbraced segment

M_A = absolute value of moment at quarter point of unbraced segment

M_B = absolute value of moment at centerline of unbraced segment

M_C = absolute value of moment at three-quarter point of unbraced segment

A = Full Cross-Sectional Area

r_o = Polar Radius of Gyration of the full cross-section about the shear center

Notes: Bending is about the axis of symmetry.
For singly symmetric sections, X-axis is axis of symmetry,
shear center has negative X coordinate.
M_e = 0.5 Me for point symmetric sections (Z).

And:

$$\sigma_{ey} = \frac{\pi^2 \cdot E}{\left(\frac{K_y \cdot L_y}{r_y}\right)^2} \qquad \text{(Eq. C3.1.2-9)}$$

$$\sigma_t = \frac{1}{A \cdot r_o^2} \cdot \left[(G) \cdot J + \frac{\pi^2 \cdot E \cdot C_w}{(K_t \cdot L_t)^2}\right] \qquad \text{(Eq. C3.1.2-10)}$$

Where:

K_y = Effective length factor for bending about the X axis

K_t = Effective length factor for twist

L_y = Unbraced length of compression member for bending about the Y axis

L_t = Unbraced length of compression member for twist

r_y = Radius of gyration of full section about Y axis

G = Shear Modulus

J = St. Venant torsion constant for cross-section

C_w = Torsional warping constant of cross-section

Method (b) For Z sections with bending about X-axis

$$M_e = \frac{\pi^2 \cdot E \cdot C_b \cdot d \cdot I_{yc}}{2 \cdot L^2} \qquad \text{(Eq. C3.1.2-16)}$$

Where:

d = Depth of section

L = Unbraced length of member

I_{yc} = Moment of inertia of the compression portion of the cross-section about the y axis

For $M_e \geq 2.78 M_y$

$$M_c = M_y \qquad \text{(Eq. C3.1.2-2)}$$

For $2.78 M_y > M_e > 0.56 M_y$

$$M_c = \frac{10}{9} \cdot M_y \cdot \left(1 - \frac{10 \cdot M_y}{36 \cdot M_e}\right) \qquad \text{(Eq. C3.1.2-3)}$$

For $M_c \leq 0.56 M_y$

$$M_c = M_e \qquad \text{(Eq. C3.1.2-4)}$$

Where:

M_y = Moment causing initial yield at extreme compression fiber of full section
= $S_f F_y$

Shear Strength: Section C3.2 Strength for Shear Only

The nominal shear strength at any section shall be calculated as follows:

(a) For $\frac{h}{t} \le 0.96 \cdot \sqrt{\frac{E \cdot k_v}{F_y}}$

$$V_n = 0.60 F_y h t \qquad \text{(Eq. C3.2-1)}$$

(b) For $0.96 \cdot \sqrt{\frac{E \cdot k_v}{F_y}} < \frac{h}{t} \le 1.415 \cdot \sqrt{\frac{E \cdot k_v}{F_y}}$

$$V_n = 0.64 \cdot t^2 \cdot \sqrt{E \cdot k_v \cdot F_y} \qquad \text{(Eq. C3.2-2)}$$

(c) For $\frac{h}{t} > 1.415 \cdot \sqrt{\frac{E \cdot k_v}{F_y}}$

$$V_n = \frac{0.905 \cdot E \cdot k_v \cdot t^3}{h} \qquad \text{(Eq. C3.2-3)}$$

Where:

V_n = Nominal Shear Strength of Beam
t = Web Thickness
h = Depth of flat portion of Web
k_v = Shear Buckling Coefficient = 5.34 for unreinforced webs

Combined Bending and Shear: Section C3.3 Strength for Combined Bending and Shear

For Beams with unreinforced webs, the required flexural strength, M, and required shear strength, V, shall satisfy the following interaction equation:

$$\left(\frac{M}{M_n}\right)^2 + \left(\frac{V}{V_n}\right)^2 \le 1.0 \qquad \text{(Eq. C3.3.1-1)}$$

5.4.3 Strength Comparisons Assuming the Inflection Point is not a Brace Point

Table 5.1 lists the effective section modulus, S_e, the measured material yield stress, F_y, effective yield moment, S_eF_y, the distance from the end of the lap to the theoretical inflection point, L_b, and the standing seam roof system reduction factor, R, for the failed purlin in each test. The reduction factor R was determined using the AISI Base Test Method.

Table 5.2 lists the moment and shear strength calculated using the above specification provisions and the properties from Table 5.1. The negative moment strength was determined using a C_b value of 1.0. The predicted failure load, determined using the critical limit state, and the experimental failure load are also listed. (The experimental failure load is the sum of the applied load plus the weight of the roof sheeting times the tributary width plus the purlin weight.) The ratio of the experimental-to-predicted failure loads varies between 0.955 and 1.226 with an average value of 1.056 and a standard deviation of 0.0896.

Table 5.1 Purlin Properties

Test Number	S_e in^3	F_y ksi	S_eF_y in-kips	L_b in	R	C_b
Test 1 Z-TF	3.54	55.5	196.5	52.5	1.00	1.76
Test 2 Z-SS	3.78	50.6	191.3	54.8	0.44	1.77
Test 3 C-SS	3.15	87.5	275.6	53.2	0.45	1.76
Test 4 C-TF	2.42	75.0	181.5	53.2	1.00	1.76
I.P. Test 1 Z-SS	2.66	69.5	184.9	78.0	0.44	1.78
I.P. Test 2 Z-SS	2.66	69.5	184.9	78.0	0.44	1.78
I.P. Test 3 Z-TF	2.66	69.5	184.9	78.0	1.00	1.78

Note: L_b is the distance from the end of the lap to the inflection point in the test bay.

Table 5.2 Strength Comparison Assuming Inflection Point not as Brace point

Test Number	Positive Moment Strength in-kips	Negative Moment Strength in-kips	Shear Strength kips	Shear + Bending Negative Moment Strength in-kips	Critical Limit State	Predicted Failure Load plf	Experimental Failure Load plf	Experimental / Predicted for Shear + Bending	Experimental / Predicted for Critical Limit State
Test 1 Z-TF	196.5	195.7	19.8	191.6	Shear + Bending	295.7	320.8	1.085	1.085
Test 2 Z-SS	83.4	191.3	8.4	171.9	Positive Moment	138.8	142.4	0.563	1.026
Test 3 C-SS	125.0	275.6	7.2	210.1	Positive Moment	220.7	210.8	0.618	0.955
Test 4 C-TF	181.5	179.1	9.1	164.4	Shear + Bending	255.7	280.3	1.096	1.096
I.P. Test 1 Z-SS	80.5	162.1	8.3	155.0	Positive Moment	103.5	104.8	0.797	1.013
I.P. Test 2 Z-SS	80.5	162.1	8.3	155.0	Positive Moment	103.5	102.8	0.782	0.993
I.P. Test 3 Z-TF	184.9	162.1	8.3	155.0	Shear + Bending	131.5	161.2	1.226	1.226

5.4.4 Strength Comparisons Assuming the Inflection Point is a Brace Point

Table 5.3 has the same data as Table 5.2 except that the negative moment strength was calculated using the C_b value listed in Table 5.1 as determined from AISI Specifications Equation C3.1.2-11. The ratio of the experimental-to-predicted failure loads varies between 0.955 and 1.110 with an average value of 1.037 and a standard deviation of 0.056.

Table 5.3 Strength Comparison Assuming Inflection Point as Brace Point

Test Number	Positive Moment Strength in-kips	Negative Moment Strength in-kips	Shear Strength kips	Shear + Bending Negative Moment Strength in-kips	Critical Limit State	Predicted Failure Load plf	Experimental Failure Load plf	Experimental / Predicted for Shear + Bending	Experimental / Predicted for Critical Limit State
Test 1 Z-TF	196.5	196.5	19.8	192.2	Shear + Bending	296.7	320.8	1.081	1.081
Test 2 Z-SS	83.4	191.3	8.4	171.9	Positive Moment	138.8	142.4	0.563	1.026
Test 3 C-SS	125.0	275.6	7.2	210.1	Positive Moment	220.7	210.8	0.618	0.955
Test 4 C-TF	181.5	181.5	9.1	166.2	Shear + Bending	258.7	280.3	1.083	1.083
I.P. Test 1 Z-SS	80.5	179.0	8.3	170.1	Positive Moment	103.5	104.8	0.722	1.013
I.P. Test 2 Z-SS	80.5	179.0	8.3	170.1	Positive Moment	103.5	102.8	0.708	0.993
I.P. Test 3 Z-TF	184.9	179.0	8.3	170.0	Shear + Bending	145.2	161.2	1.110	1.110

5.4.5 Strength Comparison Assuming a Fully Braced Cross-section

Lateral buckling strength is addressed in section C3.1.2 of the AISI Specifications and important equations from this section are listed above in section 5.4.2. AISI Specifications Section C3.1.2 states "The nominal strength of the laterally unbraced segments of singly-, doubly-, and point-symmetric sections* subject to lateral buckling, M_n shall be calculated as follows." The asterisk (*) leads to a footnote that states "The provisions of this Section apply to I-, Z-, C- and other singly-symmetric section flexural members (not including multiple-web deck, U- and closed box-type members, and curved or arch members). The Provisions of this section do not apply to laterally unbraced compression flanges of otherwise laterally stable sections. Refer to C3.1.3 for C- and Z-purlins in which the tension flange is attached to sheathing."

The multiple span lapped continuous Z- and C-purlins evaluated in this research have laterally unbraced compression flanges between the face of the lap and the inflection point. However, the cross-section is otherwise laterally stable because of the sheathing fastened to the top flange of the purlins. This would seem to indicate that applicable strength provisions would be provided in Section C3.1.3. Section C3.1.3 Beams Having One Flange Through-Fastened to Deck or Sheathing begins by stating: "This section does not apply to a continuous beam for the region between the inflection points adjacent to a support, or to a cantilever beam". This section clearly does not apply to the negative moment region of the tests that were conducted. The AISI Specifications provide no other guidance for predicting the strength of the negative moment region.

In the absence of design provisions the negative moment strength was set equal to the effective yield moment, $M_n = S_eF_y$ (Equation C3.1.1-1.of the AISI Specifications). Predicted loads and strengths were calculated based on this assumption and compared to experimental values. Table 5.4 lists the results. The ratio of predicted/experimental failure loads ranged from 0.955 to 1.083. The average value was 1.033 and had a standard deviation of 0.0504.

Table 5.4 Strength Comparison Assuming Fully Braced Cross-Section

Test Number	Positive Moment Strength (in-kips)	Negative Moment Strength (in-kips)	Shear Strength (kips)	Shear + Bending Negative Moment Strength (in-kips)	Critical Limit State	Predicted Failure Load (plf)	Experimental Failure Load (plf)	Experimental / Predicted for Shear + Bending	Experimental / Predicted for Critical Limit State
Test 1 Z-TF	196.5	196.5	19.8	192.2	Shear + Bending	296.7	320.8	1.081	1.081
Test 2 Z-SS	83.4	191.3	8.4	171.9	Positive Moment	138.8	142.4	0.563	1.026
Test 3 C-SS	125.0	275.6	7.2	210.1	Positive Moment	220.7	210.8	0.618	0.955
Test 4 C-TF	181.5	181.5	9.1	166.2	Shear + Bending	258.7	280.3	1.083	1.083
I.P. Test 1 Z-SS	80.5	184.9	8.3	174.6	Positive Moment	103.5	104.8	0.702	1.013
I.P. Test 2 Z-SS	80.5	184.9	8.3	174.6	Positive Moment	103.5	102.8	0.689	0.993
I.P. Test 3 Z-TF	184.9	184.9	8.3	174.6	Shear + Bending	149.2	161.2	1.080	1.080

5.4.6 Summary of Test Results

For Test 1 Z–TF the experimental failure load that was 8.5 percent higher than the load predicted assuming the inflection point is not a brace point and 8.1 percent higher than the predicted failure load assuming the inflection point is a brace point. The experimental load is also 8.1 percent higher than the predicted load given by setting the negative moment strength to the yield moment. It is noted that the provisions of AISI Section C3.1.2 and the assumption that the inflection point is a brace point predict negative moment strength equal to the effective yield moment strength. The purlins rolled inward on both sides of the inflection point for this test. However, the inflection point movement was quite small. The predicted failure mode was combined shear and bending near the face of the lap for this test. The experimental failure occurred near the lap in the negative moment region.

For Test 2 Z–SS the experimental failure load that was 2.6 percent higher than the predicted load for the controlling limit state of positive moment strength using a R value determined from the Base Test Method. The purlins rolled inward on both sides of the inflection point for this test. The predicted and experimental failure mode was positive moment failure.

For Test 3 C-SS the experimental failure load was 4.5 percent below the load predicted by AISI Specifications and the Base Test Method. The purlins rolled outward on both sides of the inflection point for this test. The predicted and experimental failure mode was positive moment failure.

For Test 4 C–TF the experimental failure load was 9.6 percent higher than the load predicted assuming the inflection point is not a brace point and 8.3 percent higher than the predicted failure load assuming the inflection point is a brace point. Setting the negative moment strength to the yield moment predicted a load that was also 8.3 percent below the experimental load. Again, the assumption that the inflection point is a brace point resulted in the full moment strength in the negative moment region. The purlins rolled outward on both sides of the inflection point for this test. The predicted failure mode was combined shear and bending near the face of the lap for this test. The experimental failure occurred near the lap in the negative moment region. The magnitude of the spread was greater than the values of Test 1 Z–TF.

I. P. Test 1 Z–SS was performed at Ceco Building Systems and consisted of two 30 ft. spans and standing seam panels. The experimental failure load was 1.0 percent higher than the load predicted by AISI Specifications and the AISI Base Test Method. The purlins moved inward on both sides of the inflection point.. The predicted and experimental failure mode was positive moment failure.

I. P. Test 2 Z–SS was identical to I. P. Test 1 Z–SS except that a brace was attached between the two facing purlin lines at calculated location of the inflection point that was attached between the two facing purlin lines. The experimental load achieved was almost 1 percent lower than the load predicted by AISI Specifications and the AISI Base Test Method. The purlins moved inward on both sides of the inflection point for this test. The predicted and experimental failure mode was positive moment failure.

I. P. Test 3 Z–TF used the same purlins as I. P. Test 1 Z–SS and I. P. Test 2 Z–SS. The decking used for this test was the standing seam panel used in all other standing seam tests. The difference for this test was that the panel was screw fastened directly to the purlin top flange making through-fastened panel. This test achieved an experimental load that was 22.6 percent higher than the than the load predicted assuming the inflection point is not a brace point and 11 percent higher than the predicted failure load assuming the inflection point is a brace point. The assumption that the negative moment strength is the effective yield moment (that is, fully braced) leads to an experimental failure load that is 8 percent above the predicted failure load The predicted failure mode was combined shear plus bending near the face of the lap. The experimental failure occurred in the negative moment region near the face of the lap. The purlins rolled inward on both sides of the inflection point for this test.

5.4.7 Comparison of Results

Both the predicted and experimental failure limit state for Test 1 Z-TF and Test 4 C-TF is shear plus bending. For these tests the unbraced length in the negative moment region of the test bay was approximately 53 in. For both tests, the predicted moment strengths are essentially unaffected by the inflection/brace point assumption. (195.7 in-kips versus 196.5 in-kips for Test 1 Z-TF and 179.1 in-kips and 181.5 in-kips for Test 4 C-TF.) The effective yield moment strengths are 196.5 in-kips for Test 1 Z-TF and 181.5 in-kips for Test 4 C-TF; the same as for the inflection point is a brace point assumption.

Tests 2 Z-SS and Test 3 C-SS were standing seam panel tests controlled by positive moment strength. Because of low R- values (0.44) for the standing seam roof system used in the tests, it was not possible to configure a reasonable system where positive moment strength did not control. However, excellent agreement between the predicted and experimental failure loads based on the limit state of positive moment strength was found.

The unbraced lengths in the negative moment region of the test bay in Test 2 Z-SS and Test 3 C-SS were approximately 55 and 53 in., respectively. There is no difference between the negative moment strengths calculated using the three assumptions (191.3 in-kips and 191.3 in-kips for Test 2 Z-SS and 378.0 in-kips and 378.0 in-kips for Test 3 C-SS).

For the three I.P. designated tests, the unbraced length was 78 in. The predicted negative moment strengths are considerably different 162.1 in-kips assuming the inflection point is not a brace point and 179.0 in-kips for the opposite assumption. The negative moment strength based on yield is 184.9 in-kips. The Z-SS I.P. tests were designed for the limit state of shear plus bending, however, the purlins used in the tests had an unexpected high yield stress causing the actual limit state to be positive moment strength. Because the controlling limit state was positive bending, the addition of an actual brace at the theoretical inflection point had essentially no effect on the test results.

I.P. Test 3 Z-TF was identical in configuration to the other two I.P. tests except that the standing seam panel was through-fastened to the purlins in an attempt to limit positive moment failure. The predicted and actual limit state was shear plus bending, but the experimental failure loaded exceeded all predicted failure loads: 22.6 percent for the inflection point is not a brace point assumption, 11.1 percent for the inflection point as a brace point assumption, and 8.0 percent for the yield moment assumption.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

An experimental and analytical investigation was conducted in an attempt to evaluate the inflection point as a brace point in multiple span lapped purlin roof systems subjected to uniform gravity loading. Seven tests were conducted: four three-span continuous and three two-span continuous. Five tests were conducted using Z-purlins and two tests were conducted using C-purlins. Standing seam panels were used in four tests and through-fastened panes were used in three tests. Anti-roll clips were used at all purlin-to-rafter support locations. Intermediate lateral bracing was used only in IP test 2.

Instrumentation was used to verify the actual location of the inflection point and to measure lateral movement or spread of the bottom flange of the purlins on each side of the inflection point. The results were compared to movement predicted by finite element models of two of the tests. Both the experimental and analytical results showed that although lateral movement did occur at the inflection point, the movement was considerably less than at other locations along the purlins.

From the lateral movement measurements and analytical results of the seven tests conducted, it is apparent that relatively little movement occurs near the inflection point of Z-purlin lapped systems. Both sides of the inflection point move in the same direction and no double curvature was exhibited from either the experimental measurements or the analytical results. Lateral movement near the inflection point was found to be much less than that at the point of maximum moment. Systems using lapped C-purlins exhibit larger movement than Z-purlin systems, but the values are still relatively small.

For the four tests using standing seam panels, both the predicted and experimental controlling limit state was positive moment region failure. Also, excellent agreement between the predicted and experimental failure loads was found. The predicted failure loads were calculated using the AISI Specifications provisions and the Base Test Method to determine the positive moment bending strength. The experimental-to-predicted load ratios are 1.026, 0.955, 1.013, and 0.993.

The predicted and experimental controlling limit state for the three tests using through fastened roof systems was shear plus bending failure immediately outside the lap in the exterior test bay. The experimental failure loads were compared to predicted values using provisions of the AISI Specifications and assuming (1) the inflection point is not a brace point, (2) the inflection point is a brace point, and (3) the negative moment region strength is equal to the effective yield moment (S_eF_y). For the two three-span continuous tests, all three methods predict the same failure load. The ratios of experimental-to-predicted load for these tests are 1.081 and 1.083 which means that the predictions are approximately 8 percent conservative. For the two-span continuous test, the predicted failure loads for the three assumptions are 131.5 plf, 145.2 plf, and 149.2 plf. The experimental failure load is 161.2 plf, thus all three assumptions are conservation with the fully braced assumption being the least conservative with an experimental-to-predicted load ration of 1.080.

6.2 Conclusions

From the limited data developed in this research, it is difficult to draw definite conclusions. It is clear that the bottom flange of a continuous purlin line move laterally in the same direction on both sides of the inflection point but that the movement is relatively small. It is also evident, that there is very little difference in predicted strength of the negative moment region of continuous purlin lines for usual end of lap-to-inflection point distances, that is, less than approximately 60 in. For larger distances, it appears that even assuming full lateral restraint for through fastened roof systems is conservative. It is believed that the full lateral restraint assumption for the negative moment region of continuous purlin lines is permitted by the AISI Specifications, however, the specification language is ambiguous.

6.3 Recommendations

From the limited results of this research, it is recommended that the negative moment region of continuous purlin lines supporting through fastened roof systems be designed using the effective yield moment strength, S_eF_y, as defined in Section C3.1.1 of the AISI Specifications. It is also recommended that the AISI specification language in Section C3.1.2 Lateral Buckling Strength be revised to clarify the intent. Finally, it is recommended that several tests using Z- and C-purlins be conducted with the following conditions: (1) standing seam roof panels, (2) configured such that the controlling limit is shear plus bending, and (3) that the predicted limit state, assuming that distance from the end of the lap to the inflection point is unbraced, is controlled by inelastic lateral buckling using the provisions of Section C3.1.2 Lateral Buckling Strength.

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APPENDIX A

TEST 1 Z–TF DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: Test 1 Z-TF
DATE: 8/26/98

TEST DESCRIPTION:

Loading	Gravity
Panel Type	Through Fastened Panel
Span	2@25'-0", 1@23'-0"
Purlin Spacing	5' o.c. with 1' deck overhang
Lateral Bracing	None
Anti-roll Clips	At the supports of both purlin lines
Web Stiffeners	None
Purlin Orientation	Top flanges opposed
Insulation	None

FAILURE MODE:

Combined Shear plus Bending at Face of Lap

EXPERIMENTAL FAILURE LOAD:

Pressure =	16.45	in. of water
Applied Line Loading =	320.78	plf
Weight of Deck =	4.00	plf
Weight of Purlin =	5.05	plf
Total Applied Load =	329.82	plf
Maximum Pos. Moment =	190.61	kip in.
Neg. Moment at Lap =	207.67	kip in.
Shear at Lap =	4.68	kips

PREDICTED FAILURE LOAD: (F_y= 55.5 ksi)

Inflection Point As Bracepoint

Combined Shear + Bending:

Neg. Moment at Lap =	192.60	kip in.
Shear at Lap =	4.33	kips
Predicted Line Load =	306.35	plf

Inflection Point Not As Bracepoint

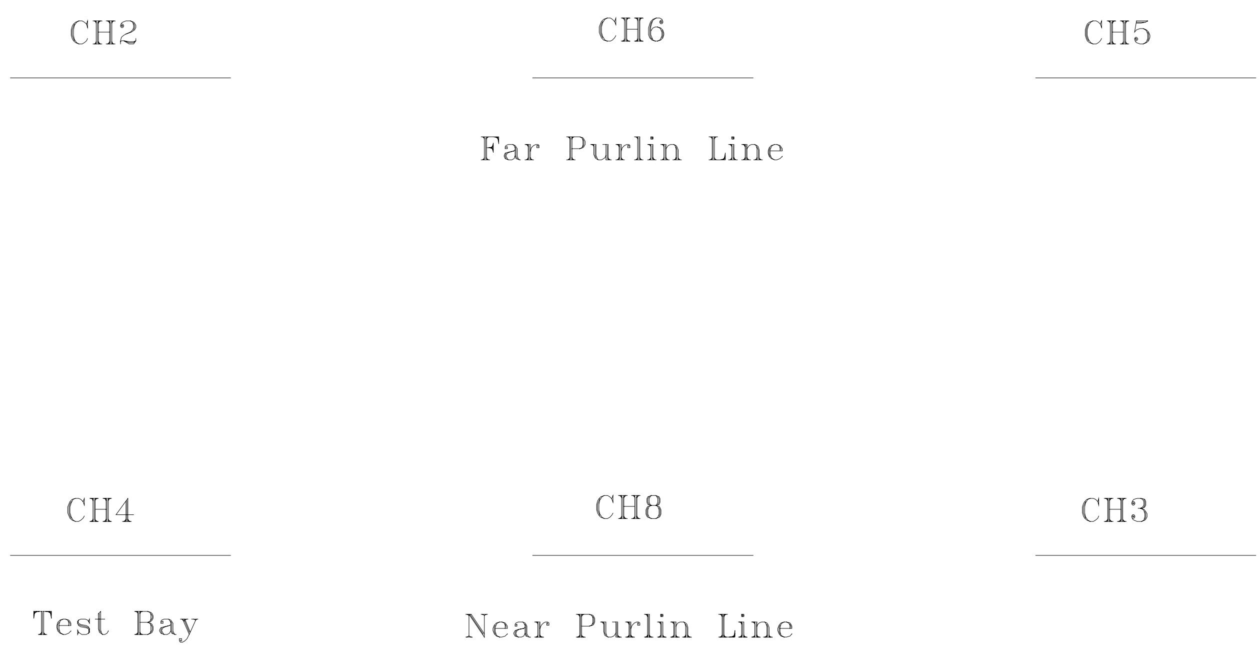
Combined Shear + Bending:

Neg. Moment at Lap =	191.56	kip in.
Shear at Lap =	4.32	kips
Predicted Line Load =	304.85	plf

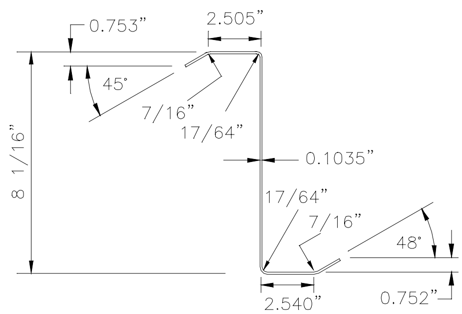
Experimental/Predicted:

Failure/Predicted =	329.82/306.35 =	1.077	**I.P. Braced**
Failure/Predicted =	329.82/304.85 =	1.082	**I.P. Not Braced**

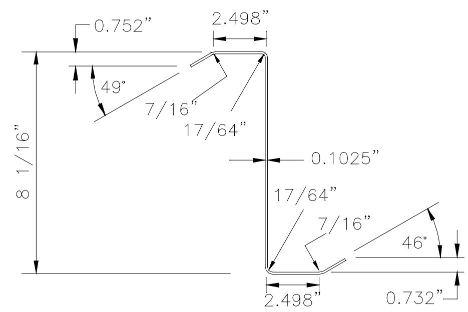
Test 1 Z-TF (Z8) Purlin Locations



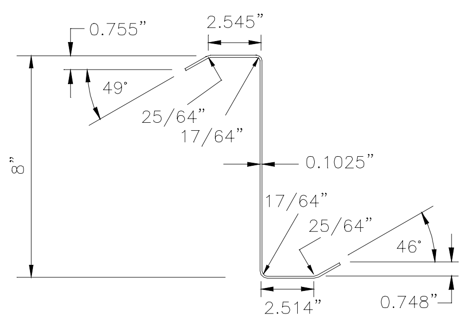
Test 1 Z-TF (Z8) Measured Dimensions



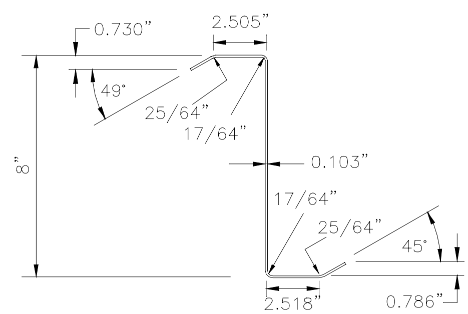
Purlin (CH2)



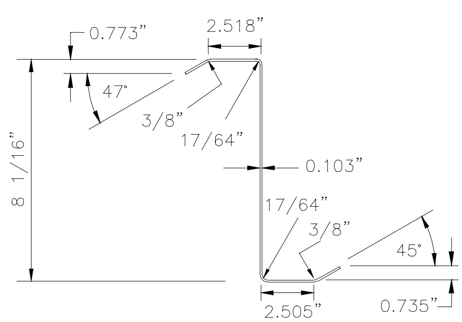
Purlin (CH4)



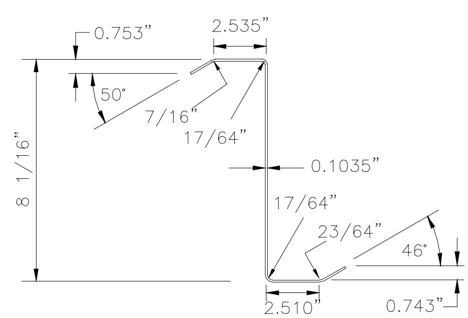
Purlin (CH6)



Purlin (CH8)



Purlin (CH5)



Purlin (CH3)

Results From Commercial Software

TEST 1 Z-TF 8 in. Z-TF 3 span CH 2

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.0649 in.	1.0119 in.
Lip Angle	45 °	48 °
Radii:		
Lip to Flange	0.4375 in.	0.4375 in.
Flange to Web	0.2656 in.	0.2656 in.
Flange Width	2.505 in.	2.540 in.
Purlin Depth	8.0625 in.	
Purlin Thickness	0.1035 in.	
Yield Stress	55.5 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.51 in^2
Ix	14.60 in^4
Iy	2.64 in^4
Ixy	4.54 in^4

Flexural Strength

Ie	14.60 in^4
Se	3.63 in^3

TEST 1 Z-TF 8 in. Z-TF 3 span CH 4

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.9964 in.	1.0176 in.
Lip Angle	49 °	46 °
Radii:		
Lip to Flange	0.4375 in.	0.4375 in.
Flange to Web	0.2656 in.	0.2656 in.
Flange Width	2.498 in.	2.498 in.
Purlin Depth	8.0625 in.	
Purlin Thickness	0.1025 in.	
Yield Stress	55.5 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.48 in^2
Ix	14.32 in^4
Iy	2.48 in^4
Ixy	4.36 in^4

Flexural Strength

Ie	14.32 in^4
Se	3.54 in^3

Other properties for CH 4

rx	3.1056	in.
ry	1.2947	in.
ro	3.3652	in.
Cw	28.159	in^6
J	0.00519	in^4
α	-18.204	°

TEST 1 Z-TF 8 in. Z-TF 3 span CH 6

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top	Bottom
Overall Lip Dimension	1.004 in.	1.0398 in.
Lip Angle	49 °	46 °
Radii:		
Lip to Flange	0.3906 in.	0.3906 in.
Flange to Web	0.2656 in.	0.2656 in.
Flange Width	2.545 in.	2.514 in.
Purlin Depth	8.0625 in.	
Purlin Thickness	0.1025 in.	
Yield Stress	55.5 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.49 in^2
Ix	14.46 in^4
Iy	2.59 in^4
Ixy	4.48 in^4
Flexural Strength	
Ie	14.46 in^4
Se	3.58 in^3

TEST 1 Z-TF 8 in. Z-TF 3 span CH 8

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top	Bottom
Overall Lip Dimension	0.9673 in.	1.1116 in.
Lip Angle	49 °	45 °
Radii:		
Lip to Flange	0.3906 in.	0.3906 in.
Flange to Web	0.2656 in.	0.2656 in.
Flange Width	2.505 in.	2.518 in.
Purlin Depth	8.0625 in.	
Purlin Thickness	0.103 in.	
Yield Stress	55.5 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.50 in^2
Ix	14.52 in^4
Iy	2.60 in^4
Ixy	4.50 in^4
Flexural Strength	
Ie	14.52 in^4
Se	3.57 in^3

TEST 1 Z-TF 8 in. Z-TF 3 span CH 5

Purlin Geometry and Material Properties Bay #3 (End Bay) | Purlin Properties

	Top	Bottom		
Overall Lip Dimension	1.0569 in.	1.0394 in.	Ag	1.50 in^2
Lip Angle	47 °	45 °	Ix	14.56 in^4
Radii:			Iy	2.63 in^4
Lip to Flange	0.375 in.	0.375 in.	Ixy	4.53 in^4
Flange to Web	0.2656 in.	0.2656 in.	Flexural Strength	
Flange Width	2.518 in.	2.505 in.	Ie	14.56 in^4
			Se	3.62 in^3
Purlin Depth	8.0625 in.			
Purlin Thickness	0.103 in.			
Yield Stress	55.5 ksi			
Modulus of Elasticity	29500 ksi			

TEST 1 Z-TF 8 in. Z-TF 3 span CH3

Purlin Geometry and Material Properties Bay #3 (End Bay) | Purlin Properties

	Top	Bottom		
Overall Lip Dimension	0.983 in.	1.0329 in.	Ag	1.50 in^2
Lip Angle	50 °	46 °	Ix	14.53 in^4
Radii:			Iy	2.56 in^4
Lip to Flange	0.4375 in.	0.4375 in.	Ixy	4.46 in^4
Flange to Web	0.2656 in.	0.2656 in.	Flexural Strength	
Flange Width	2.535 in.	2.510 in.	Ie	14.53 in^4
			Se	3.60 in^3
Purlin Depth	8.0625 in.			
Purlin Thickness	0.1035 in.			
Yield Stress	55.5 ksi			
Modulus of Elasticity	29500 ksi			

Predicted Through Fastened Capacity (ASD) From Commercial Software

173.1 lbs/ft x 1.67 = 289.1 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

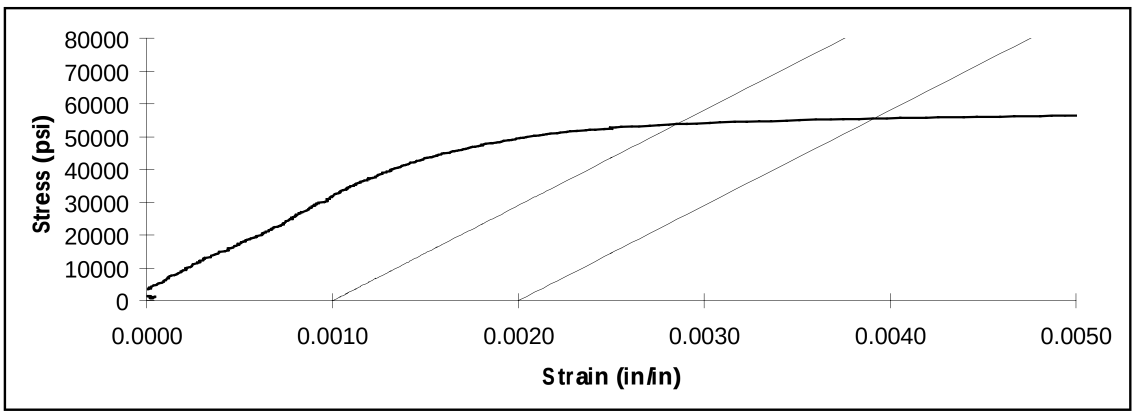
Test Designation:	Chief Multispan Test #1
Specimen Identification:	MB CH 4
Coupon Number:	9
Date:	12/18/98
Gage length (in.):	2.000
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.104
Width (in.):	1.504

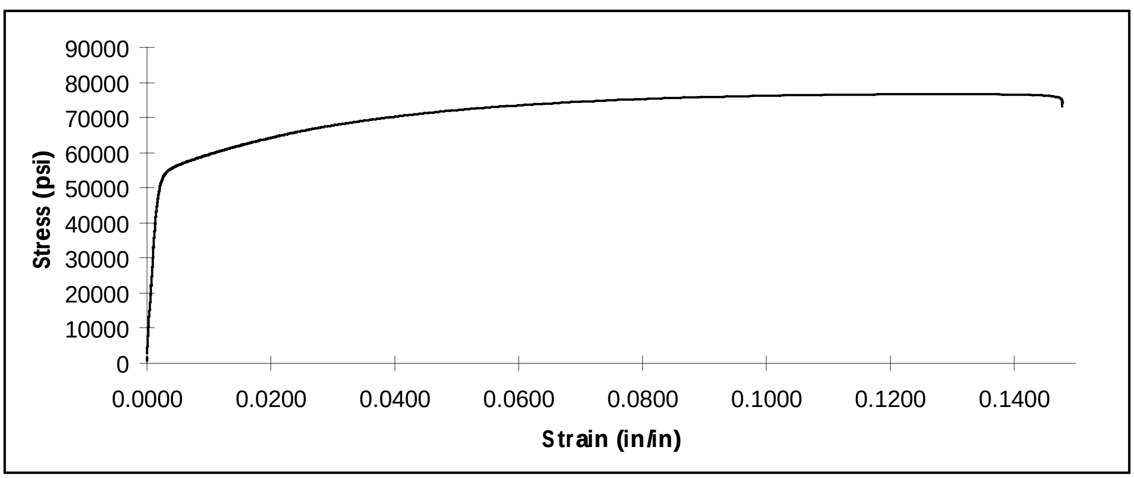
Test Setup:

	Procedure:	Tensile Test
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	53700 psi
.2% Offset Yield:	**55500 psi**
.5 in/in Yield:	56400 psi
Ulimate Strength:	76700 psi
Modulus of elasticity:	29.0 ksi
% Elongation:	37%





RESULTS FROM STIFFNESS MODEL

TEST 1 Z-TF

Deck Type	Through Fastened
Spans	2@25, 1@23
Total Lap Length	2'-0"
Extension into Test Bay	1'-0"
Purlin Designation	CH 4
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	14.32	in^4
Ag =	1.48	in^2
Iy =	2.48	in^4

Middle Bay Section Properties

Ix =	14.32	in^4
Ag =	1.48	in^2
Iy =	2.48	in^4

End Bay Section Properties

Ix =	14.32	in^4
Ag =	1.48	in^2
Iy =	2.48	in^4

Lap Section Properties

Ix =	28.64	in^4
Ag =	2.96	in^2
Iy =	4.96	in^4

Test Bay

Max. (+) Moment =	**4.816**	k-ft
Moment at End of Lap =	**5.247**	k-ft
Shear at End of Lap =	**1.419**	k
Moment at Support =	**6.715**	k-ft
Shear at Support =	**1.519**	k
Max Deflection =	**1.054**	in.

Inflection Point Located at 19.63 ft. from exterior Support.
Max. (+) Moment located at 9.789 ft. from exterior Support
Max. Deflection Located at 10.5 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 4.37 ft. = 52.44 in.

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	5.247	k-ft
Ma =	1.135	k-ft
Mb =	2.386	k-ft
Mc =	3.757	k-ft

Cb = **1.757**

Test ID: Test 1 Z-TF

Michael R. Bryant
8/26/98

Test Span, L = 25.0 ft

I_x = 14.32 in.^{4}

Scan ID	Time	Load w plf	Near Purlin Deflection (6st) in.	Far Purlin Deflection (5st) in.	Theoretical Deflection in.	Manometer in. h2o
1	4:04:22.56 PM	0.000	0.000	0.000	0.000	0.000
2	4:04:32.56 PM	0.112	0.000	0.000	0.001	0.006
3	4:17:12.75 PM	19.099	0.214	0.192	0.202	0.979
4	4:21:50.75 PM	39.761	0.442	0.406	0.420	2.039
5	4:22:34.75 PM	59.754	0.670	0.611	0.631	3.064
6	4:23:16.75 PM	79.636	0.889	0.816	0.841	4.084
7	4:24:20.75 PM	98.064	1.094	1.008	1.036	5.029
8	4:26:28.75 PM	117.053	1.309	1.204	1.236	6.003
9	4:28:58.75 PM	137.604	1.541	1.414	1.453	7.057
10	4:30:28.75 PM	156.255	1.746	1.614	1.650	8.013
11	4:31:18.75 PM	176.025	1.965	1.829	1.859	9.027
12	4:32:40.75 PM	195.683	2.193	2.043	2.066	10.035
13	4:33:32.75 PM	197.340	2.234	2.075	2.084	10.120
14	4:46:02.75 PM	200.363	2.257	2.079	2.116	10.275
15	4:46:32.75 PM	205.160	2.316	2.134	2.167	10.521
16	4:47:22.75 PM	209.859	2.376	2.193	2.216	10.762
17	4:47:52.75 PM	215.436	2.444	2.248	2.275	11.048
18	4:48:08.75 PM	218.342	2.476	2.280	2.306	11.197
19	4:48:14.75 PM	221.579	2.517	2.312	2.340	11.363
20	4:48:26.75 PM	224.601	2.554	2.344	2.372	11.518
21	4:48:48.75 PM	227.721	2.595	2.380	2.405	11.678
22	4:48:56.75 PM	230.178	2.622	2.412	2.431	11.804
23	4:49:10.75 PM	232.206	2.649	2.435	2.452	11.908
24	4:49:38.75 PM	235.541	2.695	2.537	2.487	12.079
25	4:49:58.75 PM	238.349	2.736	2.567	2.517	12.223
26	4:50:16.75 PM	242.366	2.786	2.610	2.559	12.429
27	4:50:24.75 PM	244.257	2.813	2.630	2.579	12.526
28	4:50:40.75 PM	246.168	2.845	2.651	2.599	12.624
29	4:50:48.75 PM	248.391	2.882	2.675	2.623	12.738
30	4:51:04.75 PM	252.525	2.941	2.720	2.667	12.950

Scan ID	Time	Load w plf	Near Purlin Deflection (6st) in.	Far Purlin Deflection (5st) in.	Theoretical Deflection in.	Manometer in. h2o
31	4:51:14.75 PM	254.085	2.973	2.736	2.683	13.030
32	4:52:16.75 PM	260.111	3.078	2.801	2.747	13.339
33	4:52:24.75 PM	262.353	3.119	2.825	2.771	13.454
34	4:52:32.75 PM	263.699	3.146	2.840	2.785	13.523
35	4:52:56.75 PM	267.267	3.215	2.878	2.822	13.706
36	4:53:02.75 PM	268.496	3.242	2.891	2.835	13.769
37	4:53:16.75 PM	270.173	3.279	2.910	2.853	13.855
38	4:53:34.75 PM	272.747	3.333	2.937	2.880	13.987
39	4:53:56.75 PM	278.207	3.434	3.078	2.938	14.267
40	4:54:22.75 PM	282.243	3.539	3.165	2.980	14.474
41	4:54:34.75 PM	282.789	3.566	3.178	2.986	14.502
42	4:54:44.75 PM	285.578	3.611	3.215	3.016	14.645
43	4:54:52.75 PM	289.497	3.684	3.274	3.057	14.846
44	4:54:54.75 PM	290.609	3.707	3.297	3.069	14.903
45	4:55:00.75 PM	293.066	3.771	3.342	3.095	15.029
46	4:55:08.75 PM	295.308	3.839	3.388	3.118	15.144
47	4:55:16.75 PM	296.420	3.885	3.425	3.130	15.201
48	4:55:28.75 PM	297.648	3.940	3.461	3.143	15.264
49	4:55:46.75 PM	300.768	4.026	3.525	3.176	15.424
50	4:56:02.75 PM	302.679	4.099	3.575	3.196	15.522
51	4:56:12.75 PM	305.351	4.163	3.621	3.225	15.659
52	4:56:26.75 PM	306.813	4.236	3.671	3.240	15.734
53	4:56:34.75 PM	308.588	4.291	3.703	3.259	15.825
54	4:56:42.75 PM	310.265	4.341	3.744	3.276	15.911
55	4:56:48.75 PM	310.713	4.382	3.762	3.281	15.934
56	4:56:58.75 PM	312.956	4.455	3.817	3.305	16.049
57	4:57:04.75 PM	314.516	4.514	3.849	3.321	16.129
58	4:57:12.75 PM	317.187	4.624	3.935	3.350	16.266
59	4:57:16.75 PM	318.981	4.701	3.985	3.369	16.358
60	4:57:40.75 PM	319.547	4.847	4.049	3.374	16.387
61	4:57:44.75 PM	320.775	4.911	4.081	3.387	16.450

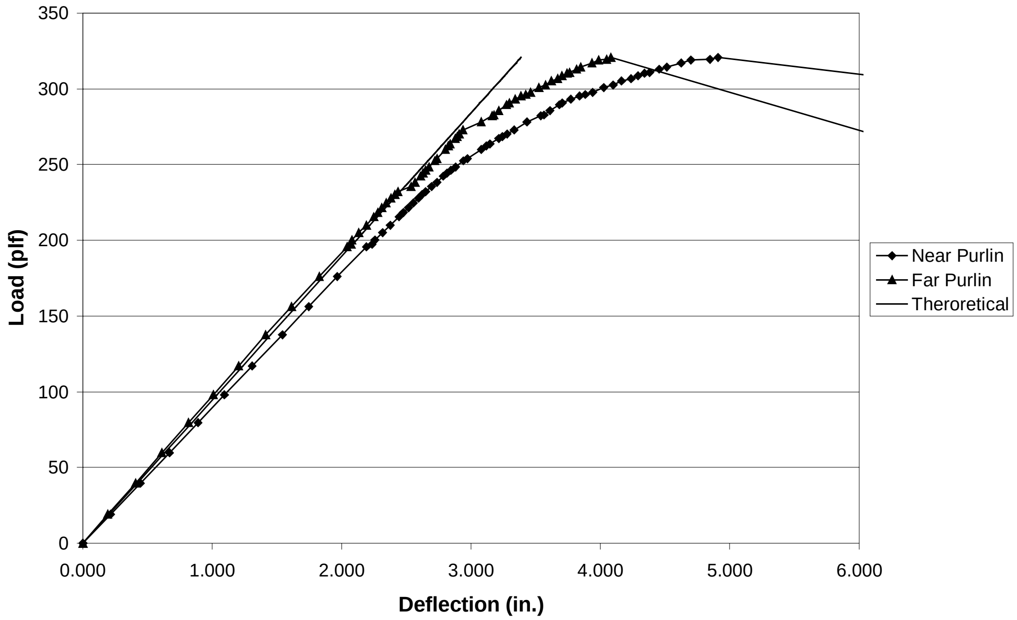
Properti	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange V	A_g, Area
Units	plf	in.	in.	in.	in.	in^2
CH4	4.00	8.06	0.103	2.539	2.565	1.48

S_{et}	F_y	w_o, Self Weig	w_{ts}	S_{et}	F_y
in^3	ksi	plf	plf	in^3	ksi
3.54	55.5	9.05	329.8218	3.54	55.5

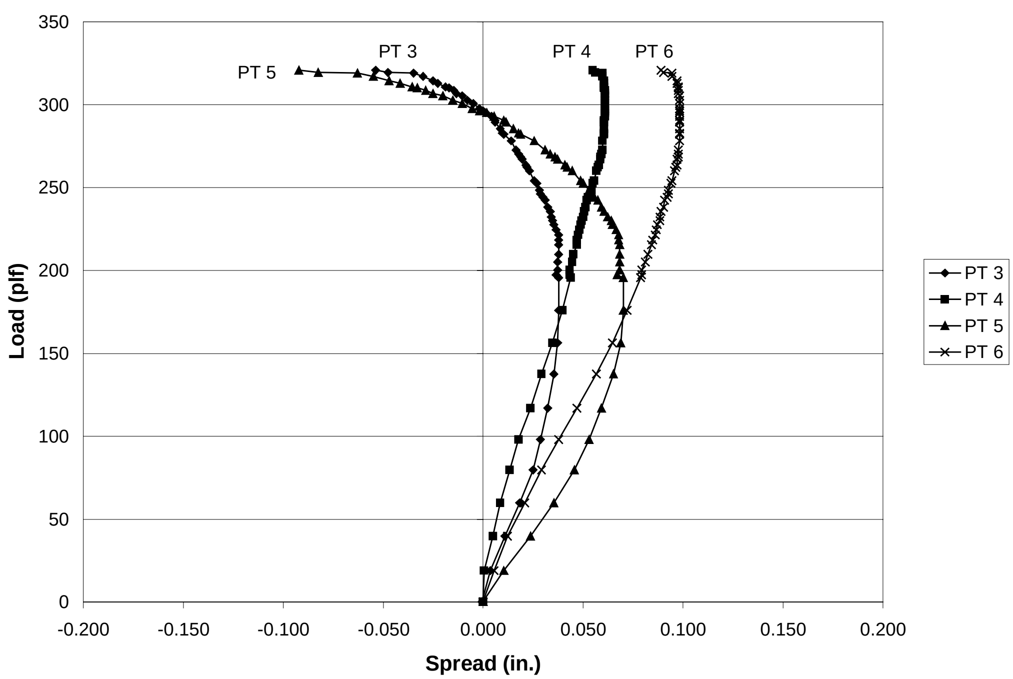
Notes: Opposed Purlins
Through Fastened Panel

Scan ID	Load w plf	Manometer in. h2o	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
1	0.000	0.000	-0.001	0.000	0.000	0.000
2	0.112	0.006	-0.001	0.000	0.000	0.000
3	19.099	0.979	0.004	0.001	0.010	0.005
4	39.761	2.039	0.011	0.005	0.024	0.012
5	59.754	3.064	0.018	0.009	0.035	0.021
6	79.636	4.084	0.025	0.013	0.046	0.029
7	98.064	5.029	0.029	0.018	0.053	0.038
8	117.053	6.003	0.032	0.024	0.059	0.047
9	137.604	7.057	0.035	0.029	0.065	0.057
10	156.255	8.013	0.037	0.035	0.069	0.065
11	176.025	9.027	0.038	0.040	0.070	0.072
12	195.683	10.035	0.038	0.044	0.070	0.079
13	197.340	10.120	0.037	0.043	0.067	0.079
14	200.363	10.275	0.037	0.043	0.068	0.079
15	205.160	10.521	0.037	0.045	0.068	0.081
16	209.859	10.762	0.038	0.045	0.068	0.082
17	215.436	11.048	0.038	0.047	0.068	0.084
18	218.342	11.197	0.038	0.047	0.068	0.085
19	221.579	11.363	0.038	0.048	0.068	0.086
20	224.601	11.518	0.037	0.048	0.067	0.087
21	227.721	11.678	0.035	0.049	0.065	0.087
22	230.178	11.804	0.035	0.049	0.064	0.089
23	232.206	11.908	0.034	0.050	0.062	0.089
24	235.541	12.079	0.034	0.051	0.060	0.089
25	238.349	12.223	0.032	0.051	0.059	0.090
26	242.366	12.429	0.031	0.052	0.057	0.091
27	244.257	12.526	0.030	0.052	0.056	0.092
28	246.168	12.624	0.029	0.054	0.054	0.093
29	248.391	12.738	0.028	0.054	0.053	0.093
30	252.525	12.950	0.027	0.055	0.050	0.094

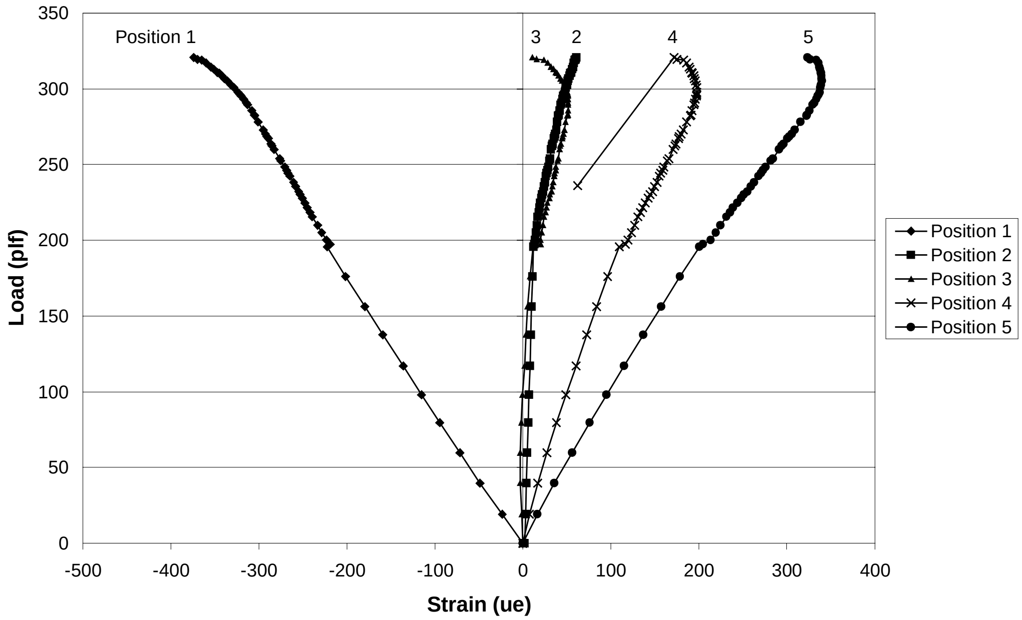
Scan ID	Load w plf	Manometer in. h2o	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
31	254.085	13.030	0.026	0.056	0.049	0.095
32	260.111	13.339	0.023	0.057	0.045	0.096
33	262.353	13.454	0.022	0.057	0.042	0.096
34	263.699	13.523	0.021	0.058	0.041	0.097
35	267.267	13.706	0.020	0.059	0.037	0.097
36	268.496	13.769	0.019	0.059	0.036	0.098
37	270.173	13.855	0.018	0.059	0.034	0.098
38	272.747	13.987	0.016	0.060	0.031	0.098
39	278.207	14.267	0.014	0.060	0.026	0.098
40	282.243	14.474	0.010	0.060	0.019	0.098
41	282.789	14.502	0.010	0.060	0.018	0.098
42	285.578	14.645	0.009	0.060	0.015	0.098
43	289.497	14.846	0.006	0.060	0.012	0.098
44	290.609	14.903	0.006	0.060	0.010	0.098
45	293.066	15.029	0.004	0.061	0.005	0.098
46	295.308	15.144	0.001	0.061	0.002	0.098
47	296.420	15.201	0.000	0.061	-0.002	0.098
48	297.648	15.264	-0.002	0.061	-0.005	0.098
49	300.768	15.424	-0.005	0.061	-0.010	0.098
50	302.679	15.522	-0.008	0.061	-0.015	0.098
51	305.351	15.659	-0.010	0.061	-0.020	0.098
52	306.813	15.734	-0.013	0.061	-0.025	0.098
53	308.588	15.825	-0.015	0.061	-0.029	0.098
54	310.265	15.911	-0.017	0.060	-0.033	0.098
55	310.713	15.934	-0.019	0.060	-0.035	0.098
56	312.956	16.049	-0.023	0.060	-0.042	0.097
57	314.516	16.129	-0.025	0.060	-0.047	0.097
58	317.187	16.266	-0.030	0.060	-0.055	0.095
59	318.981	16.358	-0.035	0.060	-0.063	0.095
60	319.547	16.387	-0.048	0.056	-0.082	0.090
61	320.775	16.450	-0.054	0.055	-0.092	0.089



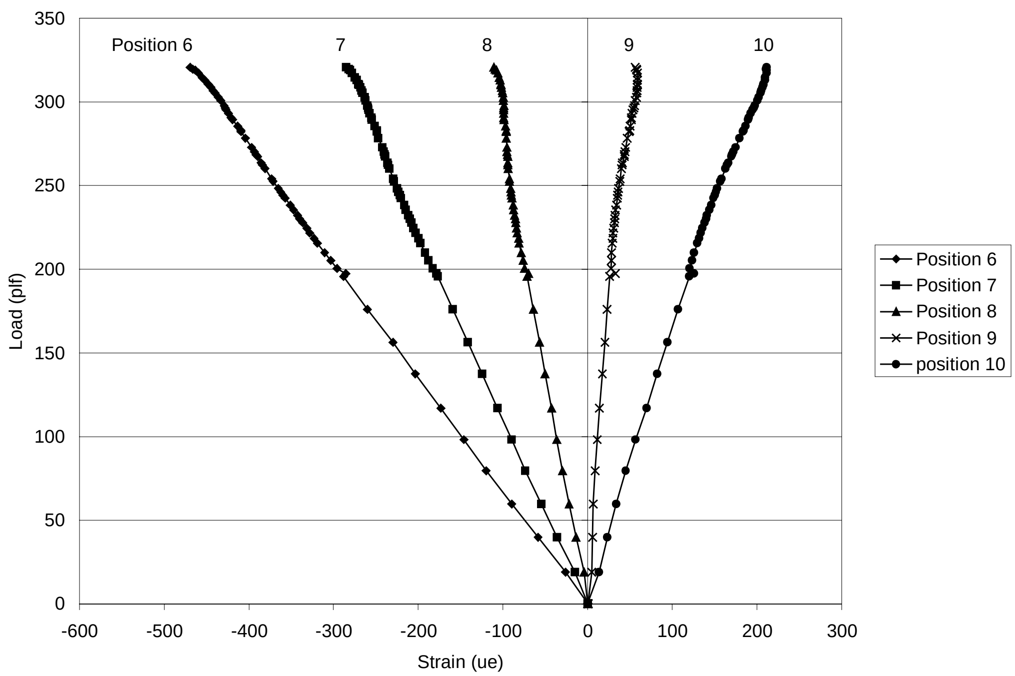
Test 1 Z–TF Load vs. Deflection



Test 1 Z–TF Load vs. Spread



Test 1 Z–TF Load vs. Strain Near Purlin Line



Test 1 Z–TF Load vs. Strain Far Purlin Line

APPENDIX B

TEST 2 Z–SS DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: Test 2 Z-SS
DATE: 1/5/99

TEST DESCRIPTION:

Loading……………………………… Gravity
Panel Type………………………… Standing Seam Panel R= 0.435
Span……………………………… 2@25'-0", 1@23'-0"
Purlin Spacing…………………… 5' o.c. with 1' deck overhang
Lateral Bracing…………………… None
Anti-roll Clips…………………… At the supports of both purlin lines
Web Stiffeners…………………… None
Purlin Orientation………………… Top flanges opposed
Insulation………………………….. 6 in. Blanket with foam blocks

FAILURE MODE:

Positive moment failure of near purlin.

EXPERIMENTAL FAILURE LOAD:

Pressure = 7.27 in. of water

Applied Line Loading = 141.72 plf
Weight of Deck = 4.00 plf
Weight of Purlin = 4.88 plf
Total Applied Load = 150.60 plf

Maximum Moment = 85.30 kip in.
Neg. Moment at Lap = 99.07 kip in.
Shear at Lap = 2.15 kips

PREDICTED FAILURE LOAD: (F_y= 50.6 ksi)

Inflection Point As Bracepoint

Moment = R $F_y S_{eff}$ = 50.6(2.39)(0.435)= 83.20 kip-in.
Predicted Line Load = 147.71 plf

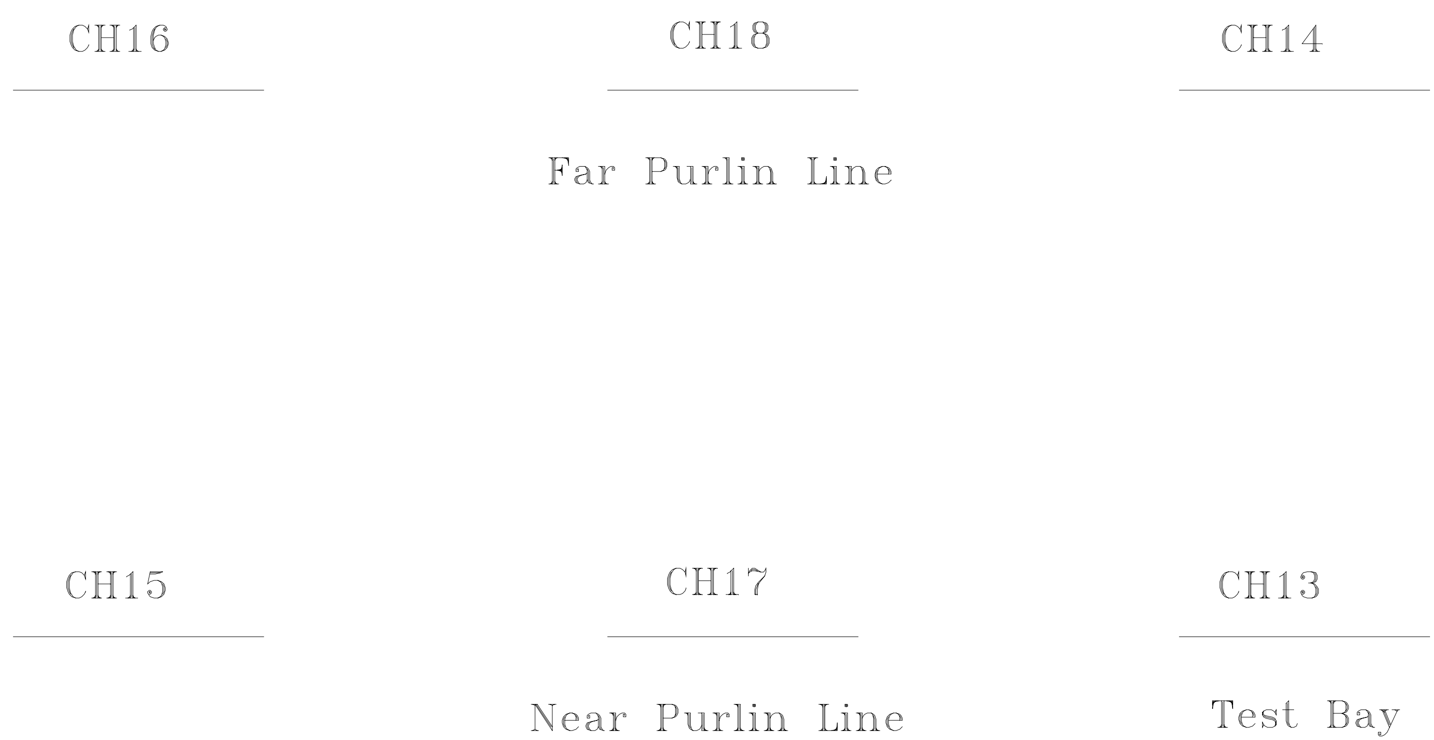
Inflection Point Not As Bracepoint

Moment = R $F_y S_{eff}$ = 50.6(2.39)(0.435)= 83.20 kip-in.
Predicted Line Load = 147.71 plf

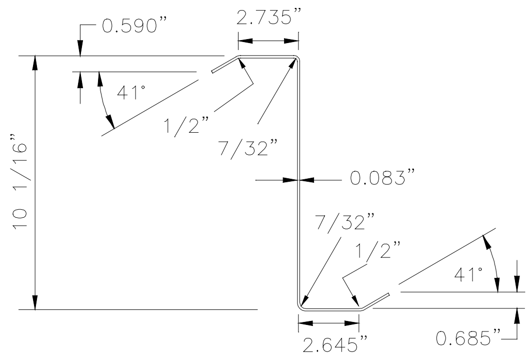
Experimental/Theoretical:

Failure/Predicted = 150.60/147.71 = 1.020 **I.P. Braced**
Failure/Predicted = 150.60/147.71 = 1.020 **I.P. Not Braced**

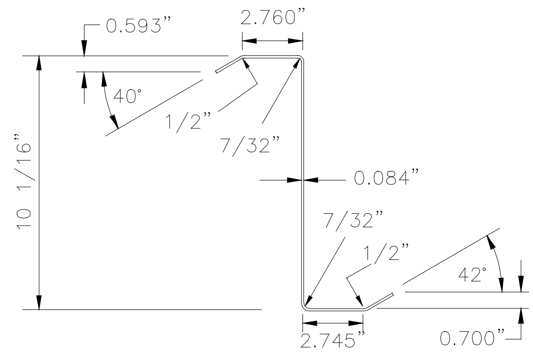
Test 2 Z-SS (Z10) Purlin Locations



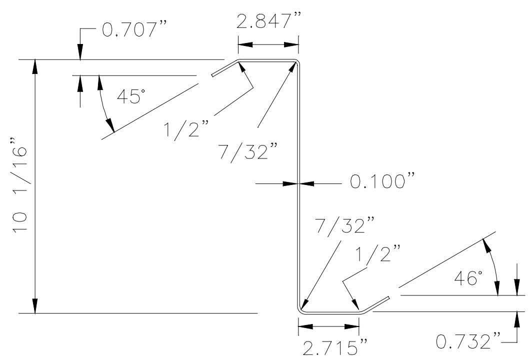
Test 2 Z-SS (Z10) Measured Dimensions



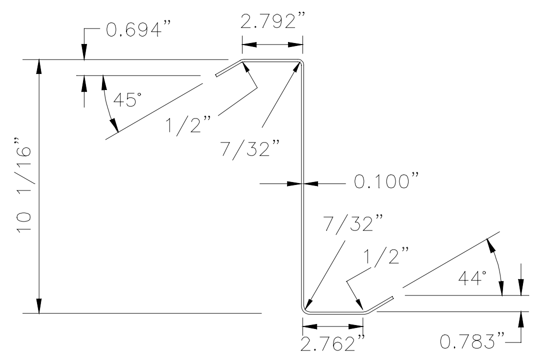
Purlin (CH14)



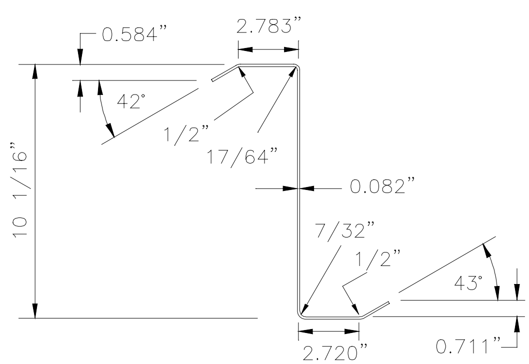
Purlin (CH13)



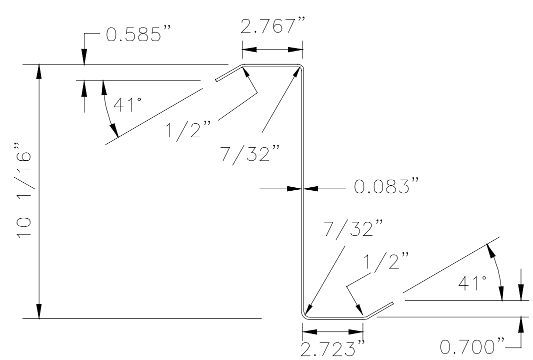
Purlin (CH18)



Purlin (CH17)



Purlin (CH16)



Purlin (CH15)

Results From Commercial Software

TEST 2 Z-SS 10 in. Z-SS 3 span CH 14

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.8993 in.	1.0441 in.
Lip Angle	41 °	41 °
Radii:		
Lip to Flange	0.5 in.	0.5 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.735 in.	2.645 in.
Purlin Depth	10.0625 in.	
Purlin Thickness	0.083 in.	
Yield Stress	50.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.40 in^2
Ix	20.70 in^4
Iy	2.42 in^4
Ixy	5.05 in^4
Flexural Strength	
Ie	19.31 in^4
Se	3.68 in^3

TEST 2 Z-SS 10 in. Z-SS 3 span CH 13

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.9964 in.	1.0176 in.
Lip Angle	49 °	46 °
Radii:		
Lip to Flange	0.4375 in.	0.4375 in.
Flange to Web	0.2656 in.	0.2656 in.
Flange Width	2.498 in.	2.498 in.
Purlin Depth	10.0625 in.	
Purlin Thickness	0.084 in.	
Yield Stress	50.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.43 in^2
Ix	21.12 in^4
Iy	2.60 in^4
Ixy	5.33 in^4
Flexural Strength	
Ie	19.80 in^4
Se	3.78 in^3

Other properties for CH 13

rx	3.8494	in.
ry	1.3538	in.
ro	4.0853	in.
Cw	42.697	in^6
J	0.00249	in^4
α	-14.982	°

TEST 2 Z-SS 10 in. Z-SS 3 span CH 18

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top		Bottom	
Overall Lip Dimension	1.0566	in.	1.0176	in.
Lip Angle	42	°	46	°
Radii:				
Lip to Flange	0.5	in.	0.5	in.
Flange to Web	0.2188	in.	0.2188	in.
Flange Width	2.847	in.	2.715	in.
Purlin Depth	10.0625	in.		
Purlin Thickness	0.100	in.		
Yield Stress	50.6	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.71	in^2
Ix	25.36	in^4
Iy	3.23	in^4
Ixy	6.49	in^4
Flexural Strength		
Ie	24.97	in^4
Se	4.97	in^3

TEST 2 Z-SS 10 in. Z-SS 3 span CH 17

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top		Bottom	
Overall Lip Dimension	0.9815	in.	1.1272	in.
Lip Angle	45	°	44	°
Radii:				
Lip to Flange	0.5	in.	0.5	in.
Flange to Web	0.2188	in.	0.2188	in.
Flange Width	2.792	in.	2.762	in.
Purlin Depth	10.0625	in.		
Purlin Thickness	0.100	in.		
Yield Stress	50.6	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.72	in^2
Ix	25.41	in^4
Iy	3.25	in^4
Ixy	6.52	in^4
Flexural Strength		
Ie	24.90	in^4
Se	4.86	in^3

TEST 2 Z-SS 10 in. Z-SS 3 span CH 16

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top	Bottom
Overall Lip Dimension	0.8728 in.	1.0425 in.
Lip Angle	42 °	43 °
Radii:		
Lip to Flange	0.5 in.	0.5 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.783 in.	2.720 in.
Purlin Depth	10.0625 in.	
Purlin Thickness	0.082 in.	
Yield Stress	50.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.39 in^2
Ix	20.63 in^4
Iy	2.48 in^4
Ixy	5.12 in^4
Flexural Strength	
Ie	19.03 in^4
Se	3.60 in^3

TEST 2 Z-SS 10 in. Z-SS 3 span CH 15

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top	Bottom
Overall Lip Dimension	0.8917 in.	1.067 in.
Lip Angle	41 °	41 °
Radii:		
Lip to Flange	0.5 in.	0.5 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.767 in.	2.723 in.
Purlin Depth	10.0625 in.	
Purlin Thickness	0.083 in.	
Yield Stress	50.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.41 in^2
Ix	20.95 in^4
Iy	2.55 in^4
Ixy	5.23 in^4
Flexural Strength	
Ie	19.43 in^4
Se	3.68 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

149.1 lbs/ft x 1.67 = 249 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

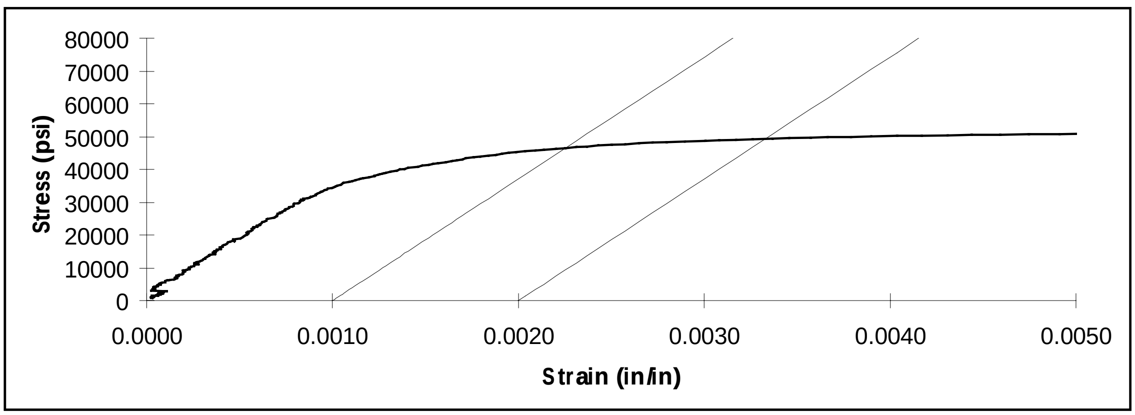
Test Designation:	Chief Multispan Test #2
Specimen Identification:	MB CH 13
Coupon Number:	CH 13
Date:	4/7/99
Gage length (in.):	8.010
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.076
Width (in.):	1.501

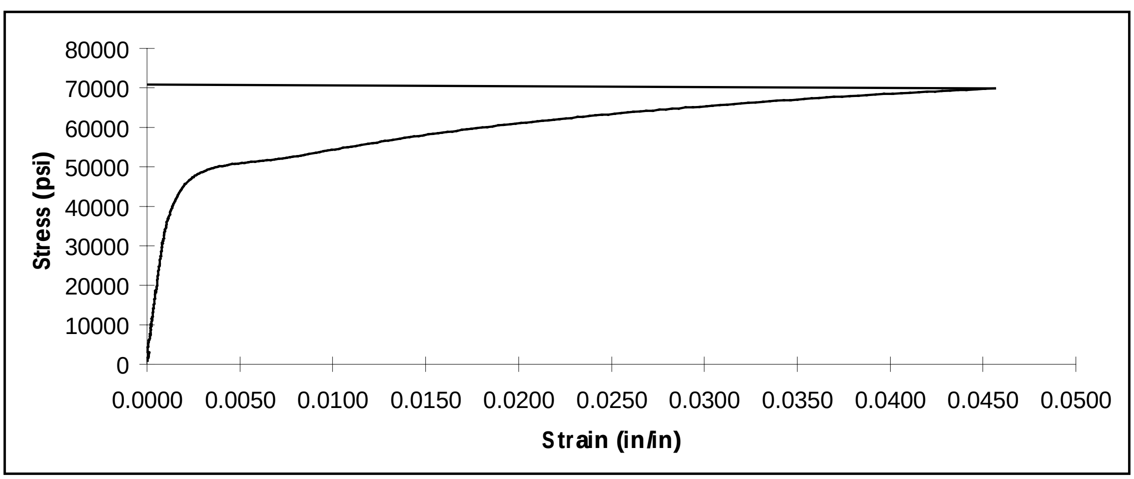
Test Setup:

Procedure: Tensile Test			
Range 1	Rate:	50000 psi/min	
	End Level:	55000 psi	
Range 2	Rate:	10000 psi/min	
	End Level:	0.2 in/in	
Range 3	Rate:	25000 psi/min	
	End Level:	Sample Break	

Test Data:

.1% Offset Yield:	46600 psi
.2% Offset Yield:	**49300 psi**
.5 in/in Yield:	50800 psi
Ulimate Strength:	76000 psi
Modulus of elasticity:	37.1 ksi
% Elongation:	23%





TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

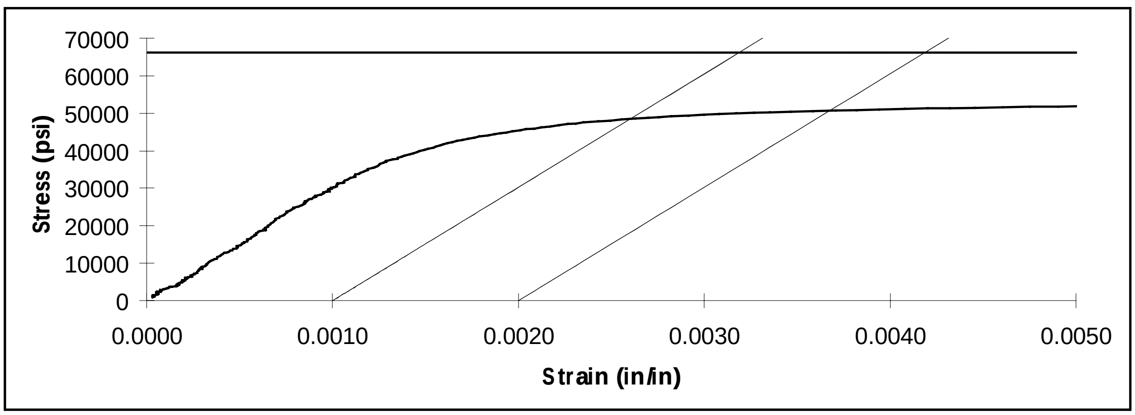
Test Designation:	Chief Multispan Test #2
Specimen Identification:	MB CH 14
Coupon Number:	CH 14
Date:	4/7/99
Gage length (in.):	8.015
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.076
Width (in.):	1.500

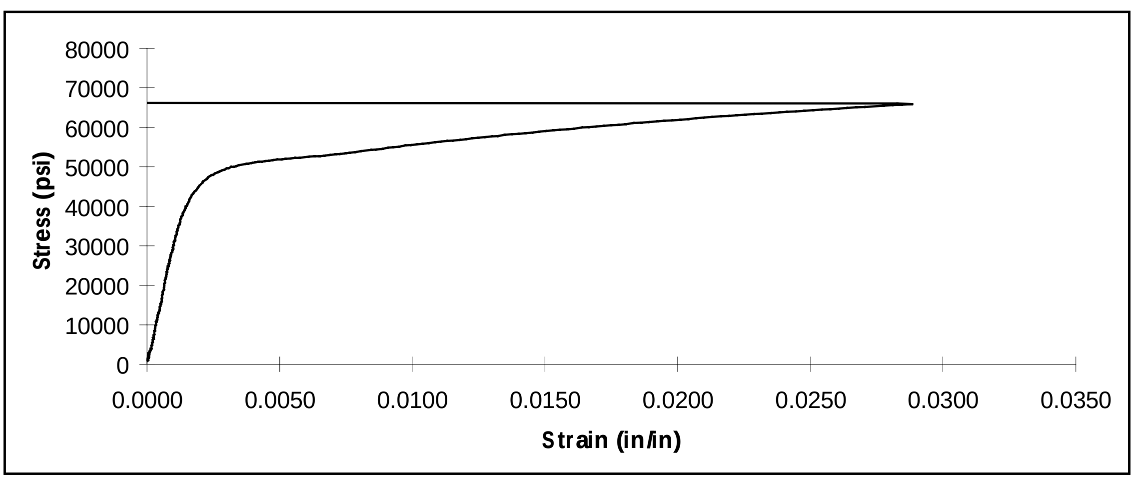
Test Setup:

	Procedure:	Tensile Test
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	48300 psi
.2% Offset Yield:	**50600 psi**
.5 in/in Yield:	51800 psi
Ulimate Strength:	77000 psi
Modulus of elasticity:	30.3 ksi
% Elongation:	21%





RESULTS FROM STIFFNESS MODEL

TEST 2 Z-SS

Deck Type	Standing Seam
Spans	2@25, 1@23
Total Lap Length	2'-0"
Extension into Test Bay	1'-0"
Purlin Designation	CH13, CH17, CH15
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	18.75	in^4
Ag =	1.25	in^2
Iy =	2.29	in^4

Middle Bay Section Properties

Ix =	25.42	in^4
Ag =	1.72	in^2
Iy =	3.25	in^4

End Bay Section Properties

Ix =	18.75	in^4
Ag =	1.25	in^2
Iy =	2.29	in^4

Lap Section Properties

Ix =	44.15	in^4
Ag =	2.97	in^2
Iy =	5.54	in^4

Test Bay

Max. (+) Moment =	**4.735**	k-ft
Moment at End of Lap =	**5.445**	k-ft
Shear at End of Lap =	**1.427**	k
Moment at Support =	**6.922**	k-ft
Shear at Support =	**1.527**	k
Max Deflection =	**0.7855**	in.

Inflection Point Located at 19.43 ft. from exterior Support.
Max. (+) Moment located at 9.737 ft. from exterior Support
Max. Deflection Located at 10.9 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 4.57 ft. = 54.84 in.

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	5.445	k-ft
Ma =	1.174	k-ft
Mb =	2.479	k-ft
Mc =	3.916	k-ft
Cb =	**1.754**	

Test ID: Test 2 Z-SS

Michael R. Bryant
1/5/99

Test Span, L = 25.0 ft I_x = 21.12 $in.^4$

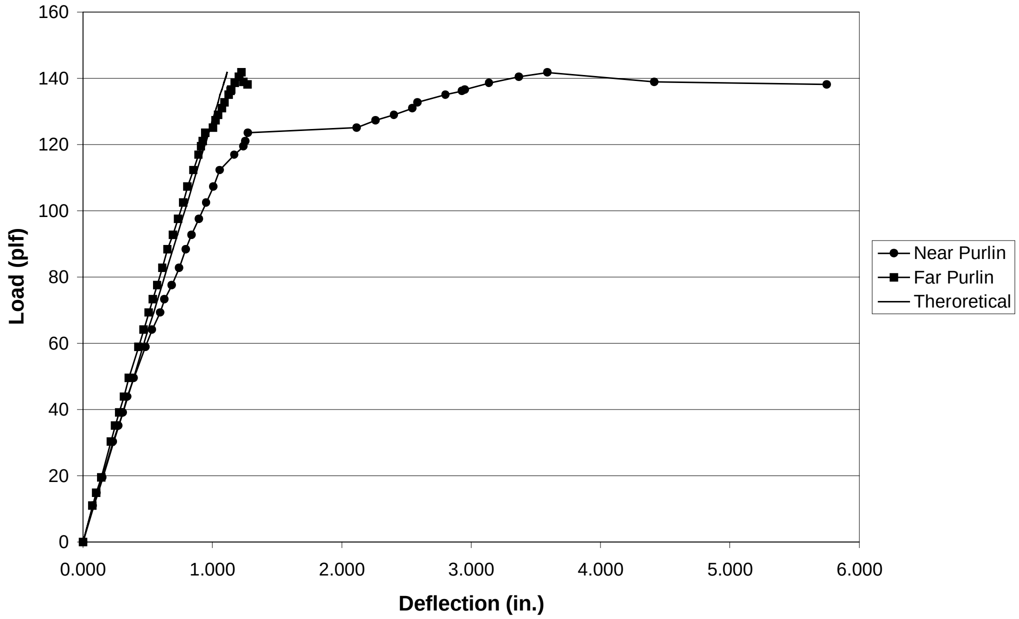
Scan ID	Time	Load w plf	Near Purlin Deflection (7dc) in.	Far Purlin Deflection (9dc) in.	Theoretical Deflection in.	Manometer in. h2o	Lateral Deflection in.
1	2:33:40.87 PM	0.000	0.000	0.000	0.000	0.000	0.000
2	2:35:33.87 PM	10.924	0.078	0.075	0.086	0.560	-0.021
3	2:35:45.87 PM	14.859	0.105	0.101	0.117	0.762	-0.020
4	2:37:04.87 PM	19.499	0.149	0.141	0.153	1.000	-0.026
5	2:37:26.87 PM	30.246	0.231	0.215	0.238	1.551	-0.032
6	2:37:47.87 PM	35.121	0.273	0.248	0.276	1.801	-0.037
7	2:38:21.87 PM	39.115	0.309	0.281	0.307	2.006	-0.035
8	2:39:17.87 PM	43.873	0.343	0.315	0.345	2.250	-0.040
9	2:41:09.87 PM	49.511	0.393	0.354	0.389	2.539	-0.043
10	2:42:20.87 PM	58.910	0.483	0.428	0.463	3.021	-0.056
11	2:43:30.87 PM	64.077	0.534	0.468	0.503	3.286	-0.069
12	2:45:16.87 PM	69.246	0.595	0.508	0.544	3.551	-0.092
13	2:45:54.87 PM	73.299	0.630	0.541	0.576	3.759	-0.096
14	2:46:48.87 PM	77.528	0.686	0.574	0.609	3.976	-0.114
15	2:48:30.87 PM	82.813	0.743	0.614	0.651	4.247	-0.131
16	2:49:40.87 PM	88.452	0.794	0.653	0.695	4.536	-0.133
17	2:50:17.87 PM	92.740	0.839	0.695	0.728	4.756	-0.141
18	2:51:26.87 PM	97.555	0.896	0.733	0.766	5.003	-0.156
19	2:53:11.87 PM	102.430	0.952	0.774	0.805	5.253	-0.172
20	2:53:52.87 PM	107.246	1.008	0.807	0.842	5.500	-0.189
21	2:54:37.87 PM	112.238	1.057	0.854	0.882	5.756	-0.197
22	2:55:23.87 PM	116.879	1.169	0.893	0.918	5.994	-0.266
23	2:56:36.87 PM	119.463	1.240	0.914	0.938	6.126	-0.313
24	2:56:45.87 PM	121.048	1.254	0.927	0.951	6.208	-0.306
25	2:56:51.87 PM	123.573	1.275	0.947	0.971	6.337	-0.308
26	2:57:07.87 PM	125.042	2.115	1.006	0.982	6.412	-1.070
27	2:57:13.87 PM	127.333	2.262	1.027	1.000	6.530	-1.193
28	2:57:22.87 PM	128.977	2.403	1.046	1.013	6.614	-1.307
29	2:57:43.87 PM	130.915	2.546	1.073	1.028	6.714	-1.424
30	2:58:08.87 PM	132.737	2.586	1.093	1.043	6.807	-1.445
31	2:59:00.87 PM	135.028	2.802	1.127	1.061	6.925	-1.607
32	2:59:19.87 PM	136.085	2.928	1.140	1.069	6.979	-1.704
33	2:59:32.87 PM	136.613	2.951	1.147	1.073	7.006	-1.722
34	3:00:28.87 PM	138.610	3.139	1.173	1.089	7.108	-1.856
35	3:00:46.87 PM	140.490	3.371	1.206	1.104	7.205	-2.029
36	3:01:14.87 PM	141.722	3.589	1.226	1.113	7.268	-2.197
37	3:01:30.87 PM	138.904	4.415	1.241	1.091	7.123	-2.819
38	3:01:44.87 PM	138.140	5.750	1.272	1.085	7.084	-3.720

Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width	Ag, Area	Set
Units	plf	in.	in.	in.	in.	in^2	in^3
CH13	4.00	10.06	0.084	2.760	2.745	1.43	3.78

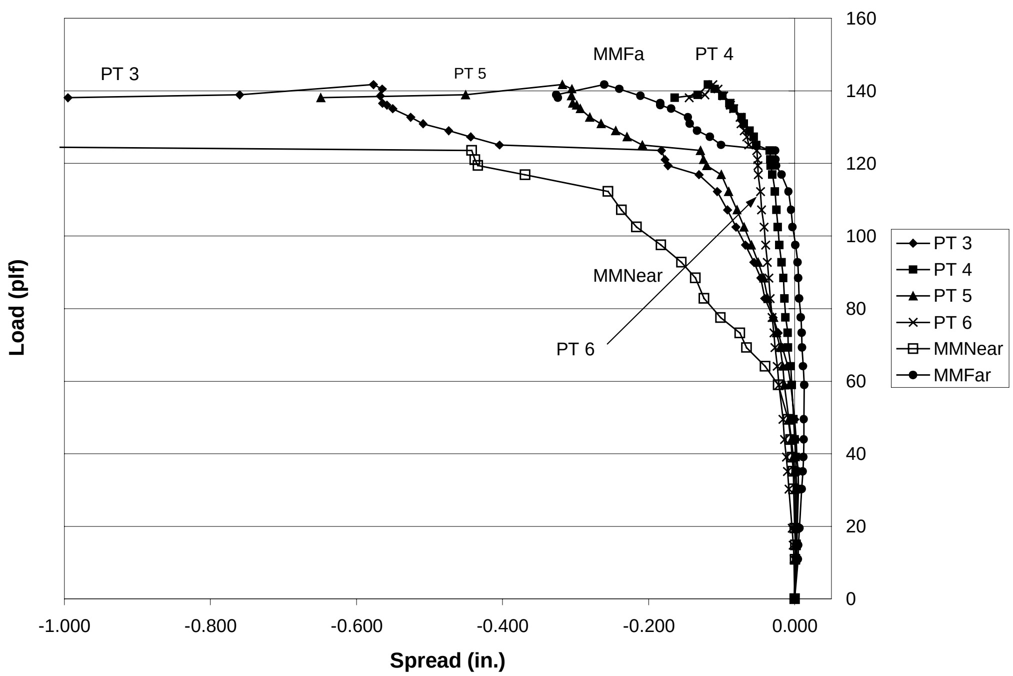
w_o, Self Weight	w_{ts}	Set	F_y
plf	plf	in^3	ksi
8.88	150.60	3.78	50.6

Notes:	
	Opposed Purlins
	Standing Seam Panel
	6 in. blanket insulation
	Foam Blocks

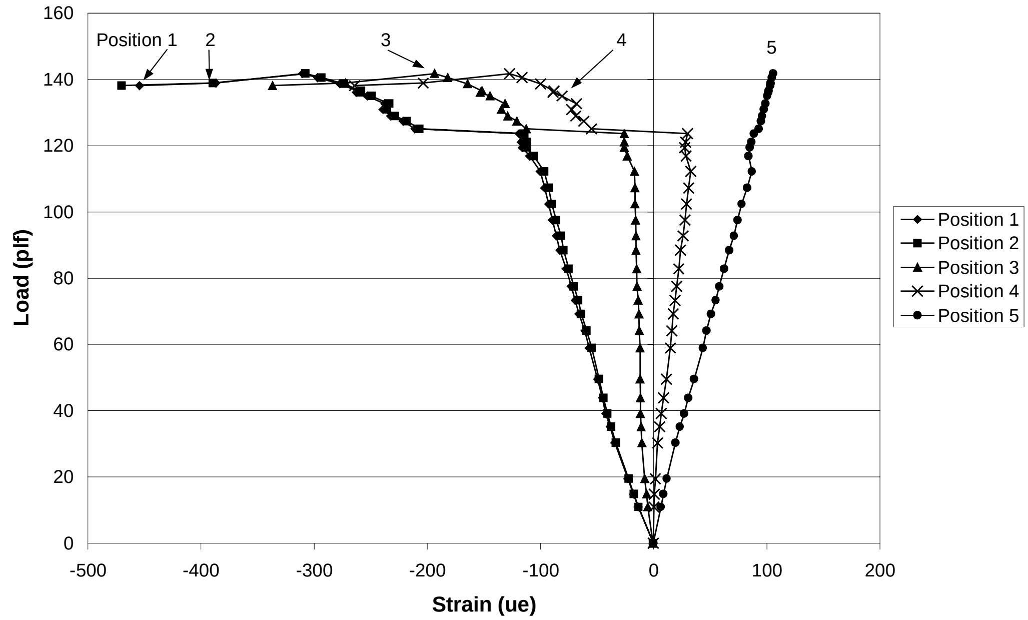
Scan ID	Manometer in. h2o	Load w plf	Max Mom Near in.	Max Mom Far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.	 (5dc) in.
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.560	10.924	0.001	0.004	0.002	0.002	0.001	-0.001	0.040
3	0.762	14.859	0.001	0.005	0.003	0.003	0.001	-0.002	0.060
4	1.000	19.499	0.000	0.007	0.004	0.003	0.001	-0.003	0.087
5	1.551	30.246	-0.001	0.010	0.005	0.003	0.001	-0.008	0.140
6	1.801	35.121	-0.002	0.011	0.005	0.001	-0.001	-0.010	0.167
7	2.006	39.115	-0.003	0.012	0.003	0.001	-0.002	-0.011	0.193
8	2.250	43.873	-0.005	0.012	0.002	0.000	-0.005	-0.014	0.213
9	2.539	49.511	-0.009	0.013	0.000	-0.001	-0.008	-0.016	0.246
10	3.021	58.910	-0.023	0.013	-0.006	-0.004	-0.014	-0.021	0.300
11	3.286	64.077	-0.040	0.011	-0.010	-0.005	-0.017	-0.024	0.326
12	3.551	69.246	-0.066	0.010	-0.017	-0.009	-0.020	-0.027	0.352
13	3.759	73.299	-0.075	0.010	-0.023	-0.010	-0.025	-0.029	0.373
14	3.976	77.528	-0.102	0.009	-0.030	-0.013	-0.029	-0.031	0.399
15	4.247	82.813	-0.124	0.006	-0.041	-0.014	-0.037	-0.033	0.426
16	4.536	88.452	-0.136	0.005	-0.047	-0.016	-0.043	-0.035	0.460
17	4.756	92.740	-0.155	0.004	-0.056	-0.018	-0.050	-0.037	0.486
18	5.003	97.555	-0.183	0.001	-0.068	-0.021	-0.060	-0.040	0.513
19	5.253	102.430	-0.217	-0.003	-0.081	-0.023	-0.070	-0.042	0.540
20	5.500	107.246	-0.237	-0.005	-0.092	-0.025	-0.079	-0.045	0.566
21	5.756	112.238	-0.256	-0.008	-0.106	-0.027	-0.090	-0.047	0.594
22	5.994	116.879	-0.369	-0.018	-0.131	-0.031	-0.101	-0.050	0.619
23	6.126	119.463	-0.434	-0.026	-0.174	-0.033	-0.121	-0.050	0.634
24	6.208	121.048	-0.438	-0.026	-0.178	-0.034	-0.125	-0.051	0.648
25	6.337	123.573	-0.442	-0.027	-0.183	-0.034	-0.129	-0.052	0.661
26	6.412	125.042	-1.398	-0.101	-0.404	-0.052	-0.209	-0.063	0.640
27	6.530	127.333	-1.407	-0.116	-0.444	-0.056	-0.230	-0.066	0.640
28	6.614	128.977	-1.397	-0.134	-0.474	-0.062	-0.245	-0.069	0.641
29	6.714	130.915	-1.398	-0.143	-0.509	-0.070	-0.265	-0.074	0.639
30	6.807	132.737	-1.400	-0.146	-0.526	-0.072	-0.281	-0.075	0.648
31	6.925	135.028	-1.402	-0.169	-0.550	-0.083	-0.294	-0.084	0.654
32	6.979	136.085	-1.403	-0.184	-0.558	-0.088	-0.299	-0.088	0.654
33	7.006	136.613	-1.404	-0.184	-0.564	-0.090	-0.304	-0.089	0.654
34	7.108	138.610	-1.411	-0.211	-0.568	-0.099	-0.305	-0.097	0.661
35	7.205	140.490	-1.402	-0.240	-0.565	-0.110	-0.305	-0.105	0.661
36	7.268	141.722	-1.332	-0.261	-0.577	-0.119	-0.318	-0.112	0.653
37	7.123	138.904	-1.577	-0.326	-0.760	-0.132	-0.451	-0.123	0.606
38	7.084	138.140	-1.560	-0.324	-0.995	-0.164	-0.649	-0.145	0.533



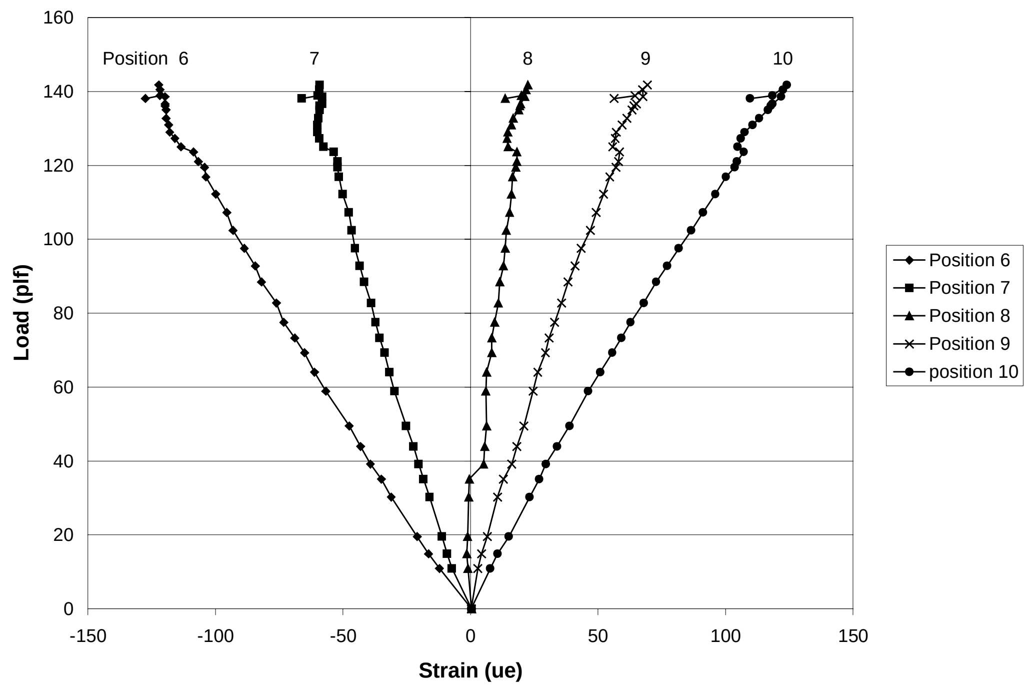
Test 2 Z–SS Load vs. Vertical Deflection



Test 2 Z-SS Load vs. Strain



Test 2 Z–SS Load vs. Strain Near Purlin Line



Test 2 Z–SS Load vs. Strain Far Purlin Line

APPENDIX C

TEST 3 C–SS DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: Test 3 C-SS
DATE: 1/21/99

TEST DESCRIPTION:

Loading……………………………… Gravity
Panel Type………………………… Standing Seam Panel (R = 0.453)
Span………………………………… 1@24'-6", 1@25'-0", 1@23'-0"
Purlin Spacing…………………… 5' o.c. with 1' deck overhang
Lateral Bracing…………………… None
Anti-roll Clips……………………… At the exterior supports of both purlin lines
Web Stiffeners…………………… None
Purlin Orientation………………… Top flanges opposed
Insulation………………………….. 6 in. Blanket with foam blocks

FAILURE MODE:

Positive moment failure of near purlin.

EXPERIMENTAL FAILURE LOAD:

Pressure =	10.81	in. of water
Applied Line Loading =	210.83	plf
Weight of Deck =	4.00	plf
Weight of Purlin =	4.81	plf
Total Applied Load =	219.64	plf
Maximum (+) Moment =	119.82	kip in.
Neg. Moment at Lap =	137.16	kip in.
Shear at Lap =	3.07	kips

PREDICTED FAILURE LOAD: (F_y= 87.5 ksi)

Inflection Point As Bracepoint

Moment = R $F_y S_{eff}$ =	87.5(3.15)(0.453)=	124.86	kip-in.
Predicted Line Load =		229.52	plf

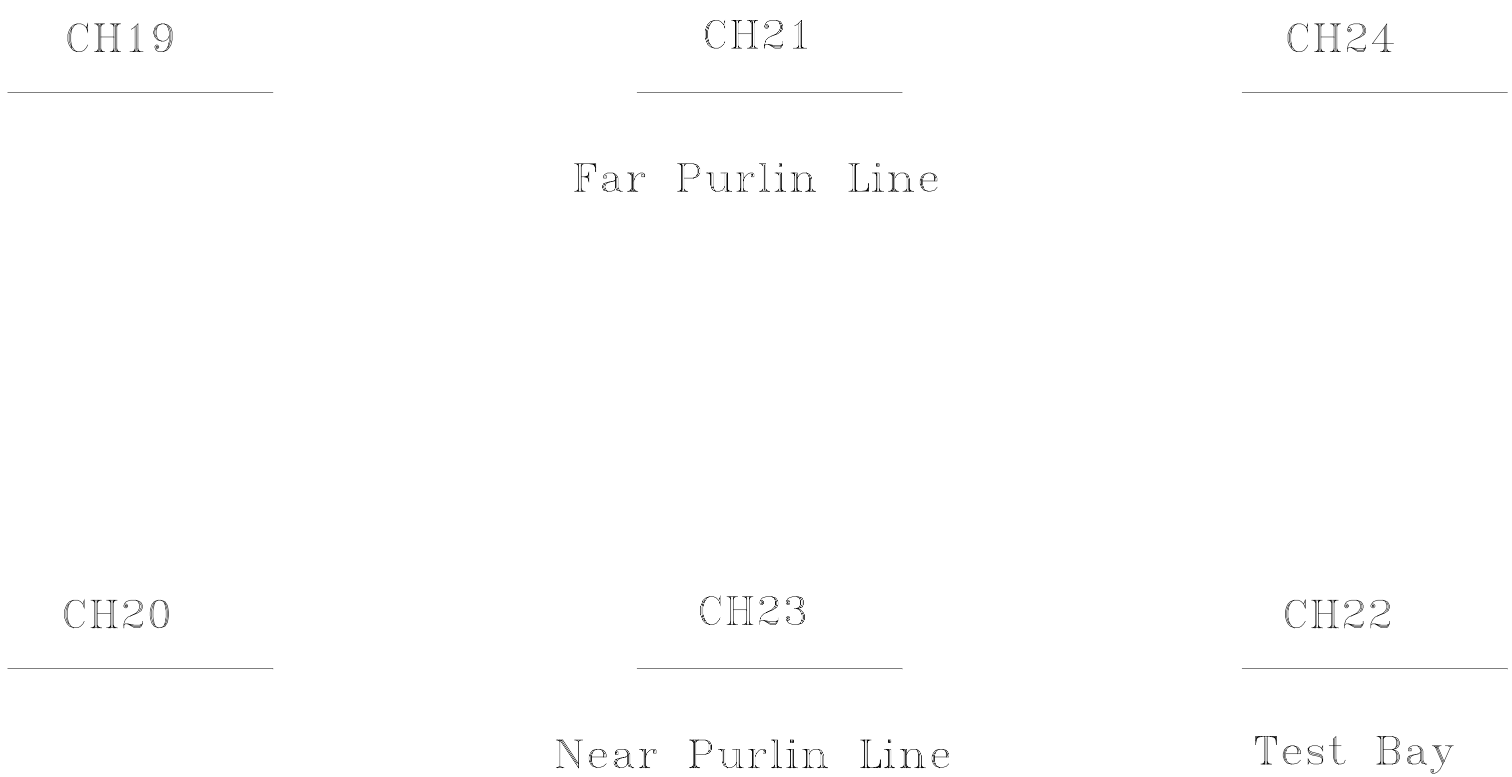
Inflection Point Not As Bracepoint

Moment = R $F_y S_{eff}$ =	87.5(3.15)(0.453)=	124.86	kip-in.
Predicted Line Load =		229.52	plf

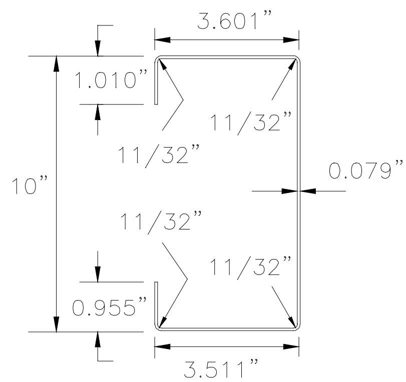
Experimental/Predicted:

Failure/Predicted =	219.64/229.52=	0.957	**I.P. Braced**
Failure/Predicted =	219.64/229.52=	0.957	**I.P. Not Braced**

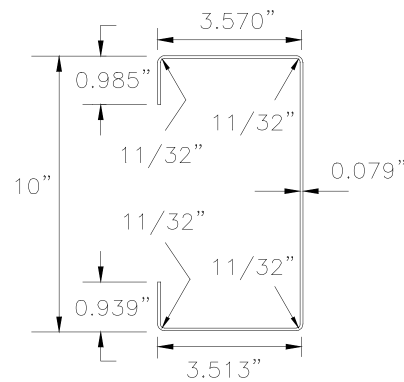
Test 3 C-SS (Z10) Purlin Locations



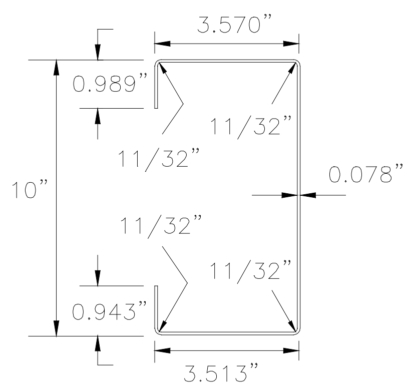
Test 3 C-SS (C10) Measured Dimensions



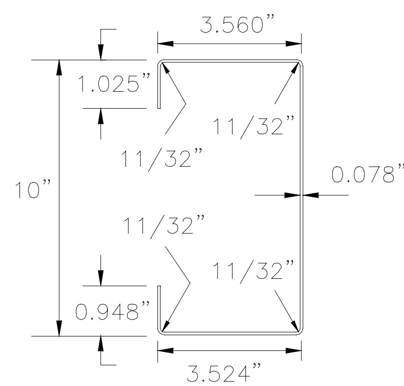
Purlin (CH24)



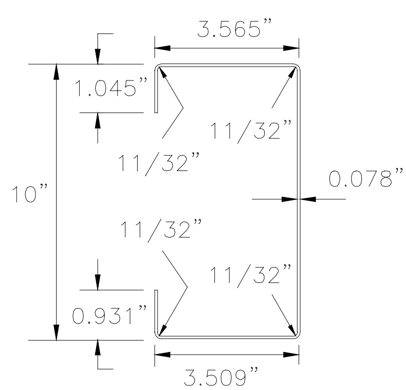
Purlin (CH22)



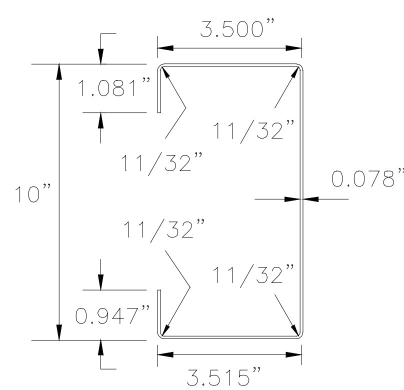
Purlin (CH21)



Purlin (CH23)



Purlin (CH19)



Purlin (CH20)

Results From Commercial Software

TEST 3 C-SS 10 in. C-SS 3 span CH 24

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.025 in.	0.9489 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3438 in.	0.3438 in.
Flange to Web	0.3438 in.	0.3438 in.
Flange Width	3.560 in.	3.524 in.
Purlin Depth	10 in.	
Purlin Thickness	0.079 in.	
Yield Stress	87.7 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.43 in^2
Ix	21.63 in^4
Iy	2.28 in^4
Ixy	0.23 in^4
Flexural Strength	
Ie	18.24 in^4
Se	3.29 in^3

TEST 3 C-SS 10 in. C-SS 3 span CH 22

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.985 in.	0.939 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3438 in.	0.3438 in.
Flange to Web	0.3438 in.	0.3438 in.
Flange Width	3.570 in.	3.513 in.
Purlin Depth	10 in.	
Purlin Thickness	0.079 in.	
Yield Stress	87.7 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.42 in^2
Ix	21.56 in^4
Iy	2.26 in^4
Ixy	0.23 in^4
Flexural Strength	
Ie	18.09 in^4
Se	3.25 in^3

Other properties for CH 22

rx	3.889	in.
ry	1.2742	in.
ro	4.7942	in.
Cw	44.849	in^6
J	0.00285	in^4
Xo	-2.4946	in.

TEST 3 C-SS 10 in. C-SS 3 span CH 21

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top		Bottom	
Overall Lip Dimension	0.989	in.	0.943	in.
Lip Angle	90	°	90	°
Radii:				
Lip to Flange	0.3438	in.	0.3438	in.
Flange to Web	0.3438	in.	0.3438	in.
Flange Width	3.570	in.	3.513	in.
Purlin Depth	10	in.		
Purlin Thickness	0.078	in.		
Yield Stress	87.7	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.41	in^2
Ix	21.31	in^4
Iy	2.24	in^4
Ixy	0.23	in^4
Flexural Strength		
Ie	17.81	in^4
Se	3.19	in^3

TEST 3 C-SS 10 in. C-SS 3 span CH 23

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top		Bottom	
Overall Lip Dimension	1.025	in.	0.948	in.
Lip Angle	90	°	90	°
Radii:				
Lip to Flange	.0.3438	in.	0.3438	in.
Flange to Web	0.3438	in.	0.3438	in.
Flange Width	3.560	in.	3.524	in.
Purlin Depth	10	in.		
Purlin Thickness	0.078	in.		
Yield Stress	87.7	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.41	in^2
Ix	21.36	in^4
Iy	2.26	in^4
Ixy	0.22	in^4
Flexural Strength		
Ie	17.94	in^4
Se	3.23	in^3

TEST 3 C-SS 10 in. C-SS 3 span CH 19

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top		Bottom	
Overall Lip Dimension	1.045	in.	0.931	in.
Lip Angle	90	°	90	°
Radii:				
Lip to Flange	0.3438	in.	0.3438	in.
Flange to Web	0.3438	in.	0.3438	in.
Flange Width	3.565	in.	3.509	in.
Purlin Depth	10	in.		
Purlin Thickness	0.078	in.		
Yield Stress	87.7	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.41 in^2
Ix	21.44 in^4
Iy	2.28 in^4
Ixy	0.23 in^4
Flexural Strength	
Ie	18.04 in^4
Se	3.25 in^3

TEST 3 C-SS 10 in. C-SS 3 span CH 20

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top		Bottom	
Overall Lip Dimension	1.081	in.	0.947	in.
Lip Angle	90	°	90	°
Radii:				
Lip to Flange	0.3438	in.	0.3438	in.
Flange to Web	0.3438	in.	0.3438	in.
Flange Width	3.500	in.	3.515	in.
Purlin Depth	10	in.		
Purlin Thickness	0.078	in.		
Yield Stress	87.7	ksi		
Modulus of Elasticity	29500	ksi		

Purlin Properties

Ag	1.41 in^2
Ix	21.30 in^4
Iy	2.23 in^4
Ixy	0.20 in^4
Flexural Strength	
Ie	18.09 in^4
Se	3.28 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

190.3 lbs/ft x 1.67 = 317.8 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

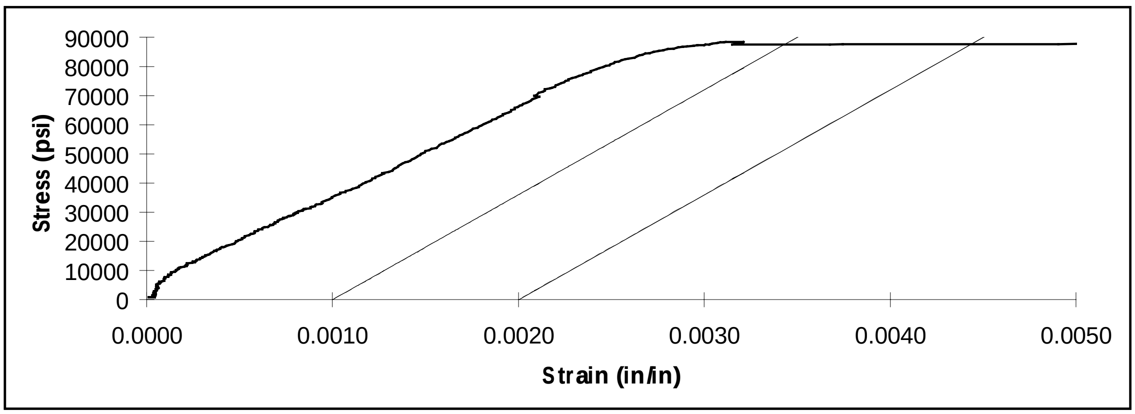
Test Designation:	Chief Multispan Test #3
Specimen Identification:	MB CH 24
Coupon Number:	1
Date:	12/18/98
Gage length (in.):	8.007
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.079
Width (in.):	1.507

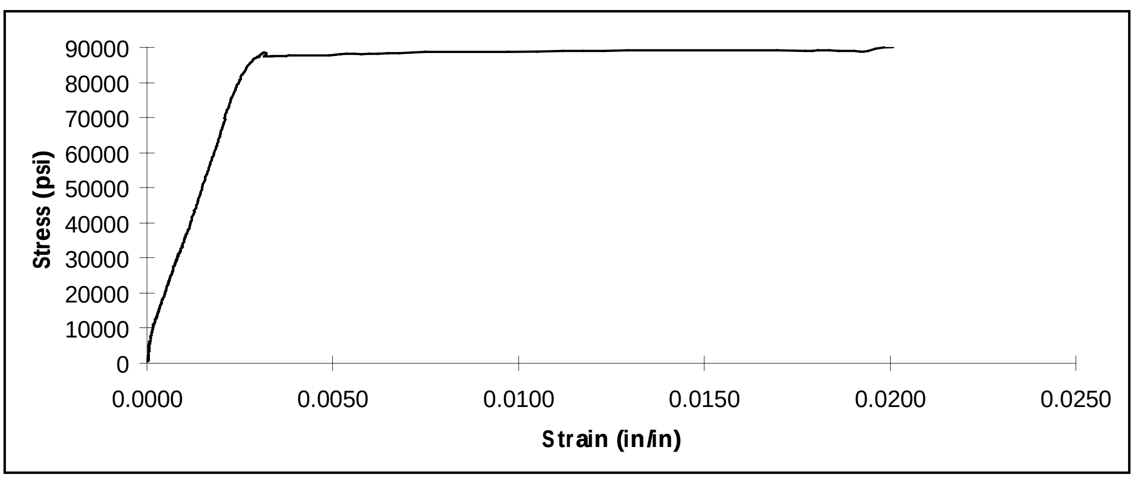
Test Setup:

Procedure: Tensile Test		
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	87500 psi
.2% Offset Yield:	**87700 psi**
.5 in/in Yield:	87700 psi
Ulimate Strength:	100700 psi
Modulus of elasticity:	36.0 ksi
% Elongation:	10%





TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

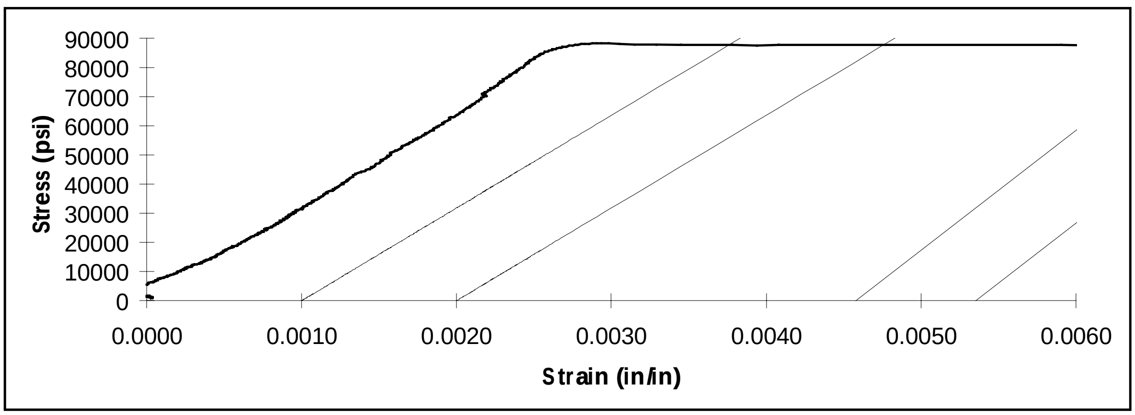
Test Designation:	Chief Multispan Test #3
Specimen Identification:	MB CH 22
Coupon Number:	2
Date:	12/18/98
Gage length (in.):	7.997
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.078
Width (in.):	1.505

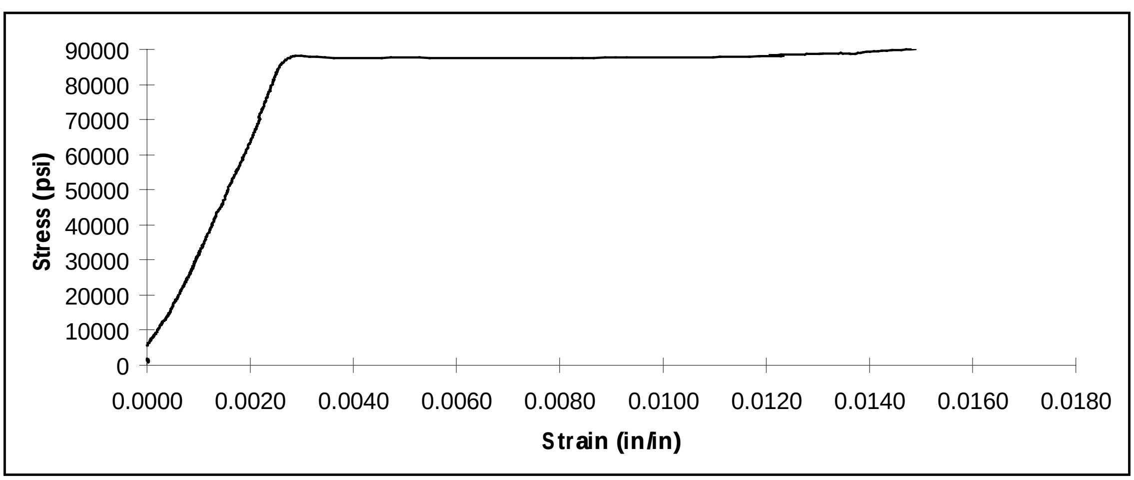
Test Setup:

Procedure: Tensile Test		
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	87600 psi
.2% Offset Yield:	**87700 psi**
.5 in/in Yield:	87700 psi
Ulimate Strength:	102500 psi
Modulus of elasticity:	31.8 ksi
% Elongation:	10%





RESULTS FROM STIFFNESS MODEL

TEST 3 C-SS

Deck Type	Standing Seam
Spans	1@24.5, 1@25, 1@23
Total Lap Length	3'-0"
Extension into Test Bay	1'-0"
Purlin Designation	CH22
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	21.56	in^4
Ag =	1.42	in^2
Iy =	2.26	in^4

Middle Bay Section Properties

Ix =	21.56	in^4
Ag =	1.42	in^2
Iy =	2.26	in^4

End Bay Section Properties

Ix =	21.56	in^4
Ag =	1.42	in^2
Iy =	2.26	in^4

Lap Section Properties

Ix =	43.12	in^4
Ag =	2.84	in^2
Iy =	4.52	in^4

Test Bay

Max. (+) Moment =	**4.548**	k-ft
Moment at End of Lap =	**5.204**	k-ft
Shear at End of Lap =	**1.396**	k
Moment at Support =	**6.646**	k-ft
Shear at Support =	**1.496**	k
Max Deflection =	**0.6168**	in.

Inflection Point Located at 19.07 ft. from exterior Support.
Max. (+) Moment located at 9.5 ft. from exterior Support
Max. Deflection Located at 10.71 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 4.43 ft. = 51.96 in.

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	5.204	k-ft
Ma =	1.117	k-ft
Mb =	2.356	k-ft
Mc =	3.719	k-ft
Cb =	**1.761**	

Test ID: Test 3 C-SS

Michael R. Bryant
1/21/99

Test Span, L = 24.5 ft

I_x = 21.56 $in.^4$

Scan ID	Time	Load w plf	Near Purlin Deflection (7dc) in.	Far Purlin Deflection (9dc) in.	Theoretical Deflection in.	Manometer in. h2o	Lateral Deflection in.
1	12:20:45 AM	0.000	0.000	0.000	0.000	0.000	-0.001
2	12:23:26 AM	6.630	0.036	0.041	0.045	0.340	-0.010
3	12:23:50 AM	9.809	0.056	0.061	0.066	0.503	-0.012
4	12:24:15 AM	15.854	0.105	0.101	0.107	0.813	-0.012
5	12:24:29 AM	19.500	0.127	0.127	0.132	1.000	-0.016
6	12:25:18 AM	25.896	0.176	0.174	0.175	1.328	-0.016
7	12:26:36 AM	32.019	0.218	0.213	0.216	1.642	-0.011
8	12:26:44 AM	34.418	0.239	0.233	0.233	1.765	-0.013
9	12:28:28 AM	38.942	0.267	0.261	0.263	1.997	-0.013
10	12:30:21 AM	43.817	0.302	0.295	0.296	2.247	-0.011
11	12:31:37 AM	48.692	0.338	0.328	0.329	2.497	-0.008
12	12:32:50 AM	55.146	0.379	0.374	0.373	2.828	-0.002
13	12:33:39 AM	59.261	0.414	0.407	0.400	3.039	0.002
14	12:35:33 AM	63.960	0.443	0.435	0.432	3.280	0.012
15	12:36:47 AM	69.537	0.484	0.475	0.470	3.566	0.018
16	12:37:46 AM	73.184	0.514	0.500	0.494	3.753	0.025
17	12:38:23 AM	75.933	0.533	0.521	0.513	3.894	0.023
18	12:38:55 AM	78.059	0.547	0.534	0.527	4.003	0.029
19	12:40:43 AM	82.934	0.576	0.567	0.560	4.253	0.050
20	12:41:34 AM	86.990	0.610	0.600	0.588	4.461	0.053
21	12:44:09 AM	93.327	0.653	0.639	0.631	4.786	0.068
22	12:44:17 AM	100.620	0.703	0.693	0.680	5.160	0.074
23	12:44:21 AM	104.598	0.732	0.720	0.707	5.364	0.083
24	12:47:01 AM	106.139	0.744	0.733	0.717	5.443	0.100
25	12:47:44 AM	109.005	0.766	0.754	0.736	5.590	0.106
26	12:48:09 AM	111.306	0.779	0.767	0.752	5.708	0.112
27	12:48:41 AM	113.120	0.794	0.781	0.764	5.801	0.116
28	12:49:03 AM	115.713	0.814	0.799	0.782	5.934	0.114
29	12:49:12 AM	117.176	0.822	0.807	0.792	6.009	0.126
30	12:49:38 AM	119.165	0.836	0.820	0.805	6.111	0.131
31	12:49:48 AM	121.115	0.850	0.833	0.818	6.211	0.133
32	12:50:16 AM	122.928	0.864	0.846	0.831	6.304	0.132
33	12:50:26 AM	124.976	0.878	0.860	0.844	6.409	0.136
34	12:50:38 AM	126.926	0.887	0.873	0.858	6.509	0.146
35	12:51:28 AM	129.617	0.907	0.892	0.876	6.647	0.154
36	12:51:34 AM	130.865	0.913	0.899	0.884	6.711	0.158
37	12:52:04 AM	132.678	0.927	0.912	0.896	6.804	0.173
38	12:52:41 AM	134.784	0.941	0.926	0.911	6.912	0.179
39	12:53:11 AM	136.617	0.955	0.940	0.923	7.006	0.183

Scan ID	Time	Load w plf	Near Purlin Deflection (7dc) in.	Far Purlin Deflection (9dc) in.	Theoretical Deflection in.	Manometer in. h2o	Lateral Deflection in.
40	12:53:48 AM	131.976	0.942	0.924	0.892	6.768	0.196
41	12:53:49 AM	127.569	0.913	0.898	0.862	6.542	0.194
42	12:53:51 AM	120.101	0.864	0.850	0.811	6.159	0.187
43	12:53:52 AM	116.883	0.843	0.828	0.790	5.994	0.189
44	12:58:12 AM	140.439	0.984	0.972	0.949	7.202	0.229
45	12:58:25 AM	142.545	0.998	0.986	0.963	7.310	0.233
46	12:58:47 AM	144.476	1.011	0.999	0.976	7.409	0.251
47	12:58:57 AM	146.367	1.025	1.012	0.989	7.506	0.248
48	12:59:10 AM	148.415	1.039	1.026	1.003	7.611	0.259
49	12:59:26 AM	150.833	1.053	1.040	1.019	7.735	0.267
50	12:59:33 AM	152.471	1.066	1.053	1.030	7.819	0.271
51	12:59:55 AM	153.992	1.081	1.059	1.040	7.897	0.275
52	12:00:36 AM	155.942	1.096	1.073	1.054	7.997	0.278
53	12:01:09 AM	158.106	1.108	1.093	1.068	8.108	0.297
54	12:01:28 AM	160.056	1.123	1.106	1.081	8.208	0.298
55	12:02:02 AM	162.162	1.137	1.120	1.096	8.316	0.304
56	12:02:18 AM	164.034	1.151	1.126	1.108	8.412	0.309
57	12:02:39 AM	165.809	1.164	1.139	1.120	8.503	0.316
58	12:03:06 AM	168.266	1.187	1.159	1.137	8.629	0.322
59	12:03:15 AM	169.982	1.200	1.173	1.148	8.717	0.326
60	12:03:29 AM	172.088	1.222	1.185	1.163	8.825	0.333
61	12:03:46 AM	175.617	1.256	1.213	1.187	9.006	0.349
62	12:04:20 AM	178.367	1.278	1.232	1.205	9.147	0.365
63	12:04:36 AM	181.370	1.313	1.253	1.225	9.301	0.376
64	12:04:52 AM	184.139	1.333	1.271	1.244	9.443	0.392
65	12:05:05 AM	186.479	1.361	1.286	1.260	9.563	0.403
66	12:05:20 AM	187.239	1.367	1.292	1.265	9.602	0.409
67	12:06:01 AM	190.359	1.390	1.312	1.286	9.762	0.433
68	12:06:07 AM	191.939	1.404	1.326	1.297	9.843	0.438
69	12:06:14 AM	193.109	1.424	1.333	1.305	9.903	0.438
70	12:06:29 AM	195.449	1.445	1.353	1.321	10.023	0.456
71	12:06:43 AM	197.340	1.473	1.366	1.333	10.120	0.455
72	12:06:50 AM	199.739	1.494	1.378	1.350	10.243	0.463
73	12:06:55 AM	201.143	1.514	1.392	1.359	10.315	0.472
74	12:07:09 AM	202.917	1.550	1.405	1.371	10.406	0.464
75	12:07:31 AM	205.257	1.571	1.419	1.387	10.526	0.482
76	12:07:39 AM	206.915	1.585	1.431	1.398	10.611	0.495
77	12:07:53 AM	209.138	1.667	1.445	1.413	10.725	0.439
78	12:08:03 AM	210.834	1.739	1.459	1.425	10.812	0.400
79	12:08:13 AM	210.308	1.952	1.455	1.421	10.785	0.122

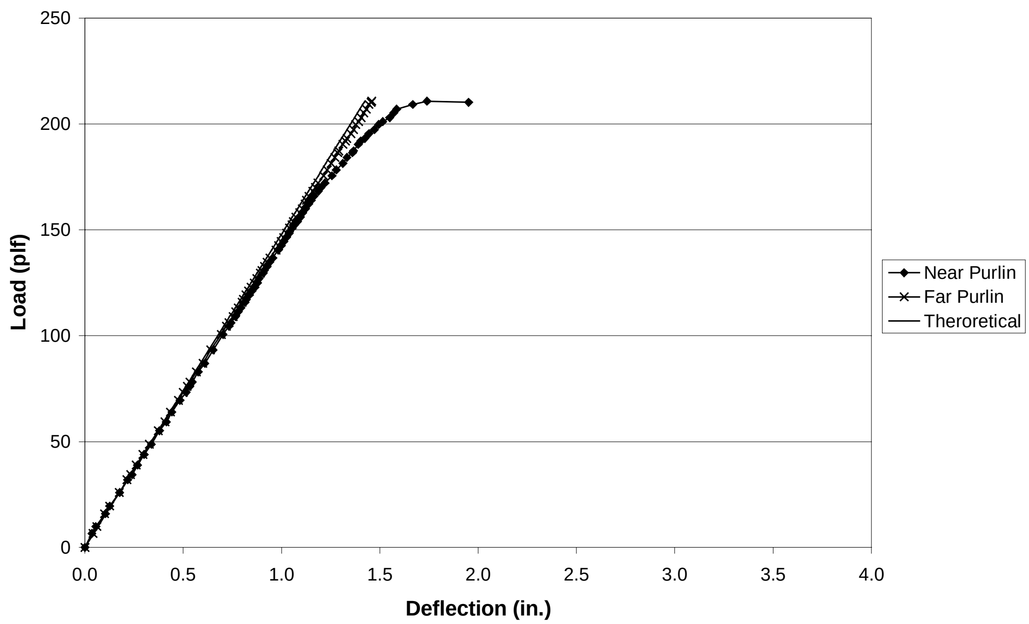
Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width	A_g, Area	S_{et}
Units	plf	in.	in.	in.	in.	in^2	in^3
CH22	4.00	10.00	0.078	3.570	3.513	1.41	3.15

w_o, Self Weigh	w_{ts}	S_{et}	F_y
plf	plf	in^3	ksi
8.81	219.6421	3.15	87.5

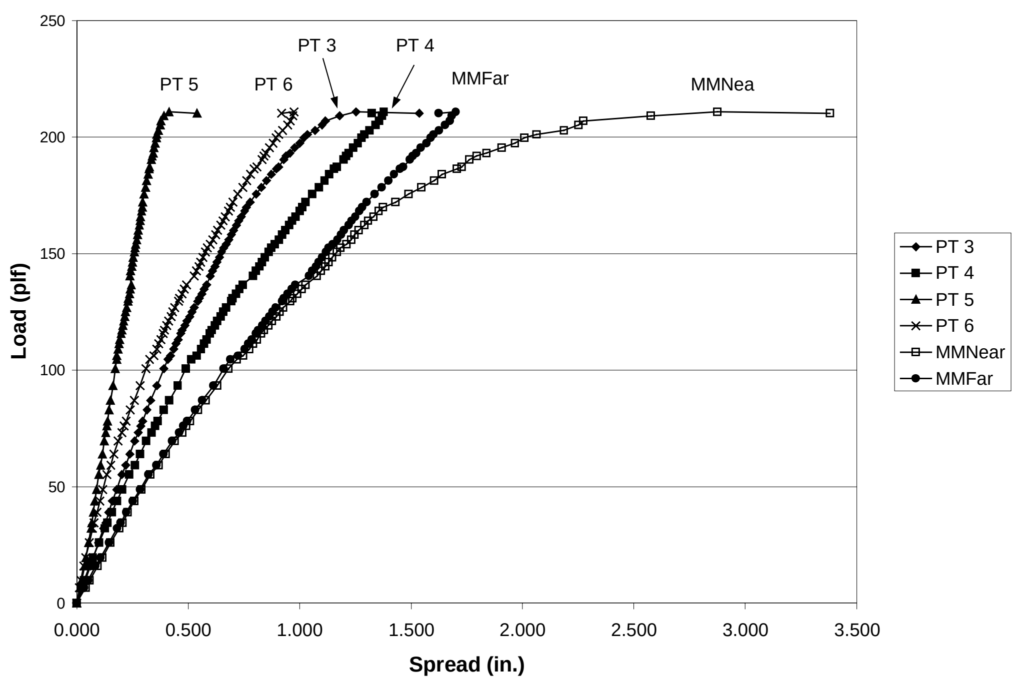
Notes:
Opposed Purlins
Standing Seam Panel
6 in. blanket insulation
Foam Blocks

Scan ID	Load w plf	Max Mom Near in.	Max Mom Far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.	(5dc) in.
1	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	-0.001
2	6.630	0.039	0.033	0.025	0.021	0.015	0.012	0.018
3	9.809	0.058	0.051	0.038	0.032	0.022	0.018	0.031
4	15.854	0.093	0.084	0.060	0.056	0.034	0.031	0.065
5	19.500	0.115	0.106	0.074	0.072	0.041	0.040	0.078
6	25.896	0.151	0.144	0.096	0.100	0.053	0.055	0.112
7	32.019	0.190	0.180	0.120	0.127	0.064	0.071	0.145
8	34.418	0.205	0.196	0.130	0.138	0.068	0.077	0.158
9	38.942	0.228	0.221	0.142	0.158	0.073	0.090	0.178
10	43.817	0.257	0.251	0.159	0.181	0.080	0.104	0.204
11	48.692	0.290	0.283	0.178	0.204	0.089	0.117	0.231
12	55.146	0.329	0.322	0.202	0.234	0.099	0.135	0.264
13	59.261	0.367	0.357	0.220	0.260	0.106	0.152	0.291
14	63.960	0.398	0.388	0.237	0.283	0.114	0.166	0.318
15	69.537	0.440	0.428	0.259	0.312	0.123	0.186	0.351
16	73.184	0.474	0.459	0.276	0.336	0.130	0.202	0.377
17	75.933	0.491	0.478	0.287	0.351	0.134	0.212	0.389
18	78.059	0.509	0.495	0.296	0.363	0.137	0.221	0.403
19	82.934	0.545	0.531	0.315	0.390	0.144	0.239	0.438
20	86.990	0.579	0.563	0.331	0.415	0.151	0.257	0.464
21	93.327	0.630	0.614	0.359	0.453	0.162	0.284	0.504
22	100.620	0.681	0.659	0.390	0.489	0.172	0.310	0.543
23	104.598	0.718	0.689	0.409	0.514	0.179	0.327	0.570
24	106.139	0.747	0.724	0.420	0.538	0.179	0.346	0.590
25	109.005	0.774	0.752	0.434	0.557	0.185	0.359	0.610
26	111.306	0.791	0.769	0.445	0.570	0.189	0.368	0.623
27	113.120	0.808	0.785	0.454	0.583	0.192	0.378	0.636
28	115.713	0.826	0.803	0.465	0.597	0.198	0.387	0.649
29	117.176	0.839	0.814	0.473	0.606	0.201	0.393	0.663
30	119.165	0.860	0.833	0.485	0.620	0.206	0.404	0.676
31	121.115	0.875	0.847	0.494	0.630	0.210	0.412	0.687
32	122.928	0.896	0.865	0.506	0.646	0.215	0.423	0.696
33	124.976	0.910	0.879	0.516	0.658	0.218	0.430	0.709
34	126.926	0.927	0.893	0.526	0.670	0.223	0.439	0.722
35	129.617	0.958	0.921	0.543	0.693	0.229	0.456	0.742
36	130.865	0.967	0.929	0.549	0.699	0.231	0.461	0.749
37	132.678	0.989	0.947	0.561	0.715	0.236	0.472	0.769
38	134.784	1.008	0.965	0.571	0.730	0.240	0.482	0.783
39	136.617	1.027	0.981	0.582	0.745	0.244	0.492	0.796

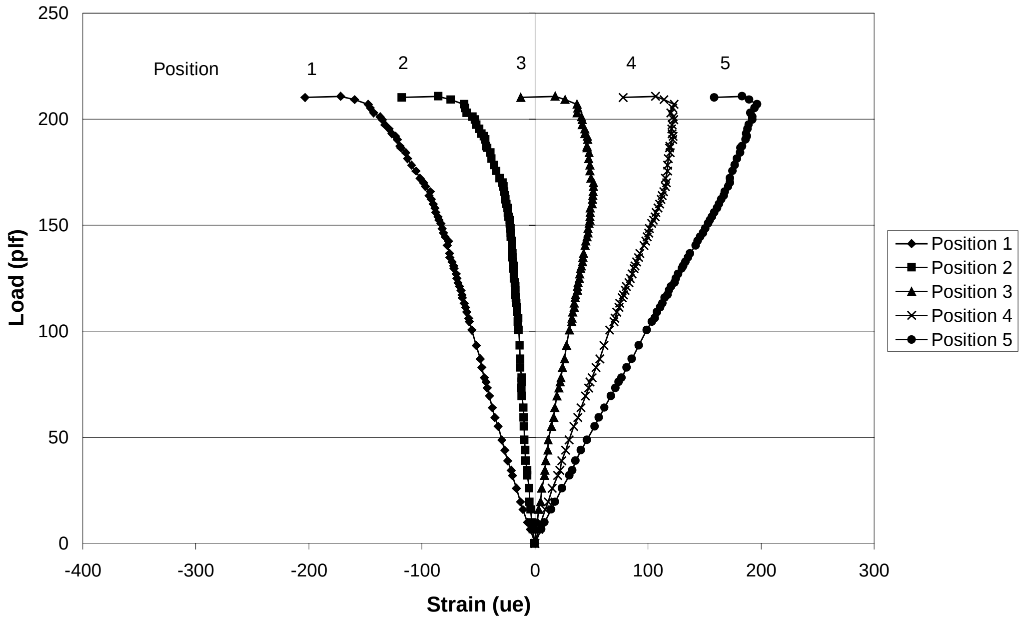
Scan ID	Load w plf	Max Mom Near in.	Max Mom Far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.	(5dc) in.
40	131.976	1.031	0.984	0.575	0.745	0.236	0.493	0.796
41	127.569	1.012	0.967	0.560	0.728	0.228	0.482	0.775
42	120.101	0.976	0.938	0.532	0.700	0.214	0.464	0.736
43	116.883	0.960	0.925	0.520	0.687	0.207	0.455	0.723
44	140.439	1.077	1.041	0.598	0.790	0.238	0.526	0.849
45	142.545	1.096	1.056	0.608	0.804	0.241	0.537	0.862
46	144.476	1.116	1.074	0.620	0.820	0.246	0.548	0.884
47	146.367	1.130	1.086	0.628	0.831	0.249	0.556	0.891
48	148.415	1.147	1.100	0.639	0.845	0.253	0.566	0.909
49	150.833	1.168	1.118	0.650	0.861	0.258	0.578	0.924
50	152.471	1.182	1.130	0.659	0.872	0.261	0.586	0.936
51	153.992	1.211	1.148	0.671	0.889	0.264	0.598	0.949
52	155.942	1.231	1.169	0.682	0.907	0.269	0.610	0.962
53	158.106	1.247	1.185	0.693	0.922	0.272	0.623	0.984
54	160.056	1.265	1.199	0.704	0.936	0.276	0.632	0.995
55	162.162	1.290	1.220	0.716	0.953	0.280	0.646	1.009
56	164.034	1.307	1.233	0.726	0.966	0.283	0.656	1.022
57	165.809	1.331	1.250	0.738	0.982	0.286	0.666	1.036
58	168.266	1.354	1.268	0.752	1.000	0.291	0.680	1.056
59	169.982	1.375	1.281	0.761	1.012	0.294	0.689	1.068
60	172.088	1.430	1.301	0.778	1.027	0.296	0.700	1.088
61	175.617	1.489	1.336	0.805	1.057	0.302	0.722	1.123
62	178.367	1.546	1.368	0.829	1.088	0.308	0.744	1.150
63	181.370	1.604	1.399	0.851	1.112	0.313	0.763	1.182
64	184.139	1.638	1.424	0.872	1.134	0.320	0.779	1.207
65	186.479	1.705	1.450	0.895	1.155	0.324	0.796	1.234
66	187.239	1.727	1.464	0.906	1.168	0.327	0.808	1.243
67	190.359	1.761	1.494	0.928	1.198	0.335	0.831	1.276
68	191.939	1.794	1.508	0.938	1.209	0.338	0.839	1.289
69	193.109	1.839	1.523	0.956	1.220	0.342	0.848	1.303
70	195.449	1.908	1.544	0.977	1.240	0.346	0.864	1.330
71	197.340	1.967	1.569	1.001	1.261	0.351	0.881	1.349
72	199.739	2.009	1.587	1.019	1.278	0.357	0.894	1.369
73	201.143	2.064	1.601	1.035	1.291	0.359	0.905	1.389
74	202.917	2.186	1.626	1.070	1.313	0.365	0.924	1.408
75	205.257	2.252	1.654	1.101	1.342	0.374	0.946	1.435
76	206.915	2.274	1.674	1.116	1.356	0.378	0.958	1.454
77	209.138	2.576	1.682	1.179	1.369	0.391	0.969	1.469
78	210.834	2.875	1.700	1.253	1.378	0.413	0.974	1.489
79	210.308	3.381	1.623	1.537	1.323	0.539	0.918	1.425



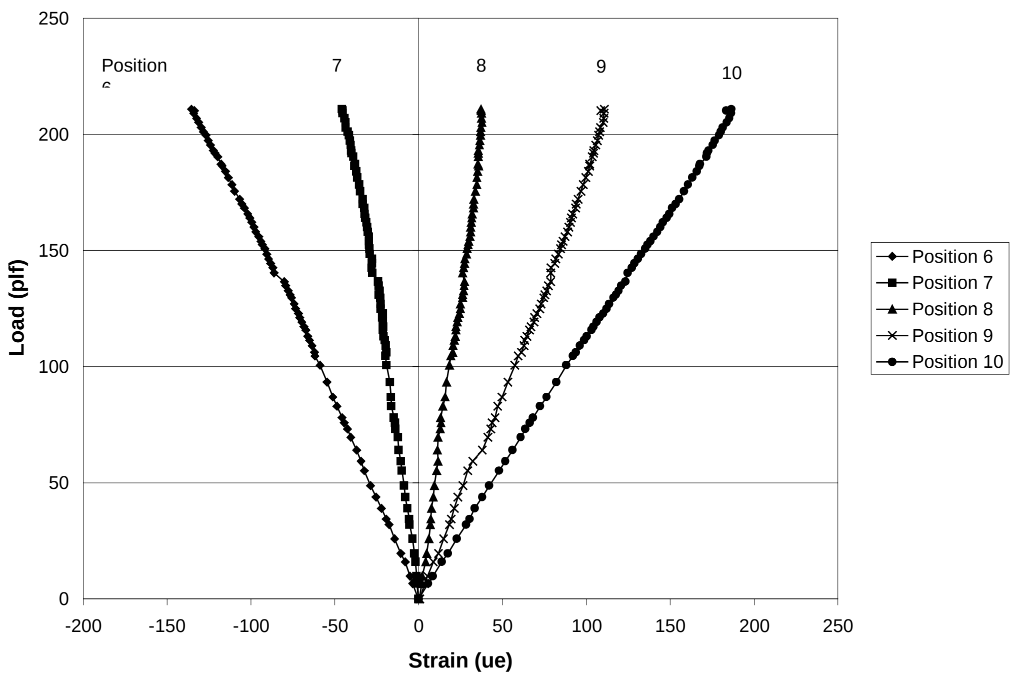
Test 3 C–SS Load vs. Vertical Deflection



Test 3 C–SS Load vs. Spread



Test 3 C–SS Load vs. Strain Near Purlin Line



Test 3 C–SS Load vs. Strain Far Purlin Line

APPENDIX D

TEST 4 C–TF DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: Test 4 C-TF
DATE: 1/29/99

TEST DESCRIPTION:

Loading……………………………….	Gravity
Panel Type………………………….	Through Fastened Panel
Span………………………………….	1@24'-6", 1@25'-0", 1@23'-0"
Purlin Spacing……………………….	5' o.c. with 1' deck overhang
Lateral Bracing………………………	None
Anti-roll Clips………………………	At the exterior supports of both purlin lines
Web Stiffeners………………………	None
Purlin Orientation……………………	Top flanges opposed
Insulation…………………………..	None

FAILURE MODE:

Combined Shear + Bending at Lap of Near Purlin

EXPERIMENTAL FAILURE LOAD:

Pressure =	14.36	in. of water
Applied Line Loading =	280.08	plf
Weight of Deck =	4.00	plf
Weight of Purlin =	3.99	plf
Total Applied Load =	288.07	plf
Maximum Pos. Moment =	157.15	kip in.
Neg. Moment at Lap =	179.89	kip in.
Shear at Lap =	4.02	kips

PREDICTED FAILURE LOAD: (F_y= 75.0 ksi)

Inflection Point As Bracepoint

Combined Shear + Bending:

Neg. Moment at Lap =	181.50	kip in.
Shear at Lap =	4.10	kips
Predicted Line Load =	266.69	plf

Inflection Point Not As Bracepoint

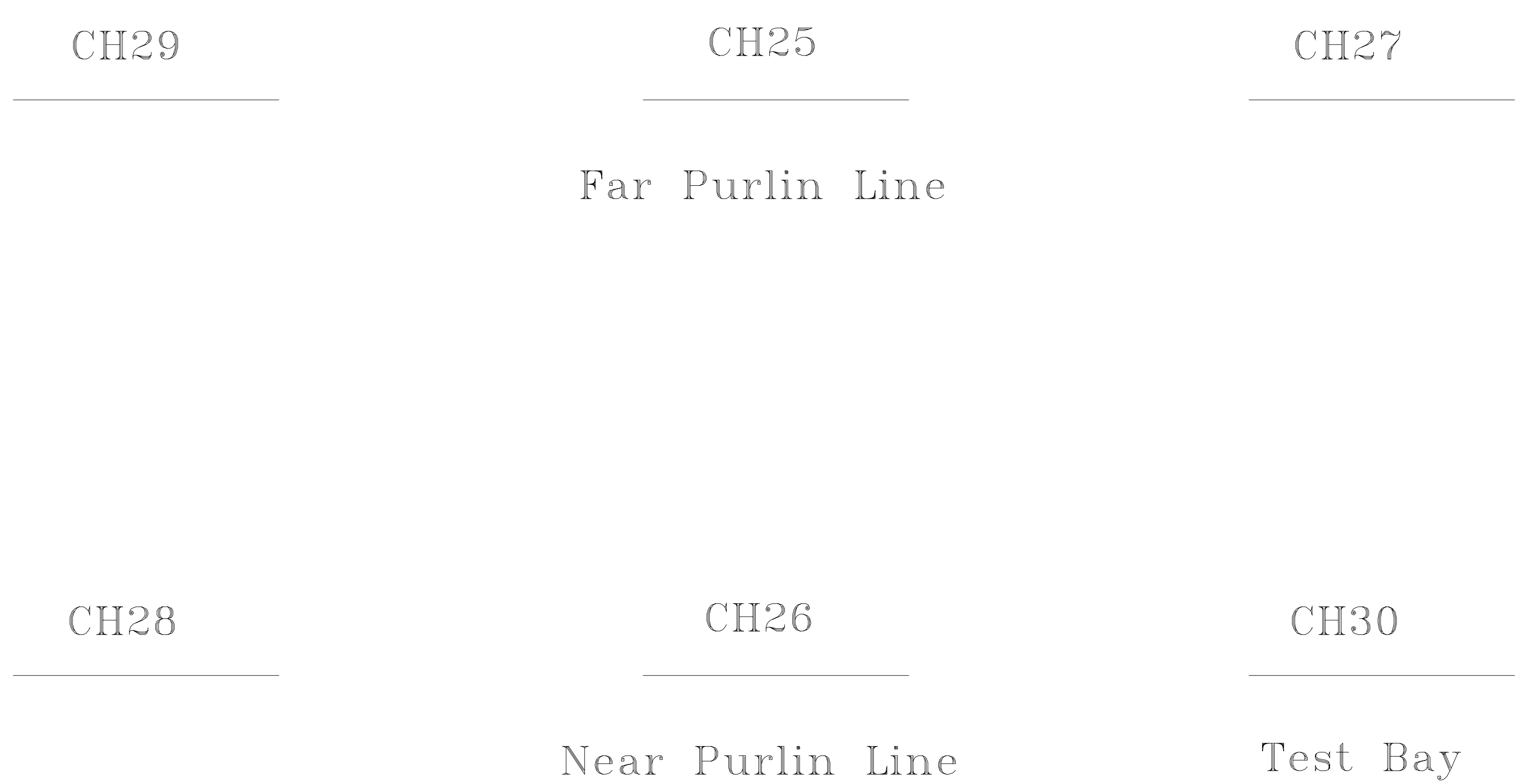
Combined Shear + Bending:

Neg. Moment at Lap =	179.10	kip in.
Shear at Lap =	4.06	kips
Predicted Line Load =	263.69	plf

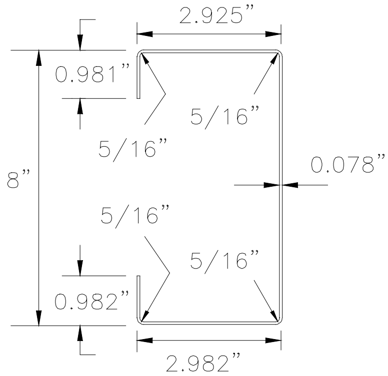
Experimental/Predicted:

Failure/Predicted =	288.08/266.69 =	1.080	**I.P. Braced**
Failure/Predicted =	288.08/263.69 =	1.092	**I.P. Not Braced**

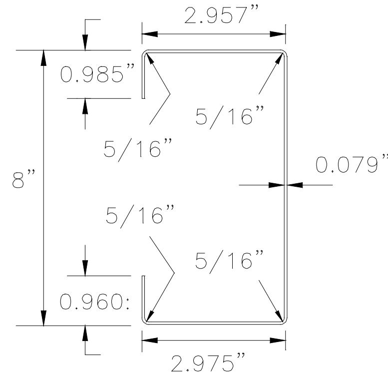
Test 4 C-TF (Z8) Purlin Locations



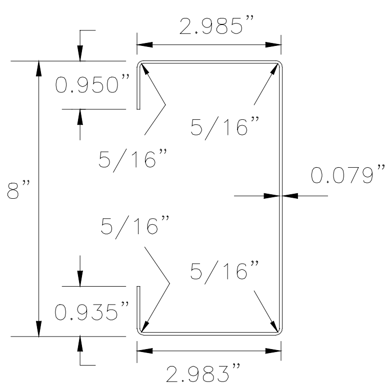
Test 4 C-TF (C8) Measured Dimensions



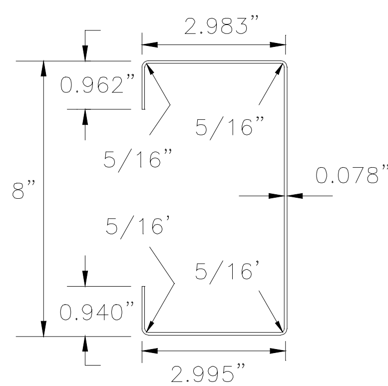
Purlin (CH27)



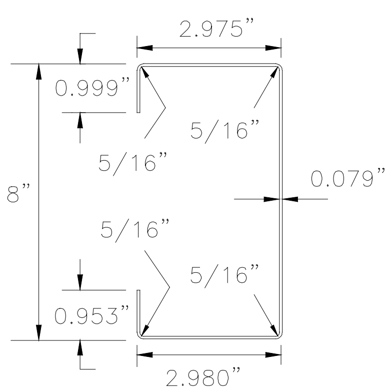
Purlin (CH30)



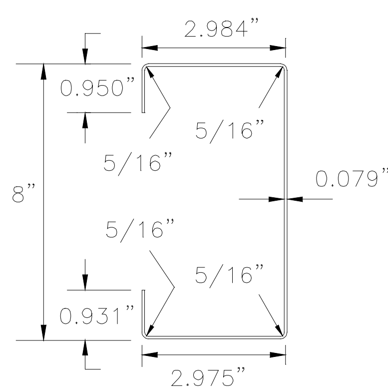
Purlin (CH25)



Purlin (CH26)



Purlin (CH29)



Purlin (CH28)

Results From Commercial Software

TEST 4 C-TF 8 in. C-TF 3 span CH 27

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.981 in.	0.972 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.925 in.	2.982 in.
Purlin Depth	8 in.	
Purlin Thickness	0.078 in.	
Yield Stress	75 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.17 in^2
Ix	11.32 in^4
Iy	1.35 in^4
Ixy	0.04 in^4
Flexural Strength	
Ie	10.28 in^4
Se	2.42 in^3

TEST 4 C-TF 8 in. C-TF 3 span CH 30

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	0.985 in.	0.960 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.957 in.	2.975 in.
Purlin Depth	8 in.	
Purlin Thickness	0.079 in.	
Yield Stress	75.3 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	11.48 in^4
Iy	1.38 in^4
Ixy	0.08 in^4
Flexural Strength	
Ie	10.41 in^4
Se	2.45 in^3

Other properties for CH 30

rx	3.1154	in.
ry	1.0955	in.
ro	3.9818	in.
Cw	18.875	in^6
J	0.00246	in^4
Xo	-2.2246	in.

TEST 4 C-TF 8 in. C-TF 3 span CH 25

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top	Bottom
Overall Lip Dimension	0.950 in.	0.935 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.985 in.	2.983 in.
Purlin Depth	8 in.	
Purlin Thickness	0.079 in.	
Yield Stress	75.2 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	11.48 in^4
Iy	1.38 in^4
Ixy	0.09 in^4
Flexural Strength	
Ie	10.37 in^4
Se	2.44 in^3

TEST 4 C-TF 8 in. C-TF 3 span CH 26

Purlin Geometry and Material Properties Bay #2 (Middle Bay)

	Top	Bottom
Overall Lip Dimension	0.962 in.	0.940 in.
Lip Angle	90 °	90 °
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.983 in.	2.995 in.
Purlin Depth	8 in.	
Purlin Thickness	0.078 in.	
Yield Stress	75.2 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.17 in^2
Ix	11.37 in^4
Iy	1.38 in^4
Ixy	0.08 in^4
Flexural Strength	
Ie	10.26 in^4
Se	2.41 in^3

TEST 4 C-TF 8 in. C-TF 3 span CH 29

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top	Bottom
Overall Lip Dimension	0.999 in.	0.953 in.
Lip Angle	90 ^{o}	90 ^{o}
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.975 in.	2.980 in.
Purlin Depth	8 in.	
Purlin Thickness	0.079 in.	
Yield Stress	75.2 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	11.52 in^4
Iy	1.40 in^4
Ixy	0.10 in^4
Flexural Strength	
Ie	10.45 in^4
Se	2.47 in^3

TEST 4 C-TF 8 in. C-TF 3 span CH 28

Purlin Geometry and Material Properties Bay #3 (End Bay)

	Top	Bottom
Overall Lip Dimension	0.950 in.	0.931 in.
Lip Angle	90 ^{o}	90 ^{o}
Radii:		
Lip to Flange	0.3125 in.	0.3125 in.
Flange to Web	0.3125 in.	0.3125 in.
Flange Width	2.984 in.	2.975 in.
Purlin Depth	8 in.	
Purlin Thickness	0.079 in.	
Yield Stress	75.2 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	11.47 in^4
Iy	0.10 in^4
Ixy	4.46 in^4
Flexural Strength	
Ie	10.36 in^4
Se	2.44 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

157.3 lbs/ft x 1.67 = 262.7 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

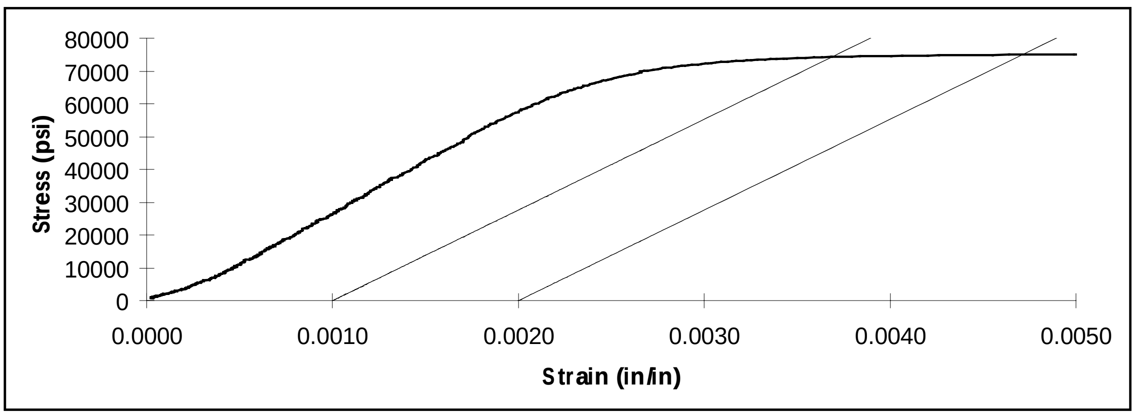
Test Designation:	Chief Multispan Test #4
Specimen Identification:	MB CH 27
Coupon Number:	3
Date:	12/18/98
Gage length (in.):	7.991
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.079
Width (in.):	1.507

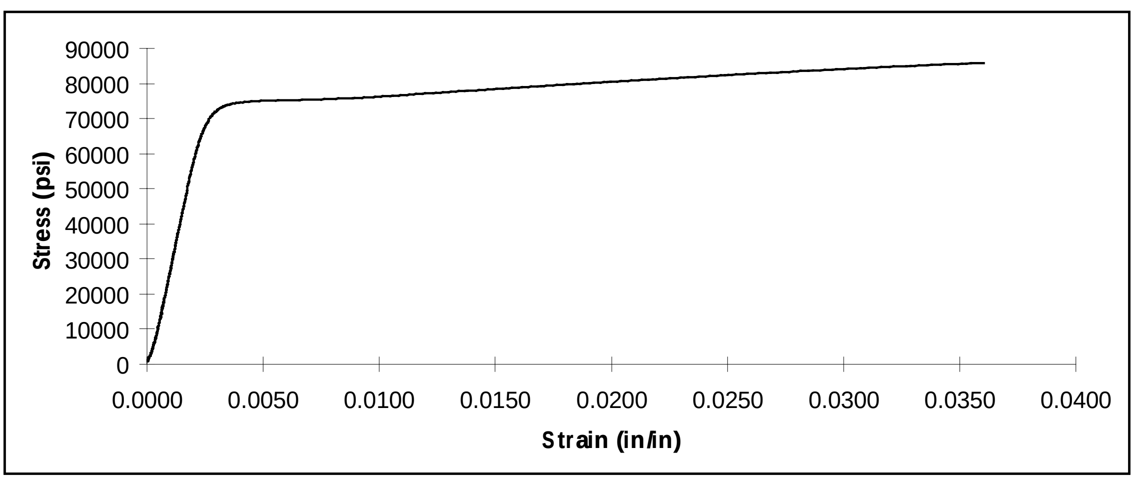
Test Setup:

Procedure:		Tensile Test
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	74300 psi
.2% Offset Yield:	**75000 psi**
.5 in/in Yield:	75100 psi
Ulimate Strength:	86000 psi
Modulus of elasticity:	27.6 ksi
% Elongation:	15%





TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

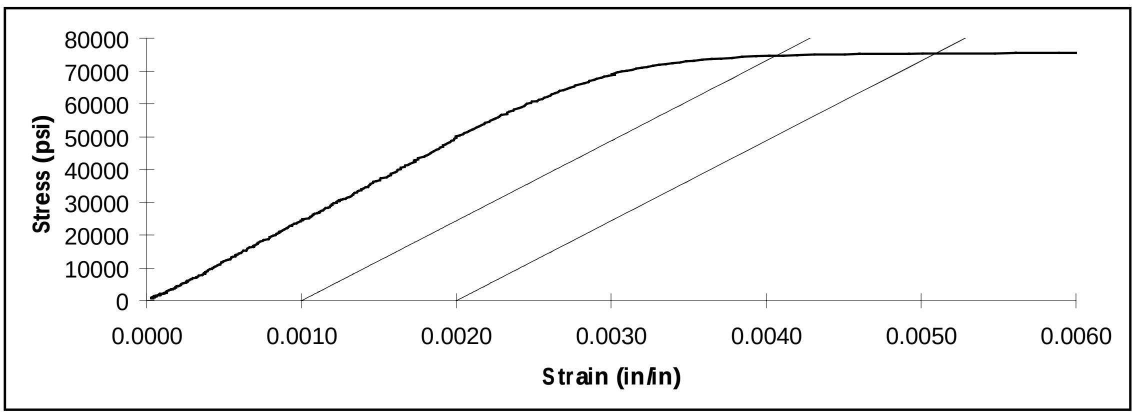
Test Designation:	Chief Multispan Test #4
Specimen Identification:	MB CH 30
Coupon Number:	4
Date:	3/23/99
Gage length (in.):	7.994
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.079
Width (in.):	1.504

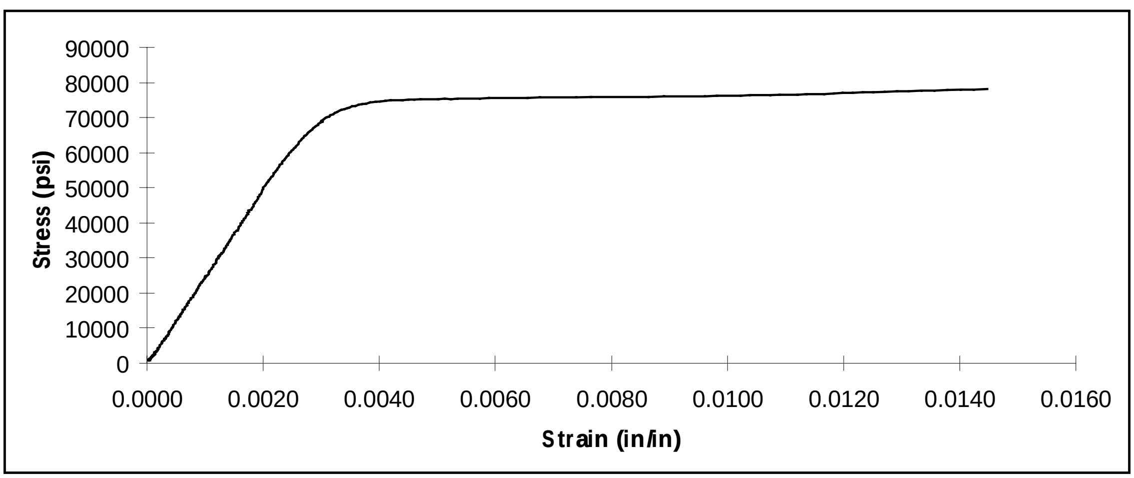
Test Setup:

Procedure:	Tensile Test		
Range 1		Rate:	50000 psi/min
		End Level:	55000 psi
Range 2		Rate:	10000 psi/min
		End Level:	0.2 in/in
Range 3		Rate:	25000 psi/min
		End Level:	Sample Break

Test Data:

.1% Offset Yield:	74600 psi
.2% Offset Yield:	**75300 psi**
.5 in/in Yield:	75300 psi
Ulimate Strength:	91400 psi
Modulus of elasticity:	24.4 ksi
% Elongation:	14%





RESULTS FROM STIFFNESS MODEL

TEST 4 C-TF

Deck Type	Through Fastened
Spans	1@24.5, 1@25, 1@23
Total Lap Length	3'-0"
Extension into Test Bay	1'-0"
Purlin Designation	CH30
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	11.48	in^4
Ag =	1.18	in^2
Iy =	1.38	in^4

Middle Bay Section Properties

Ix =	11.48	in^4
Ag =	1.18	in^2
Iy =	1.38	in^4

End Bay Section Properties

Ix =	11.48	in^4
Ag =	1.18	in^2
Iy =	1.38	in^4

Lap Section Properties

Ix =	22.96	in^4
Ag =	2.36	in^2
Iy =	2.76	in^4

Test Bay

Max. (+) Moment =	**4.547**	k-ft
Moment at End of Lap =	**5.204**	k-ft
Shear at End of Lap =	**1.396**	k
Moment at Support =	**6.648**	k-ft
Shear at Support =	**1.496**	k
Max Deflection =	**1.179**	in.

Inflection Point Located at 19.07 ft. from exterior Support.
Max. (+) Moment located at 9.5 ft. from exterior Support
Max. Deflection Located at 10.71 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 4.43 ft. = 51.96 in.

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	5.204	k-ft
Ma =	1.117	k-ft
Mb =	2.356	k-ft
Mc =	3.719	k-ft
Cb =	**1.761**	

Test ID: Test 4 C-TF

Michael R. Bryant
1/29/99

Test Span, L = 24.5 ft

I_x = 11.32 $in.^4$

Scan ID	Time	Load	Near Purlin	Far Purlin	Theoretical	Manometer
		w	Deflection (9dc)	Deflection (7dc)	Deflection	
		plf	in.	in.	in.	in. h2o
1	1:38:55.01 PM	0.059	0.001	0.001	0.001	0.003
2	1:40:58.01 PM	6.754	0.085	0.081	0.080	0.346
3	1:41:09.01 PM	9.867	0.126	0.120	0.117	0.506
4	1:42:27.01 PM	14.272	0.175	0.174	0.170	0.732
5	1:43:15.63 PM	23.669	0.295	0.287	0.282	1.214
6	1:43:44.63 PM	26.606	0.330	0.320	0.317	1.364
7	1:44:02.63 PM	31.598	0.392	0.374	0.376	1.620
8	1:44:09.63 PM	34.476	0.427	0.407	0.410	1.768
9	1:44:58.63 PM	39.293	0.484	0.460	0.467	2.015
10	1:46:08.33 PM	43.873	0.540	0.513	0.522	2.250
11	1:46:58.33 PM	49.335	0.604	0.580	0.587	2.530
12	1:47:40.15 PM	53.916	0.660	0.633	0.641	2.765
13	1:48:17.15 PM	58.615	0.723	0.693	0.697	3.006
14	1:48:57.89 PM	64.019	0.784	0.754	0.762	3.283
15	1:49:28.89 PM	67.425	0.828	0.792	0.802	3.458
16	1:50:19.82 PM	73.944	0.905	0.866	0.880	3.792
17	1:50:48.82 PM	78.702	0.961	0.927	0.936	4.036
18	1:51:20.82 PM	83.107	1.009	0.980	0.989	4.262
19	1:52:42.59 PM	89.392	1.088	1.054	1.064	4.584
20	1:53:14.59 PM	93.620	1.136	1.100	1.114	4.801
21	1:53:40.59 PM	97.613	1.185	1.147	1.161	5.006
22	1:54:40.51 PM	103.311	1.256	1.213	1.229	5.298
23	1:55:14.51 PM	107.129	1.301	1.259	1.275	5.494
24	1:56:48.18 PM	112.416	1.361	1.320	1.337	5.765
25	1:58:21.18 PM	117.230	1.423	1.381	1.395	6.012
26	1:58:57.68 PM	122.400	1.486	1.440	1.456	6.277
27	1:59:30.68 PM	126.922	1.543	1.494	1.510	6.509
28	2:00:02.68 PM	132.033	1.605	1.553	1.571	6.771
29	2:00:36.68 PM	136.672	1.663	1.606	1.626	7.009
30	2:01:24.91 PM	141.313	1.718	1.667	1.681	7.247
31	2:01:32.91 PM	143.660	1.746	1.692	1.709	7.367
32	2:02:09.91 PM	146.656	1.788	1.733	1.745	7.521
33	2:03:09.87 PM	151.355	1.844	1.787	1.801	7.762
34	2:03:25.87 PM	153.293	1.872	1.811	1.824	7.861
35	2:03:38.87 PM	156.993	1.914	1.854	1.868	8.051
36	2:04:32.82 PM	160.165	1.964	1.896	1.906	8.214
37	2:04:50.82 PM	164.804	2.020	1.949	1.961	8.452
38	2:05:24.82 PM	168.094	2.062	1.990	2.000	8.620
39	2:05:52.82 PM	170.502	2.098	2.023	2.029	8.744
40	2:06:43.87 PM	171.501	2.111	2.031	2.040	8.795
41	2:07:04.87 PM	175.553	2.161	2.084	2.089	9.003
42	2:07:53.87 PM	178.608	2.202	2.118	2.125	9.159
43	2:08:02.87 PM	179.724	2.217	2.132	2.138	9.217
44	2:08:36.87 PM	181.545	2.244	2.152	2.160	9.310
45	2:08:36.87 PM	183.659	2.272	2.178	2.185	9.418
46	2:09:39.61 PM	185.244	2.294	2.198	2.204	9.500
47	2:09:59.61 PM	188.005	2.328	2.230	2.237	9.641
48	2:10:05.61 PM	189.532	2.349	2.245	2.255	9.720
49	2:10:18.61 PM	191.176	2.377	2.265	2.275	9.804
50	2:10:35.61 PM	193.231	2.407	2.291	2.299	9.909

Scan ID	Time	Load	Near Purlin	Far Purlin	Theoretical	Manometer
		w	Deflection (9dc)	Deflection (7dc)	Deflection	
		plf	in.	in.	in.	in. h2o
51	2:10:54.61 PM	195.156	2.434	2.317	2.322	10.008
52	2:11:23.78 PM	197.223	2.462	2.339	2.346	10.114
53	2:11:44.78 PM	199.095	2.491	2.363	2.369	10.210
54	2:11:55.78 PM	199.914	2.504	2.370	2.379	10.252
55	2:12:10.78 PM	201.338	2.525	2.384	2.395	10.325
56	2:12:28.78 PM	202.391	2.539	2.397	2.408	10.379
57	2:12:28.78 PM	203.034	2.553	2.410	2.416	10.412
58	2:12:56.87 PM	205.082	2.581	2.431	2.440	10.517
59	2:13:02.87 PM	207.383	2.611	2.457	2.467	10.635
60	2:13:12.87 PM	210.132	2.652	2.484	2.500	10.776
61	2:13:19.87 PM	211.205	2.671	2.497	2.513	10.831
62	2:13:33.87 PM	212.550	2.693	2.518	2.529	10.900
63	2:14:05.87 PM	214.656	2.728	2.538	2.554	11.008
64	2:14:37.44 PM	216.899	2.763	2.563	2.581	11.123
65	2:14:48.44 PM	219.063	2.798	2.591	2.606	11.234
66	2:14:57.44 PM	220.838	2.826	2.611	2.627	11.325
67	2:15:12.44 PM	222.417	2.854	2.632	2.646	11.406
68	2:15:22.44 PM	224.640	2.890	2.657	2.673	11.520
69	2:15:33.44 PM	226.824	2.926	2.684	2.699	11.632
70	2:15:39.44 PM	228.638	2.959	2.704	2.720	11.725
71	2:15:49.44 PM	230.393	2.994	2.731	2.741	11.815
72	2:15:59.44 PM	231.465	3.015	2.744	2.754	11.870
73	2:16:11.44 PM	232.226	3.037	2.750	2.763	11.909
74	2:16:48.44 PM	234.098	3.077	2.777	2.785	12.005
75	2:17:53.84 PM	236.106	3.121	2.797	2.809	12.108
76	2:18:26.84 PM	238.212	3.169	2.824	2.834	12.216
77	2:18:38.84 PM	240.377	3.211	2.850	2.860	12.327
78	2:18:46.84 PM	242.151	3.254	2.870	2.881	12.418
79	2:18:56.84 PM	244.140	3.309	2.889	2.905	12.520
80	2:19:07.84 PM	246.207	3.371	2.911	2.929	12.626
81	2:19:19.84 PM	247.845	3.443	2.929	2.949	12.710
82	2:19:31.84 PM	248.723	3.505	2.936	2.959	12.755
83	2:19:39.84 PM	250.380	3.582	2.951	2.979	12.840
84	2:19:44.84 PM	247.611	3.832	2.914	2.946	12.698
85	2:20:17.84 PM	280.080	3.689	3.315	3.332	14.363

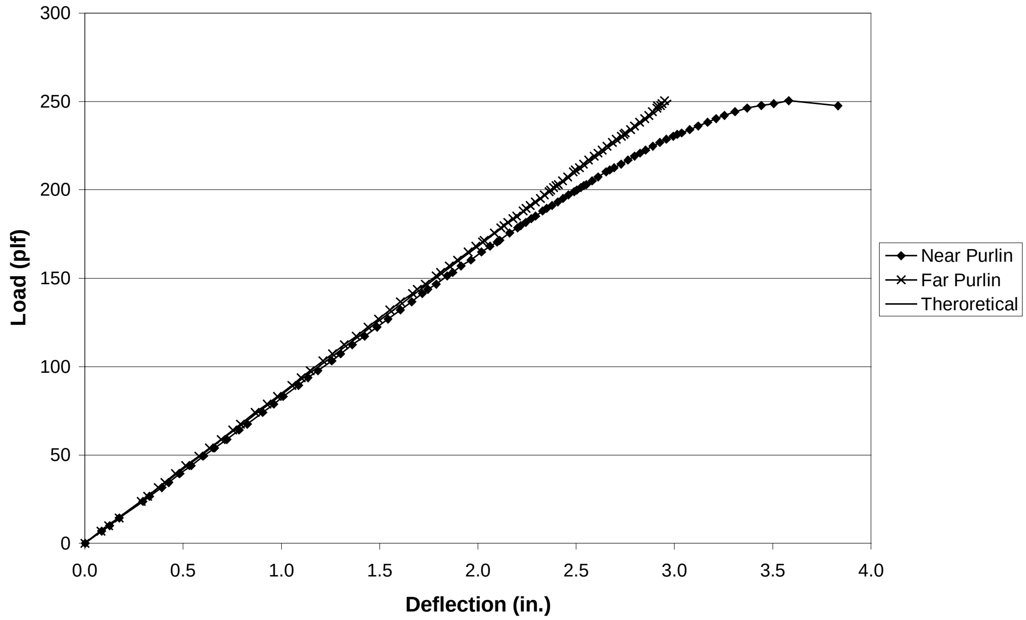
Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width	A_g, Area
Units	plf	in.	in.	in.	in.	in^2
CH27	4.00	8.00	0.078	2.925	2.982	1.17

w_o, Self Weight	w_{ts}	S_{et}	F_y
plf	plf	in^3	ksi
7.99	288.07	2.42	75.0

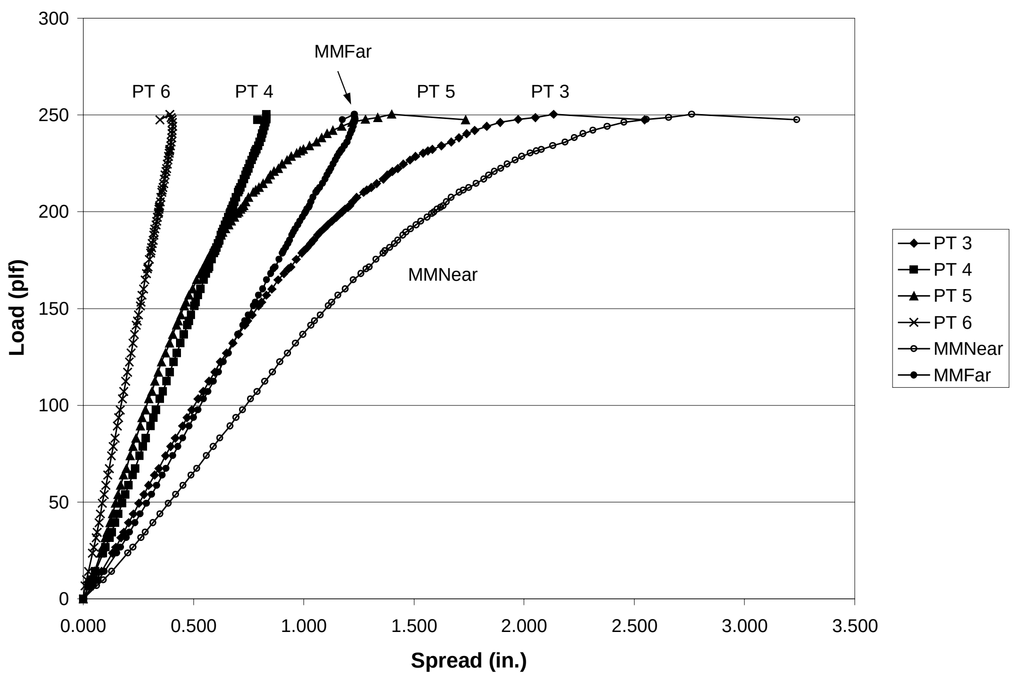
Notes: Opposed Purlins
Through Fastened Panel

Scan ID	Manometer in. h2o	Load w plf	Max Mom Near in.	Max Mom Far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
1	0.003	0.059	0.000	0.000	0.000	0.000	0.000	0.000
2	0.346	6.754	0.061	0.046	0.042	0.025	0.026	0.009
3	0.506	9.867	0.091	0.068	0.059	0.036	0.037	0.015
4	0.732	14.272	0.129	0.097	0.083	0.054	0.052	0.024
5	1.214	23.669	0.203	0.153	0.132	0.090	0.079	0.041
6	1.364	26.606	0.226	0.170	0.147	0.102	0.088	0.048
7	1.620	31.598	0.262	0.196	0.171	0.119	0.100	0.057
8	1.768	34.476	0.282	0.211	0.185	0.129	0.108	0.063
9	2.015	39.293	0.316	0.236	0.206	0.145	0.120	0.071
10	2.250	43.873	0.348	0.259	0.228	0.160	0.132	0.078
11	2.530	49.335	0.386	0.287	0.252	0.176	0.145	0.086
12	2.765	53.916	0.419	0.309	0.275	0.191	0.157	0.094
13	3.006	58.615	0.453	0.333	0.298	0.206	0.170	0.103
14	3.283	64.019	0.489	0.359	0.324	0.223	0.183	0.112
15	3.458	67.425	0.516	0.376	0.343	0.235	0.195	0.118
16	3.792	73.944	0.558	0.406	0.373	0.255	0.212	0.128
17	4.036	78.702	0.590	0.429	0.396	0.270	0.226	0.136
18	4.262	83.107	0.620	0.450	0.417	0.284	0.239	0.144
19	4.584	89.392	0.666	0.481	0.452	0.305	0.258	0.155
20	4.801	93.620	0.692	0.501	0.471	0.318	0.267	0.160
21	5.006	97.613	0.722	0.520	0.493	0.331	0.281	0.168
22	5.298	103.311	0.759	0.546	0.521	0.348	0.297	0.177
23	5.494	107.129	0.789	0.566	0.544	0.362	0.312	0.183
24	5.765	112.416	0.824	0.591	0.570	0.378	0.325	0.192
25	6.012	117.230	0.859	0.613	0.597	0.394	0.340	0.201
26	6.277	122.400	0.892	0.635	0.622	0.409	0.356	0.209
27	6.509	126.922	0.926	0.658	0.649	0.424	0.373	0.216
28	6.771	132.033	0.964	0.680	0.678	0.441	0.391	0.225
29	7.009	136.672	0.997	0.702	0.704	0.455	0.407	0.233
30	7.247	141.313	1.033	0.724	0.733	0.472	0.422	0.241
31	7.367	143.660	1.050	0.734	0.746	0.479	0.431	0.245
32	7.521	146.656	1.076	0.750	0.767	0.488	0.442	0.250
33	7.762	151.355	1.112	0.772	0.796	0.503	0.458	0.259
34	7.861	153.293	1.128	0.781	0.809	0.510	0.466	0.262
35	8.051	156.993	1.156	0.796	0.830	0.521	0.479	0.267
36	8.214	160.165	1.189	0.813	0.855	0.533	0.495	0.273
37	8.452	164.804	1.225	0.833	0.884	0.547	0.513	0.281
38	8.620	168.094	1.260	0.851	0.911	0.558	0.530	0.286
39	8.744	170.502	1.284	0.863	0.930	0.567	0.542	0.291
40	8.795	171.501	1.299	0.871	0.942	0.572	0.548	0.293
41	9.003	175.553	1.328	0.888	0.966	0.584	0.563	0.300
42	9.159	178.608	1.360	0.903	0.991	0.594	0.579	0.305
43	9.217	179.724	1.370	0.908	1.000	0.598	0.584	0.306
44	9.310	181.545	1.392	0.918	1.016	0.605	0.594	0.309
45	9.418	183.659	1.413	0.929	1.032	0.612	0.605	0.313
46	9.500	185.244	1.428	0.937	1.044	0.618	0.613	0.316
47	9.641	188.005	1.451	0.947	1.062	0.625	0.625	0.320
48	9.720	189.532	1.465	0.954	1.074	0.630	0.633	0.322
49	9.804	191.176	1.485	0.962	1.090	0.637	0.645	0.325
50	9.909	193.231	1.510	0.973	1.109	0.644	0.659	0.329

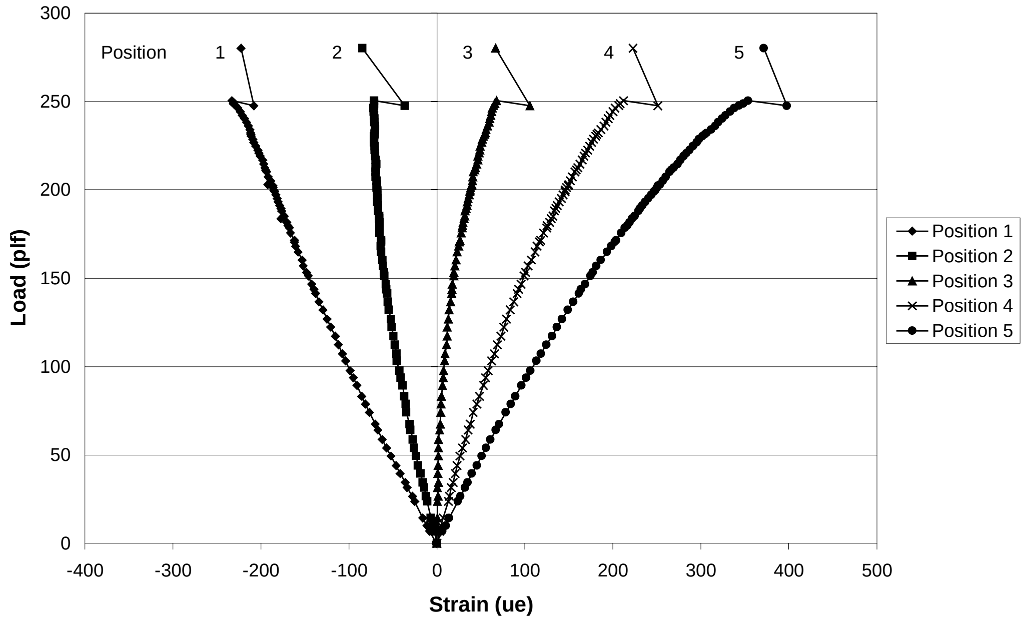
Scan ID	Manometer in. h2o	Load w plf	Max Mom Near in.	Max Mom Far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
51	10.008	195.156	1.533	0.982	1.127	0.651	0.672	0.333
52	10.114	197.223	1.561	0.995	1.150	0.659	0.687	0.336
53	10.210	199.095	1.581	1.005	1.166	0.665	0.698	0.339
54	10.252	199.914	1.591	1.009	1.174	0.668	0.704	0.341
55	10.325	201.338	1.607	1.015	1.187	0.673	0.713	0.343
56	10.379	202.391	1.622	1.023	1.200	0.678	0.721	0.345
57	10.412	203.034	1.633	1.026	1.209	0.680	0.728	0.347
58	10.517	205.082	1.648	1.034	1.222	0.686	0.736	0.349
59	10.635	207.383	1.669	1.043	1.240	0.693	0.749	0.352
60	10.776	210.132	1.706	1.056	1.271	0.703	0.771	0.357
61	10.831	211.205	1.724	1.063	1.286	0.708	0.783	0.359
62	10.900	212.550	1.749	1.072	1.306	0.714	0.798	0.362
63	11.008	214.656	1.782	1.085	1.332	0.721	0.815	0.365
64	11.123	216.899	1.817	1.097	1.360	0.730	0.837	0.368
65	11.234	219.063	1.840	1.107	1.380	0.737	0.849	0.372
66	11.325	220.838	1.866	1.115	1.402	0.743	0.866	0.375
67	11.406	222.417	1.896	1.124	1.428	0.750	0.885	0.378
68	11.520	224.640	1.923	1.133	1.452	0.756	0.902	0.381
69	11.632	226.824	1.960	1.144	1.482	0.765	0.925	0.384
70	11.725	228.638	1.989	1.153	1.508	0.770	0.943	0.387
71	11.815	230.393	2.027	1.162	1.541	0.778	0.968	0.389
72	11.870	231.465	2.056	1.169	1.564	0.782	0.984	0.392
73	11.909	232.226	2.079	1.174	1.583	0.786	0.998	0.393
74	12.005	234.098	2.130	1.185	1.624	0.794	1.027	0.396
75	12.108	236.106	2.186	1.197	1.670	0.801	1.057	0.399
76	12.216	238.212	2.228	1.206	1.705	0.807	1.081	0.401
77	12.327	240.377	2.269	1.213	1.740	0.812	1.105	0.403
78	12.418	242.151	2.313	1.219	1.777	0.817	1.132	0.404
79	12.520	244.140	2.377	1.225	1.830	0.822	1.172	0.405
80	12.626	246.207	2.453	1.230	1.892	0.828	1.218	0.405
81	12.710	247.845	2.556	1.233	1.974	0.831	1.279	0.403
82	12.755	248.723	2.656	1.232	2.051	0.830	1.337	0.398
83	12.840	250.380	2.760	1.230	2.134	0.830	1.399	0.393
84	12.698	247.611	3.238	1.176	2.546	0.791	1.735	0.348
85	14.363	280.080	2.542	1.396	1.935	0.936	1.217	0.467



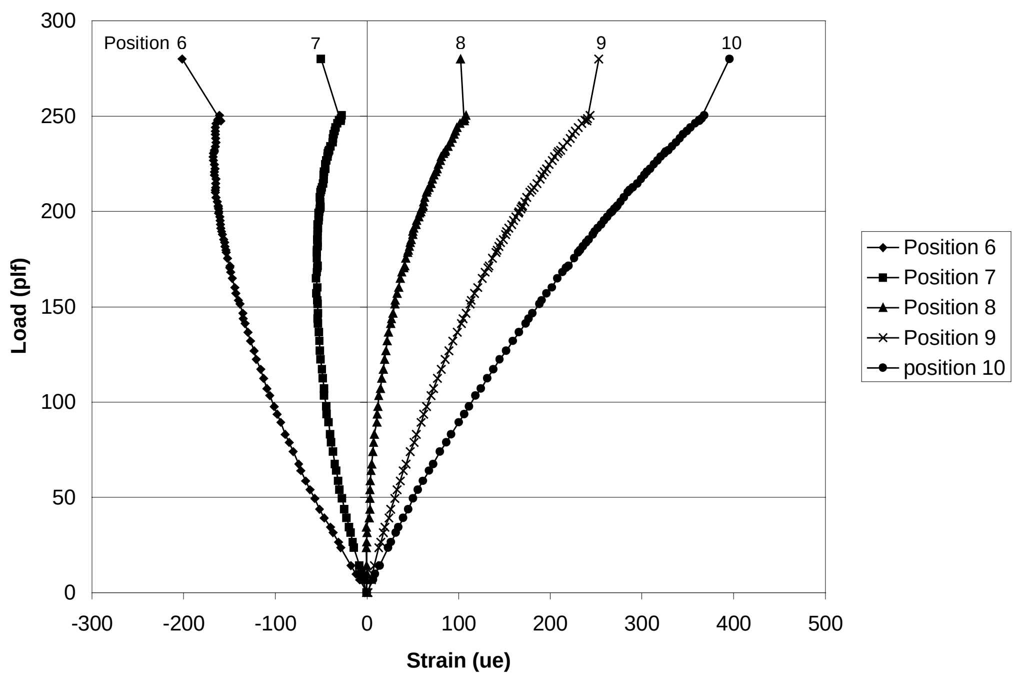
Test 4 C–TF Load vs. Vertical Deflection



Test 4 C–TF Load vs. Spread



Test 4 C–TF Load vs. Strain Near Purlin Line



Test 4 C–TF Load vs. Strain Far Purlin Line

APPENDIX E

I. P. TEST 1 Z–SS DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: I. P. Test 1 Z-SS
DATE: 3/17/99

TEST DESCRIPTION:

Loading……………………………… Gravity
Panel Type………………………… Standing Seam (R = 0.435)
Span……………………………… 2@30'-0"
Purlin Spacing…………………… 5' o.c. with 1' deck overhang
Lateral Bracing…………………… None
Anti-roll Clips…………………… At the supports of both purlin lines
Web Stiffeners…………………… None
Purlin Orientation………………… Top flanges opposed
Insulation………………………….. Foam Blocks

FAILURE MODE:

Positive moment failure of near purlin.

EXPERIMENTAL FAILURE LOAD:

Pressure = 5.20 in. of water

Applied Line Loading = 104.78 plf
Weight of Deck = 4.00 plf
Weight of Purlin = 4.06 plf
Total Applied Load = 112.84 plf

Maximum (+) Moment = 81.78 kip in.
Neg. Moment at Lap = 125.68 kip in.
Shear at Lap = 1.9758 kips

PREDICTED FAILURE LOAD: (F_y= 69.6 ksi)

Inflection Point As Bracepoint

Moment = $R F_y S_{eff}$ = 69.6(2.66)(0.435)= 80.53 kip-in.
Predicted Line Load = 111.52 plf

Inflection Point Not As Bracepoint

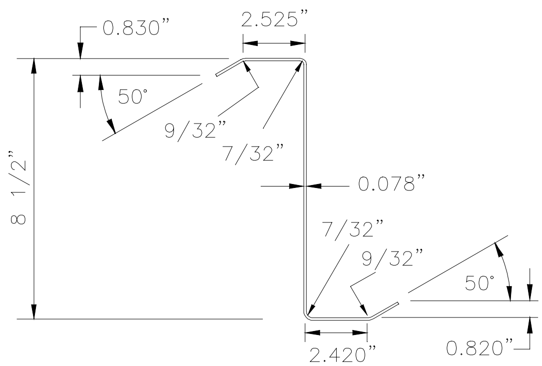
Moment = $R F_y S_{eff}$ = 69.6(2.66)(0.435)= 80.53 kip-in.
Predicted Line Load = 111.52 plf

Experimental/Predicted:

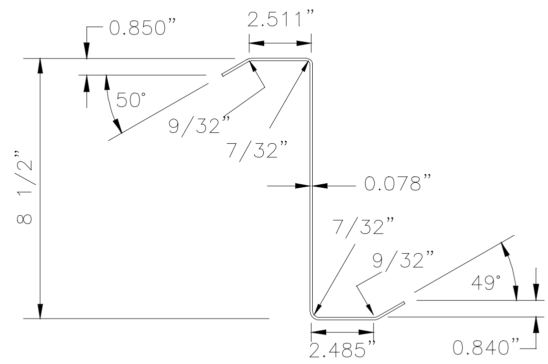
Failure/Predicted = 112.84/111.52 = 1.012 **I.P. Braced**
Failure/Predicted = 112.84/111.52 = 1.012 **I.P. Not Braced**

I. P. Test 1 Z-SS (Z8.5) Purlin Locations

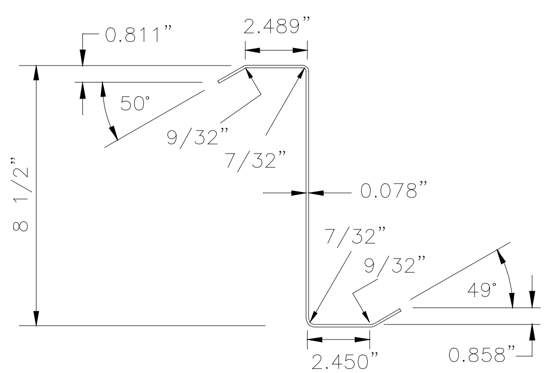
I. P. Test 1 Z-SS (Z8.5) Measured Dimensions



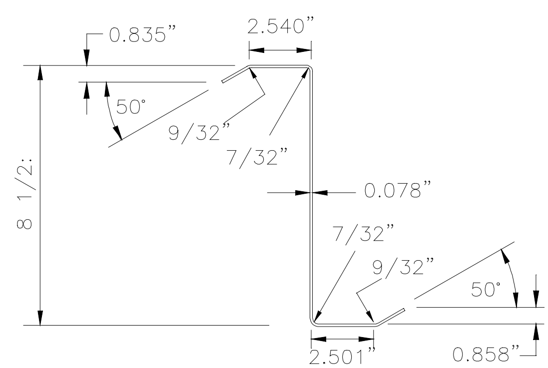
Purlin (IP2)



Purlin (IP1)



Purlin (IP3)



Purlin (IP4)

Results From Commercial Software

I. P. TEST 1 Z-SS 8.5 in. Z-SS 2 span IP 2

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.0835 in.	1.0704 in.
Lip Angle	50 °	50 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.525 in.	2.420 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	12.61 in^4
Iy	1.98 in^4
Ixy	3.62 in^4
Flexural Strength	
Ie	11.64 in^4
Se	2.63 in^3

I. P. TEST 1 Z-SS 8.5 in. Z-SS 2 span IP 1

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.1096 in.	1.113 in.
Lip Angle	50 °	49 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.511 in.	2.485 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.19 in^2
Ix	12.75 in^4
Iy	2.08 in^4
Ixy	3.74 in^4
Flexural Strength	
Ie	11.81 in^4
Se	2.66 in^3

Other properties for IP 1

rx	3.2729	in.
ry	1.325	in.
ro	3.531	in.
Cw	26.621	in^6
J	0.00232	in^4
α	-17.558	°

I. P. TEST 1 Z-SS 8.5 in. Z-SS 2 span IP 3

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.0587 in.	1.1369 in.
Lip Angle	50 ^{o}	49 ^{o}
Radii:		
Lip to Flange	0.2813 in.	0.3813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.489 in.	2.450 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	12.65 in^4
Iy	2.01 in^4
Ixy	3.65 in^4
Flexural Strength	
Ie	11.68 in^4
Se	2.62 in^3

I. P. TEST 1 Z-SS 8.5 in. Z-SS 2 span IP 4

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.09 in.	1.12 in.
Lip Angle	50 ^{o}	50 ^{o}
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.54 in.	2.501 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.19 in^2
Ix	12.79 in^4
Iy	2.11 in^4
Ixy	3.77 in^4
Flexural Strength	
Ie	11.82 in^4
Se	2.66 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

91.5 lbs/ft x 1.67 = 152.8 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

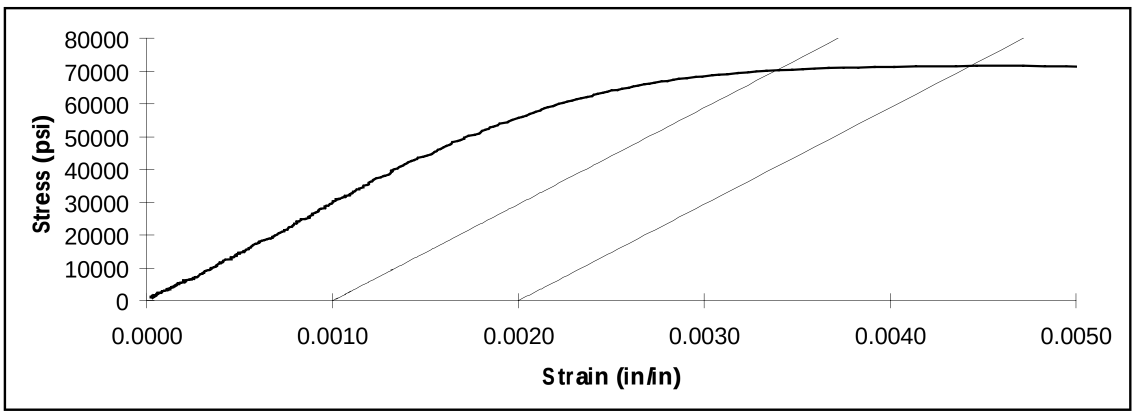
Test Designation:	I. P. Test # 1
Specimen Identification:	IP T-1A
Coupon Number:	T-1A
Date:	4/7/99
Gage length (in.):	7.994
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.077
Width (in.):	1.501

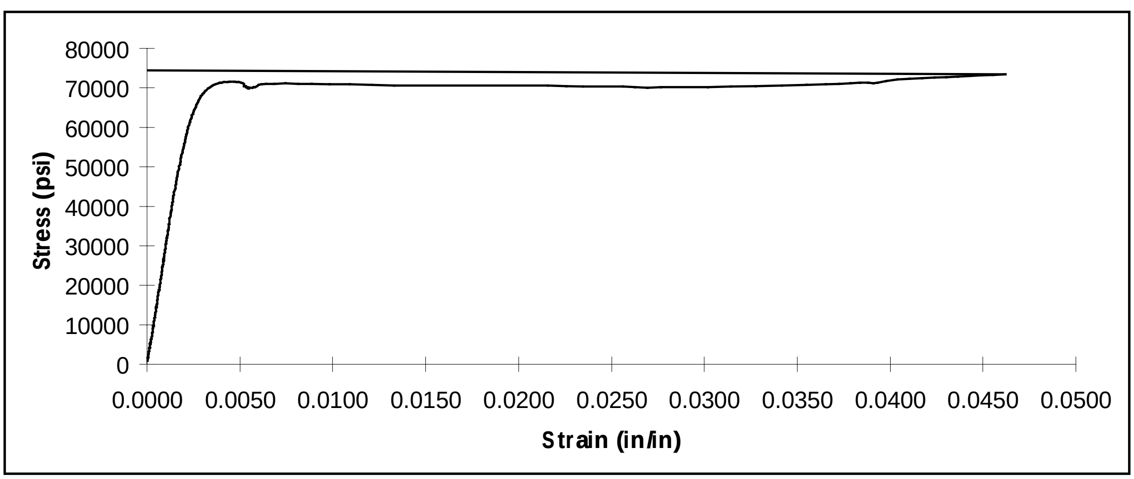
Test Setup:

Procedure:	Tensile Test	
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	70100 psi
.2% Offset Yield:	**71500 psi**
.5 in/in Yield:	71500 psi
Ulimate Strength:	79600 psi
Modulus of elasticity:	29.4 ksi
% Elongation:	21%





TENSION TEST OF MATERIALS

(In accordance with ASTM A370-95)

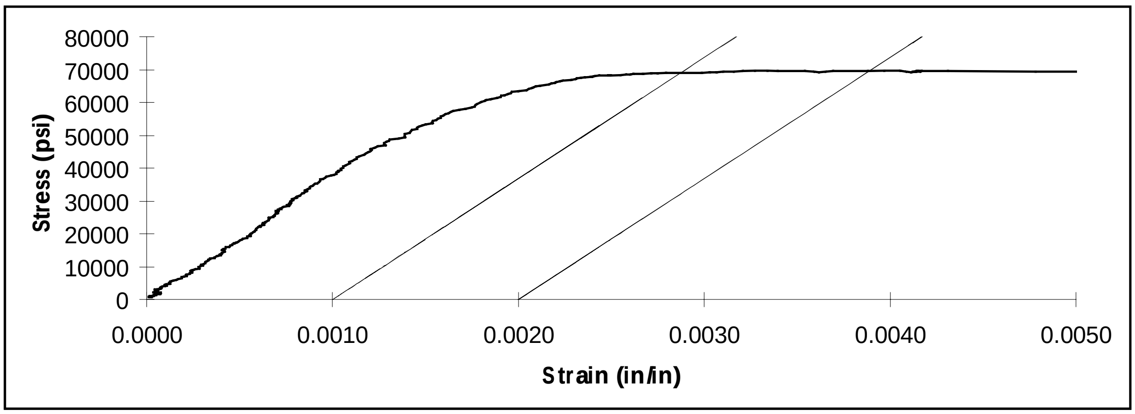
Test Designation:	I. P. Test # 1
Specimen Identification:	IP T-1B
Coupon Number:	T-1B
Date:	4/7/99
Gage length (in.):	8.006
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.077
Width (in.):	1.502

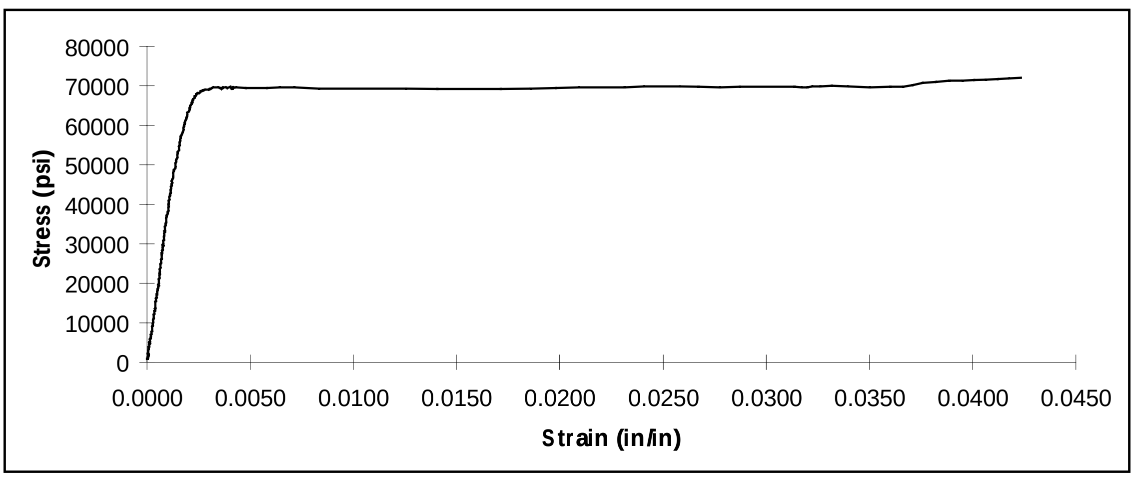
Test Setup:

Procedure:		Tensile Test
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	69100 psi
.2% Offset Yield:	**69500 psi**
.5 in/in Yield:	69400 psi
Ulimate Strength:	78300 psi
Modulus of elasticity:	36.9 ksi
% Elongation:	20%





RESULTS FROM STIFFNESS MODEL

I. P. TEST 1 Z-SS

Deck Type	Standing Seam
Spans	2@30
Total Lap Length	3'-0"
Extension into Test Bay	1'-6"
Purlin Designation	IP1
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	12.75	in^4
Ag =	1.19	in^2
Iy =	2.08	in^4

Test Bay

Max. (+) Moment =	**6.043**	k-ft
Moment at End of Lap =	**9.282**	k-ft
Shear at End of Lap =	**1.751**	k
Moment at Support =	**12.028**	k-ft
Shear at Support =	**1.901**	k
Max Deflection =	**1.886**	in.

Inflection Point Located at 21.98 ft. from exterior Support.
Max. (+) Moment located at 11.0 ft. from exterior Support
Max. Deflection Located at 12.525 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 6.52 ft. = 78.2 in.

End Bay Section Properties

Ix =	12.75	in^4
Ag =	1.19	in^2
Iy =	2.08	in^4

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	9.282	k-ft
Ma =	1.922	k-ft
Mb =	4.112	k-ft
Mc =	6.567	k-ft
Cb =	**1.782**	

Lap Section Properties

Ix =	25.5	in^4
Ag =	2.38	in^2
Iy =	4.16	in^4

Test ID: I. P. Test 1 Z-SS

Michael R. Bryant
3/17/99

Test Span, L = 30.0 ft I_x = 12.75 $in.^4$

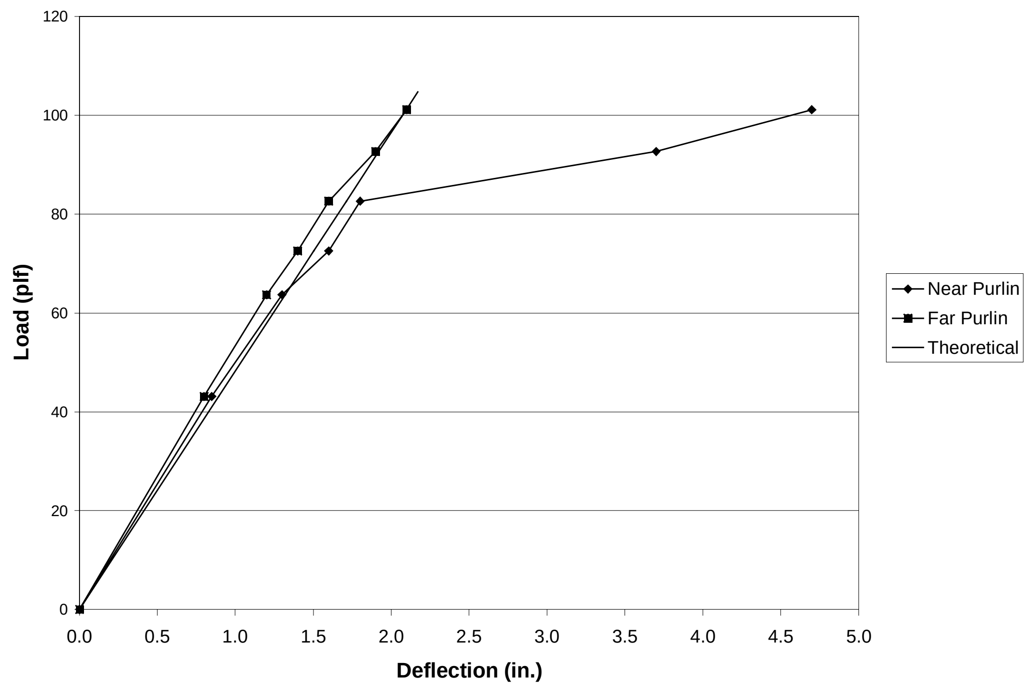
Scan ID	Time	Load w plf	Near Purlin Deflection (9dc) in.	Far Purlin Deflection (7dc) in.	Theoretical Deflection in.	Manometer in. h2o
1	4:04:22.56 PM	0.00	0	0	0.000	0.0
2	4:04:32.56 PM	43.12	0.85	0.8	0.893	2.1
3	4:17:12.75 PM	63.67	1.3	1.2	1.319	3.2
4	4:21:50.75 PM	72.54	1.6	1.4	1.503	3.6
5	4:22:34.75 PM	82.62	1.8	1.6	1.712	4.1
6	4:23:16.75 PM	92.69	3.7	1.9	1.921	4.6
7	4:24:20.75 PM	101.15	4.7	2.1	2.096	5.0
8	4:26:28.75 PM	104.78			2.171	5.2

Scan ID	Load w plf	Manometer in. h2o	Max Mom Near in.	Max Mom far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
1	0.00	0.0	0	0	0.000	0.000	0.000	0.000
2	43.12	2.1	-0.026	-0.06	-0.041	-0.054	-0.031	-0.041
3	63.67	3.2	-0.026	-0.09	-0.056	-0.085	-0.042	-0.064
4	72.54	3.6	-0.018	-0.65	-0.057	-0.096	-0.040	-0.074
5	82.62	4.1	-0.001	-0.113	-0.049	-0.107	-0.031	-0.081
6	92.69	4.6	0.991	-0.127	0.312	-0.149	0.186	-0.122
7	101.15	5.0	0.682	-0.145	0.420	-0.163	0.274	-0.139
8	104.78	5.2						

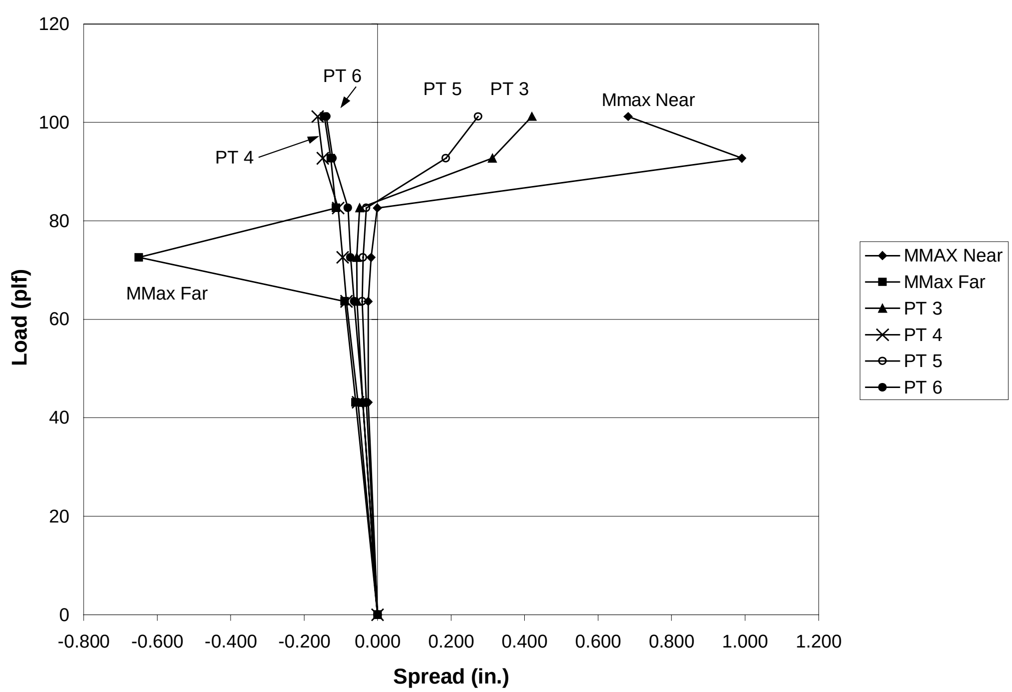
Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width
Units	plf	in.	in.	in.	in.
IP1	4.00	8.50	0.078	2.511	2.485

A_g, Area	w_o, Self Weight	w_{ts}	S_{et}	F_y
in^2	plf	plf	in^3	ksi
1.19	8.06	71.73	2.66	69.6

Notes:	
	Opposed Purlins Standing Seam Panel Foam Blocks



I. P. Test 1 Z–SS Load vs. Vertical Deflection



I. P. Test 1 Z–SS Load vs. Spread

APPENDIX F

I. P. TEST 2 Z–SS DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: I. P. Test 2 Z-SS
DATE: 3/18/99

TEST DESCRIPTION:

Loading…………………………… Gravity
Panel Type………………………… Standing Seam (R = 0.435)
Span……………………………… 2@30'-0"
Purlin Spacing…………………… 5' o.c. with 1' deck overhang
Lateral Bracing…………………… None
Anti-roll Clips…………………… At the supports of both purlin lines
Web Stiffeners…………………… None
Purlin Orientation………………… Top flanges opposed
Insulation………………………… Foam Blocks

FAILURE MODE:

Positive moment failure of Near purlin.

EXPERIMENTAL FAILURE LOAD:

Pressure =	5.10	in. of water
Applied Line Loading =	102.8	plf
Weight of Deck =	4.00	plf
Weight of Purlin =	4.02	plf
Total Applied Load =	110.82	plf
Maximum (+) Moment =	80.33	kip in.
Neg. Moment at Lap =	123.53	kip in.
Shear at Lap =	1.9405	kips

PREDICTED FAILURE LOAD: (F_y= 69.6 ksi)

Inflection Point As Bracepoint

Moment = R $F_y S_{eff}$ =	69.6(2.62)(0.435)=	80.53	kip-in.
Predicted Line Load =		111.49	plf

Inflection Point Not As Bracepoint

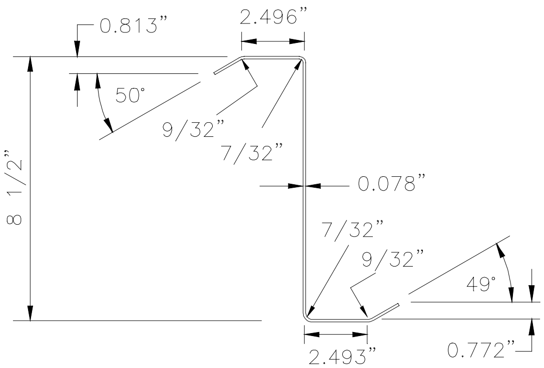
Moment = R $F_y S_{eff}$ =	69.6(2.62)(0.435)=	80.53	kip-in.
Predicted Line Load =		111.49	plf

Experimental/Predicted:

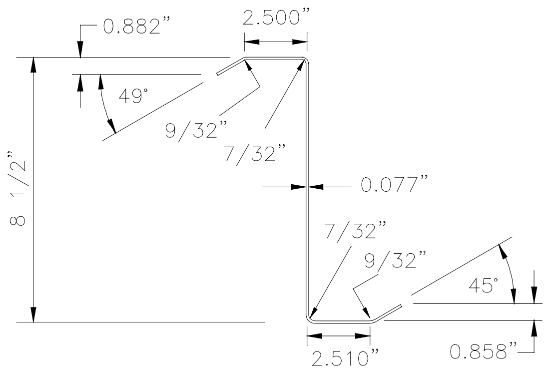
Failure/Predicted =	110.82/111.49 =	0.994	**I.P. Braced**
Failure/Predicted =	110.82/111.49 =	0.994	**I.P. Not Braced**

I. P. Test 2 Z-SS (Z8.5) Purlin Locations

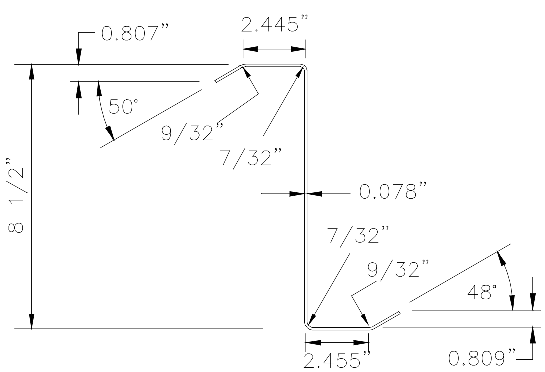
I. P. Test 2 Z-SS (Z8.5) Measured Dimensions



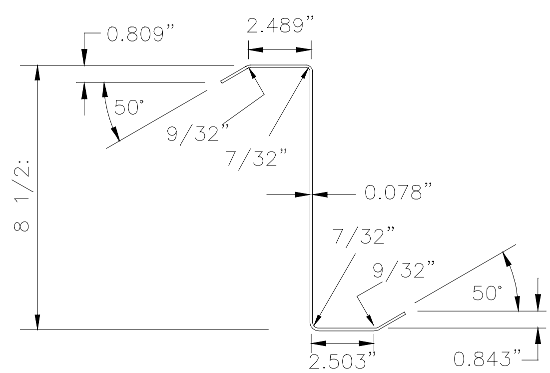
Purlin (IP7)



Purlin (IP5)



Purlin (IP6)



Purlin (IP8)

Results From Commercial Software

I. P. TEST 2 Z-SS 8.5 in. Z-SS 2 span IP 7

Purlin Geometry and Material Properties Bay #1 (Test Bay) — Purlin Properties

	Top	Bottom		
			Ag	1.18 in^2
Overall Lip Dimension	1.0613 in.	1.0229 in.	Ix	12.62 in^4
Lip Angle	50 °	49 °	Iy	1.97 in^4
Radii:			Ixy	3.61 in^4
Lip to Flange	0.2813 in.	0.2813 in.	Flexural Strength	
Flange to Web	0.2188 in.	0.2188 in.	Ie	11.65 in^4
Flange Width	2.496 in.	2.493 in.	Se	2.62 in^3
Purlin Depth	8.5 in.			
Purlin Thickness	0.078 in.			
Yield Stress	69.6 ksi			
Modulus of Elasticity	29500 ksi			

I. P. TEST 2 Z-SS 8.5 in. Z-SS 2 span IP 5

Purlin Geometry and Material Properties Bay #1 (Test Bay) — Purlin Properties

	Top	Bottom		
			Ag	1.18 in^2
Overall Lip Dimension	1.1687 in.	1.1031 in.	Ix	12.70 in^4
Lip Angle	49 °	45 °	Iy	2.13 in^4
Radii:			Ixy	3.78 in^4
Lip to Flange	0.2813 in.	0.2813 in.	Flexural Strength	
Flange to Web	0.2188 in.	0.2188 in.	Ie	11.84 in^4
Flange Width	2.500 in.	2.510 in.	Se	2.68 in^3
Purlin Depth	8.5 in.			
Purlin Thickness	0.077 in.			
Yield Stress	69.6 ksi			
Modulus of Elasticity	29500 ksi			

Other properties for IP 5

rx	3.2768	in.
ry	1.3451	in.
ro	3.5427	in.
Cw	27.817	in^6
J	0.00242	in^4
α	-17.831	°

I. P. TEST 2 Z-SS 8.5 in. Z-SS 2 span IP 6

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.0535 in.	1.0859 in.
Lip Angle	50 °	48 °
Radii:		
Lip to Flange	0.2813 in.	0.3813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.445 in.	2.455 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.17 in^2
Ix	12.55 in^4
Iy	1.93 in^4
Ixy	3.57 in^4
Flexural Strength	
Ie	11.70 in^4
Se	2.64 in^3

I. P. TEST 2 Z-SS 8.5 in. Z-SS 2 span IP 8

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.0561 in.	1.1005 in.
Lip Angle	50 °	50 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.489 in.	2.503 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	12.68 in^4
Iy	2.02 in^4
Ixy	3.67 in^4
Flexural Strength	
Ie	11.70 in^4
Se	2.62 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

88.0 lbs/ft x 1.67 = 147.0 lbs/ft

TENSION TEST OF MATERIALS
(In accordance with ASTM A370-95)

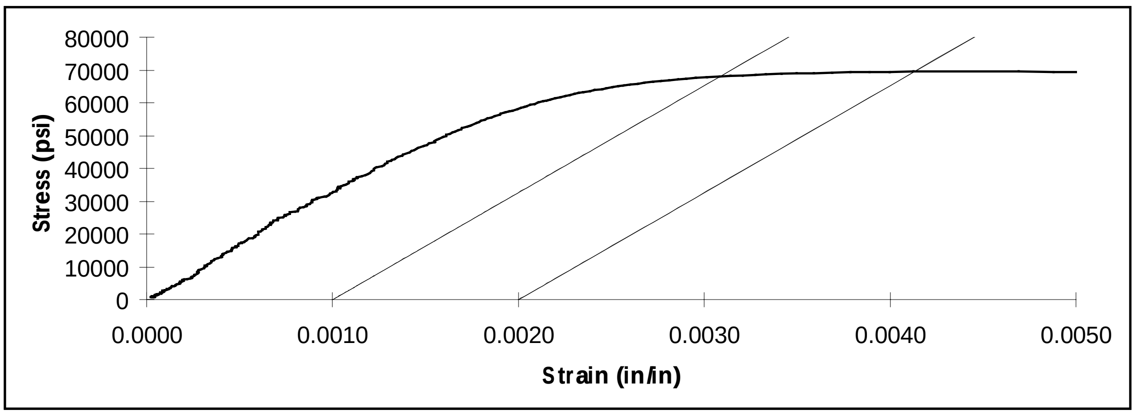
Test Designation:	I. P. Test # 2
Specimen Identification:	IP T-2A
Coupon Number:	T-2A
Date:	4/7/99
Gage length (in.):	8.011
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.078
Width (in.):	1.501

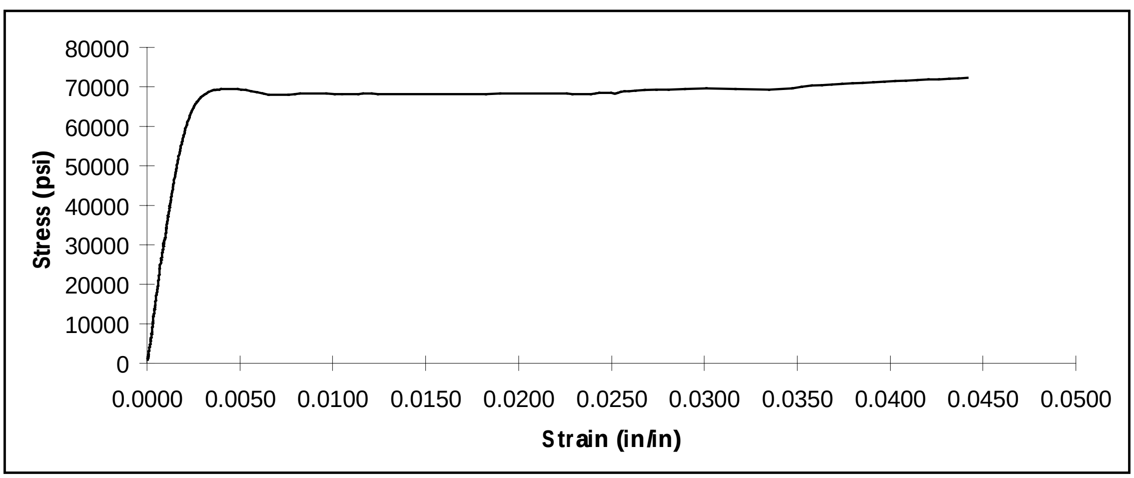
Test Setup:

Procedure:	Tensile Test	
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	68000 psi
.2% Offset Yield:	**69500 psi**
.5 in/in Yield:	69500 psi
Ulimate Strength:	78200 psi
Modulus of elasticity:	32.6 ksi
% Elongation:	21%





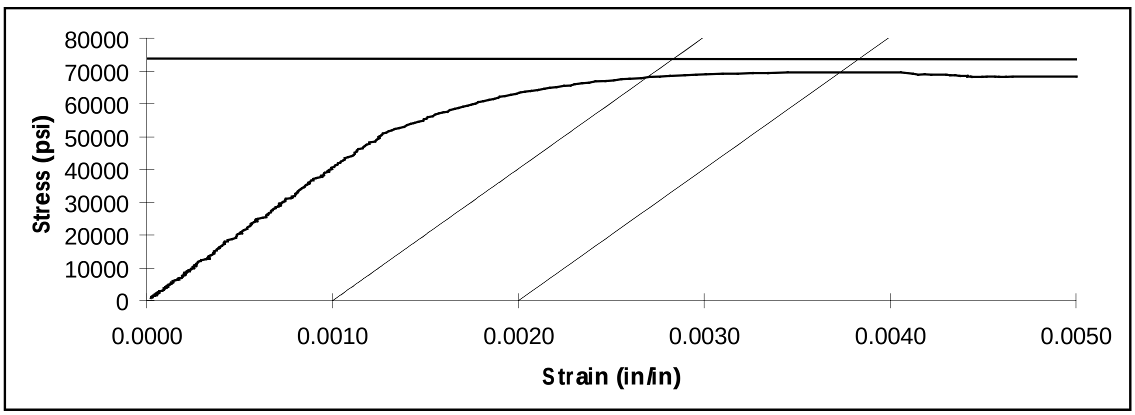
TENSION TEST OF MATERIALS

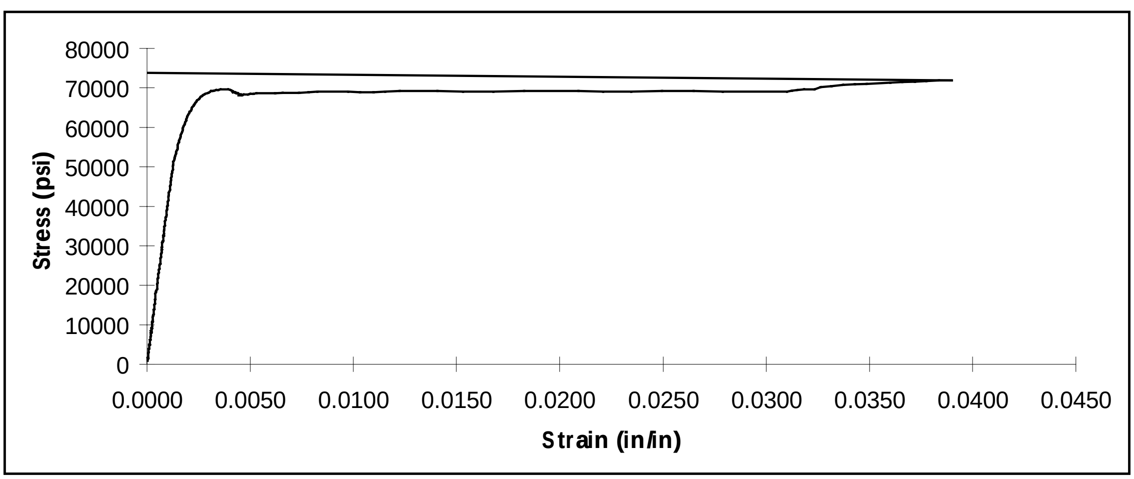
(In accordance with ASTM A370-95)

Test Designation:	I. P. Test # 2
Specimen Identification:	IP T-2B
Coupon Number:	T-2B
Date:	4/7/99
Gage length (in.):	8.001
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.077
Width (in.):	1.502

Test Setup:			
	Procedure:	Tensile Test	
Range 1	Rate:	50000 psi/min	
	End Level:	55000 psi	
Range 2	Rate:	10000 psi/min	
	End Level:	0.2 in/in	
Range 3	Rate:	25000 psi/min	
	End Level:	Sample Break	

Test Data:	
.1% Offset Yield:	67900 psi
.2% Offset Yield:	**69600 psi**
.5 in/in Yield:	68400 psi
Ulimate Strength:	78700 psi
Modulus of elasticity:	40.2 ksi
% Elongation:	21%





RESULTS FROM STIFFNESS MODEL

I. P. TEST 2 Z-SS

Deck Type	Standing Seam
Spans	2@30
Total Lap Length	3'-0"
Extension into Test Bay	1'-6"
Purlin Designation	IP5
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	12.7	in^4
Ag =	1.18	in^2
Iy =	2.13	in^4

Test Bay

Max. (+) Moment =	**6.043**	k-ft
Moment at End of Lap =	**9.282**	k-ft
Shear at End of Lap =	**1.751**	k
Moment at Support =	**12.028**	k-ft
Shear at Support =	**1.901**	k
Max Deflection =	**1.886**	in.

Inflection Point Located at 21.98 ft. from exterior Support.
Max. (+) Moment located at 11.0 ft. from exterior Support
Max. Deflection Located at 12.525 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 6.52 ft. = 78.2 in.

End Bay Section Properties

Ix =	12.7	in^4
Ag =	1.18	in^2
Iy =	2.13	in^4

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	9.282	k-ft
Ma =	1.922	k-ft
Mb =	4.112	k-ft
Mc =	6.567	k-ft
Cb =	**1.782**	

Lap Section Properties

Ix =	25.4	in^4
Ag =	2.36	in^2
Iy =	4.26	in^4

Test ID: I. P. Test 2 Z-SS

Michael R. Bryant
3/18/99

Test Span, L = 30.0 ft I_x = 12.75 in.^{4}

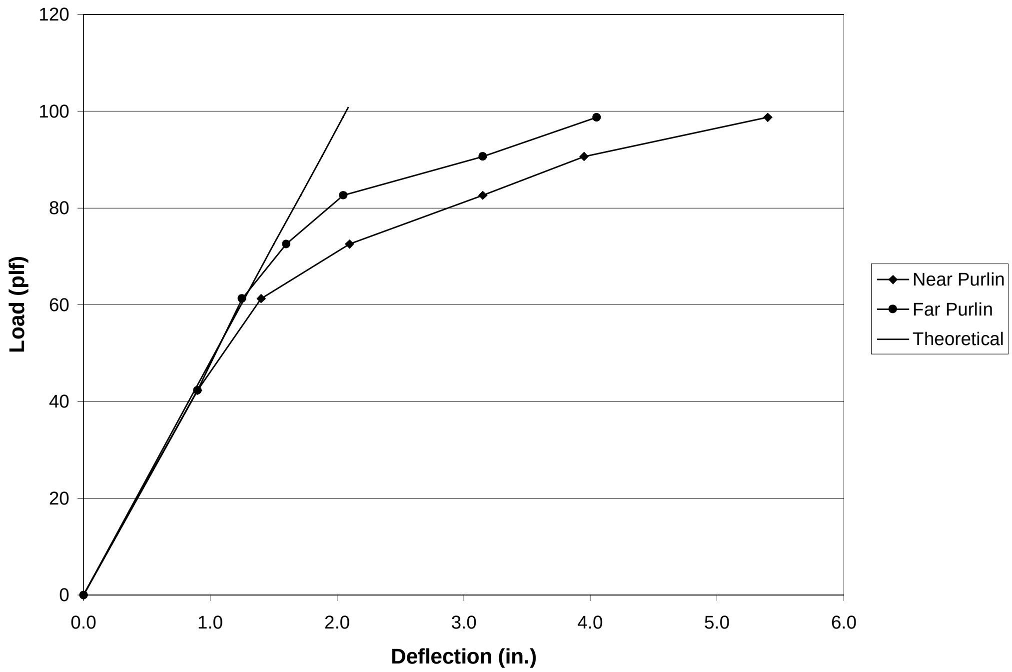
Scan ID	Time	Load w plf	Near Purlin Deflection (9dc) in.	Far Purlin Deflection (7dc) in.	Theoretical Deflection in.	Manometer in. h2o
1	4:04:22.56 PM	0.000	0	0	0.000	0.0
2	4:04:32.56 PM	42.315	0.9	0.9	0.877	2.1
3	4:17:12.75 PM	61.256	1.4	1.25	1.269	3.0
4	4:21:50.75 PM	72.540	2.1	1.6	1.503	3.6
5	4:22:34.75 PM	82.615	3.15	2.05	1.712	4.1
6	4:23:16.75 PM	90.675	3.95	3.15	1.879	4.5
7	4:24:20.75 PM	98.735	5.4	4.05	2.046	4.9
8	4:26:28.75 PM	100.750			2.088	5.0

Scan ID	Load w plf	Manometer in. h2o	Max Mom Near in.	Max Mom far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
1	0.000	0.0	0	0	0.000	0.000	0.000	0.000
2	42.315	2.1	-0.001	-0.003	0.007	-0.026	0.024	-0.025
3	61.256	3.0	0.028	0.015	0.037	-0.036	0.069	-0.031
4	72.540	3.6	0.209	0.165	0.129	-0.049	0.145	-0.039
5	82.615	4.1	1.021	0.397	0.292	-0.062	0.242	-0.059
6	90.675	4.5	1.379	0.47	0.397	-0.047	0.319	-0.064
7	98.735	4.9	1.901	0.245	0.505	-0.049	0.387	-0.071
8	100.750	5.0						

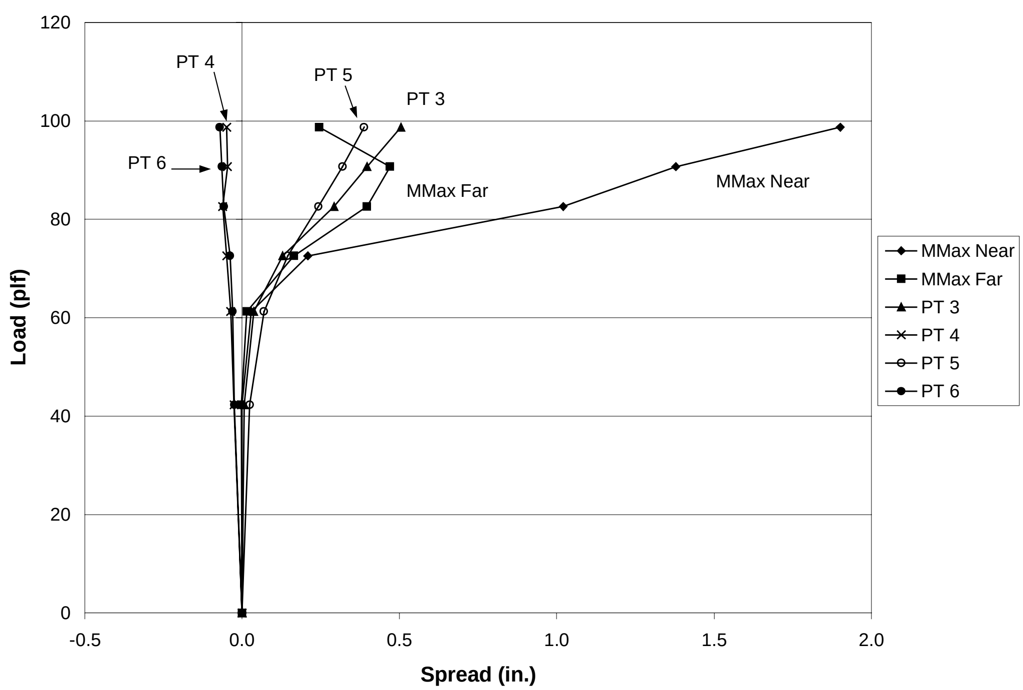
Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width
Units	plf	in.	in.	in.	in.
IP7	4.00	8.50	0.078	2.496	2.493

A_g, Area	w_o, Self Weight	w_{ts}	S_{et}	F_y
in^2	plf	plf	in^3	ksi
1.18	8.02	108.77	2.66	69.6

Notes:	Opposed Purlins Standing Seam Panel Foam Blocks



I. P. Test 2 Z–SS Load vs. Vertical Deflection



I. P. Test 2 Z–SS Load vs. Spread

APPENDIX G

I. P. TEST 3 Z–TF DATA

INFLECTION POINT INVESTIGATION TEST SUMMARY

TEST IDENTIFICATION: I. P. Test 3 Z-TF
DATE: 3/19/99

TEST DESCRIPTION:

Loading……………………………… Gravity
Panel Type………………………… Standing Seam (R = 0.435)
Span……………………………… 2@30'-0"
Purlin Spacing……………………… 5' o.c. with 1' deck overhang
Lateral Bracing……………………… None
Anti-roll Clips……………………… At the supports of both purlin lines
Web Stiffeners……………………… None
Purlin Orientation…………………… Top flanges opposed
Insulation………………………….. None

FAILURE MODE:

Combined Shear plus Bending at Face of Lap

EXPERIMENTAL FAILURE LOAD:

Pressure =	8.00	in. of water
Applied Line Loading =	161.2	plf
Weight of Deck =	4.00	plf
Weight of Purlin =	4.02	plf
Total Applied Load =	169.22	plf
Maximum (+) Moment =	122.65	kip in.
Neg. Moment at Lap =	188.49	kip in.
Shear at Lap =	2.9631	kips

PREDICTED FAILURE LOAD: (F_y= 69.6 ksi)

Inflection Point As Bracepoint

Combined Shear + Bending:

Neg. Moment at Lap =	179.0	kip in.
Shear at Lap =	2.90	kips
Predicted Line Load =	153.22	plf

Inflection Point Not As Bracepoint

Combined Shear + Bending:

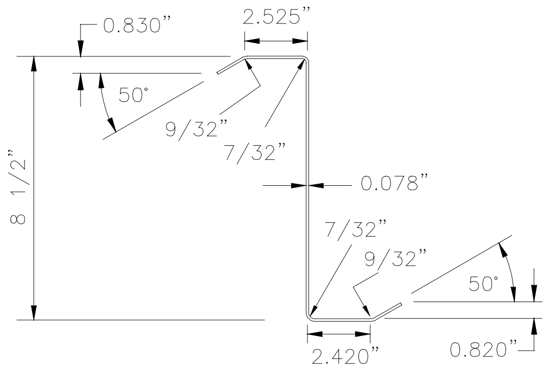
Neg. Moment at Lap =	162.10	kip in.
Shear at Lap =	2.53	kips
Predicted Line Load =	139.52	plf

Experimental/Predicted:

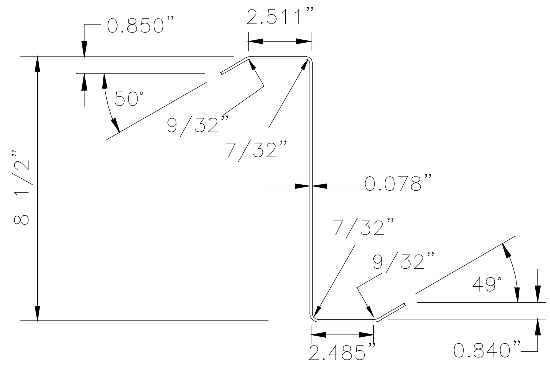
Failure/Predicted =	169.22/153.22 =	1.104	**I.P. Braced**
Failure/Predicted =	169.22/139.52 =	1.213	**I.P. Not Braced**

I. P. Test 3 Z–TF (Z8.5) Purlin Locations

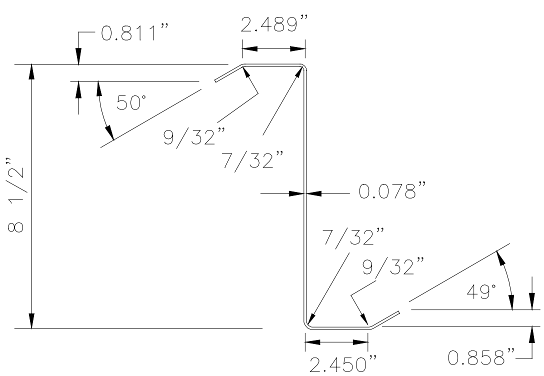
I. P. Test 3 Z–TF (Z8.5) Measured Dimensions



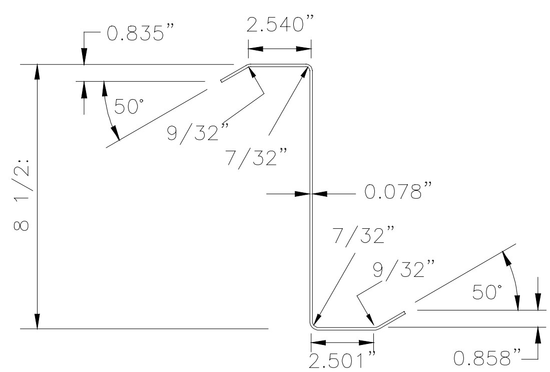
Purlin (IP9)



Purlin (IP10)



Purlin (IP11)



Purlin (IP12)

Results From Commercial Software

I. P. TEST 3 Z-TF 8.5 in. Z-TF 2 span IP 9

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.0835 in.	1.0704 in.
Lip Angle	50 °	50 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.525 in.	2.420 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	12.61 in^4
Iy	1.98 in^4
Ixy	3.62 in^4
Flexural Strength	
Ie	11.64 in^4
Se	2.63 in^3

I. P. TEST 3 Z-TF 8.5 in. Z-TF 2 span IP 10

Purlin Geometry and Material Properties Bay #1 (Test Bay)

	Top	Bottom
Overall Lip Dimension	1.1096 in.	1.113 in.
Lip Angle	50 °	49 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.511 in.	2.485 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.19 in^2
Ix	12.75 in^4
Iy	2.08 in^4
Ixy	3.74 in^4
Flexural Strength	
Ie	11.81 in^4
Se	2.66 in^3

Other properties for IP 10

rx	3.2729	in.
ry	1.325	in.
ro	3.531	in.
Cw	26.621	in^6
J	0.00232	in^4
α	-17.558	°

I. P. TEST 3 Z-TF 8.5 in. Z-TF 2 span IP 11

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.0587 in.	1.1369 in.
Lip Angle	50 °	49 °
Radii:		
Lip to Flange	0.2813 in.	0.3813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.489 in.	2.450 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.18 in^2
Ix	12.65 in^4
Iy	2.01 in^4
Ixy	3.65 in^4
Flexural Strength	
Ie	11.68 in^4
Se	2.62 in^3

I. P. TEST 3 Z-TF 8.5 in. Z-TF 2 span IP 12

Purlin Geometry and Material Properties Bay #2 (End Bay)

	Top	Bottom
Overall Lip Dimension	1.09 in.	1.12 in.
Lip Angle	50 °	50 °
Radii:		
Lip to Flange	0.2813 in.	0.2813 in.
Flange to Web	0.2188 in.	0.2188 in.
Flange Width	2.540 in.	2.501 in.
Purlin Depth	8.5 in.	
Purlin Thickness	0.078 in.	
Yield Stress	69.6 ksi	
Modulus of Elasticity	29500 ksi	

Purlin Properties

Ag	1.19 in^2
Ix	12.79 in^4
Iy	2.11 in^4
Ixy	3.77 in^4
Flexural Strength	
Ie	11.82 in^4
Se	2.66 in^3

Predicted Through Fastened Capacity (ASD) From Commercial Software

91.5 lbs/ft x 1.67 = 152.8 lbs/ft

ASSUMED BEHAVIOR FOR I. P. TEST 3 Z-TF

TENSION TEST OF MATERIALS

(In accordance with ASTM A370-95)

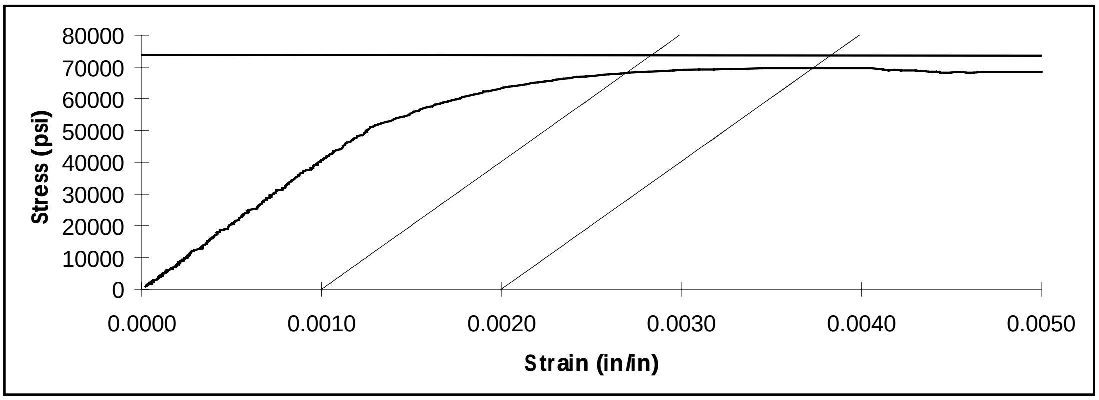
Test Designation:	I. P. Test # 2
Specimen Identification:	IP T-2B
Coupon Number:	T-2B
Date:	4/7/99
Gage length (in.):	8.001
Total length (in.):	8.0
Length between shoulders (in.):	10.0
Thickness (in.):	0.077
Width (in.):	1.502

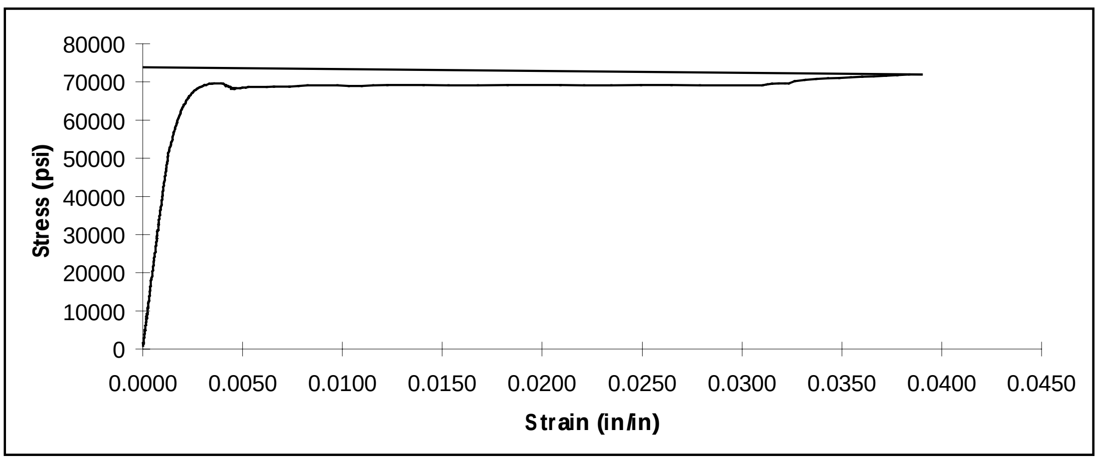
Test Setup:

Procedure: Tensile Test		
Range 1	Rate:	50000 psi/min
	End Level:	55000 psi
Range 2	Rate:	10000 psi/min
	End Level:	0.2 in/in
Range 3	Rate:	25000 psi/min
	End Level:	Sample Break

Test Data:

.1% Offset Yield:	67900 psi
.2% Offset Yield:	**69600 psi**
.5 in/in Yield:	68400 psi
Ulimate Strength:	78700 psi
Modulus of elasticity:	40.2 ksi
% Elongation:	21%





RESULTS FROM STIFFNESS MODEL

I. P. TEST 3 Z-TF

Deck Type	Through Fastened
Spans	2@30
Total Lap Length	3'-0"
Extension into Test Bay	1'-6"
Purlin Designation	IP5
Load applied to Model	100 plf

Test Bay Section Properties

Ix =	12.7	in^4
Ag =	1.18	in^2
Iy =	2.13	in^4

End Bay Section Properties

Ix =	12.7	in^4
Ag =	1.18	in^2
Iy =	2.13	in^4

Lap Section Properties

Ix =	25.4	in^4
Ag =	2.36	in^2
Iy =	4.26	in^4

Test Bay

Max. (+) Moment =	**6.043**	k-ft
Moment at End of Lap =	**9.282**	k-ft
Shear at End of Lap =	**1.751**	k
Moment at Support =	**12.028**	k-ft
Shear at Support =	**1.901**	k
Max Deflection =	**1.886**	in.

Inflection Point Located at 21.98 ft. from exterior Support.
Max. (+) Moment located at 11.0 ft. from exterior Support
Max. Deflection Located at 12.525 ft. from exterior Support
Unbraced length (lu) between I. P. and Lap = 6.52 ft. = 78.2 in.

$$C_b := \frac{12.5 \cdot Mmax}{2.5 \cdot Mmax + 3 \cdot Ma + 4 \cdot Mb + 3 \cdot Mc}$$

Mmax =	9.282	k-ft
Ma =	1.922	k-ft
Mb =	4.112	k-ft
Mc =	6.567	k-ft
Cb =	**1.782**	

Test ID: I. P. Test 3 Z-TF

Michael R. Bryant
3/19/99

Test Span, L = 30.0 ft

I_x = 12.75 in.^{4}

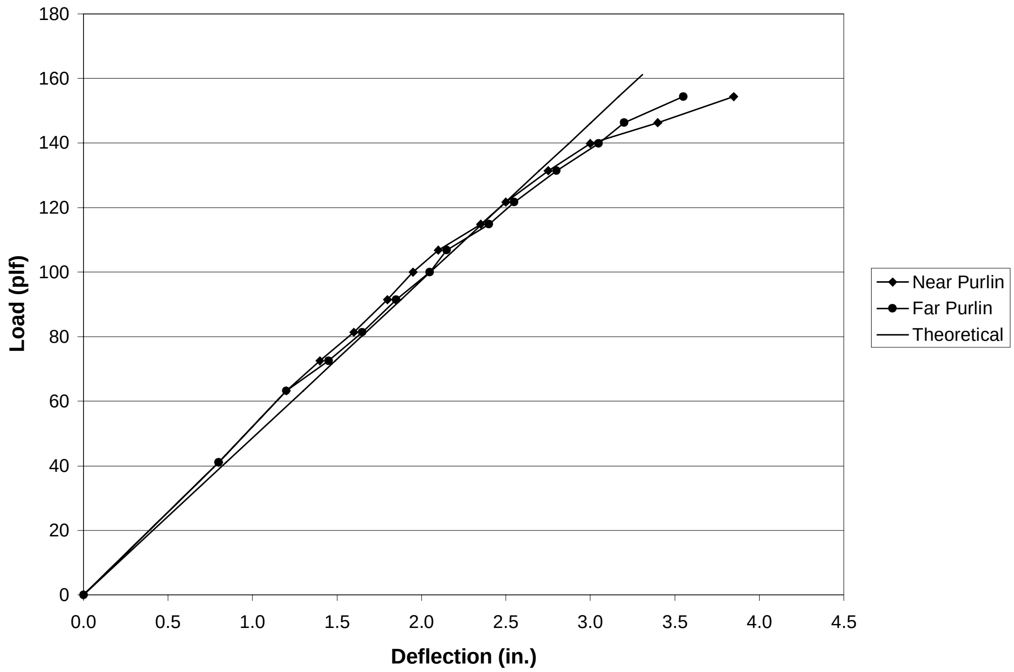
Scan ID	Load w plf	Near Purlin Deflection (9dc) in.	Far Purlin Deflection (7dc) in.	Theoretical Deflection in.	Manometer in. h2o
1	0.000	0	0	0.000	0.0
2	41.106	0.8	0.8	0.844	2.0
3	63.271	1.2	1.2	1.299	3.1
4	72.540	1.4	1.45	1.489	3.6
5	81.406	1.6	1.65	1.671	4.0
6	91.481	1.8	1.85	1.878	4.5
7	99.944	1.95	2.05	2.052	5.0
8	106.795	2.1	2.15	2.193	5.3
9	114.855	2.35	2.4	2.358	5.7
10	121.706	2.5	2.55	2.499	6.0
11	131.378	2.75	2.8	2.697	6.5
12	139.841	3	3.05	2.871	6.9
13	146.289	3.4	3.2	3.003	7.3
14	154.349	3.85	3.55	3.169	7.7
15	161.200			3.309	8.0

Scan ID	Load w plf	Manometer in. h2o	Max Mom Near in.	Max Mom far in.	PT #3 in.	PT #4 in.	PT #5 in.	PT #6 in.
1	0.000	0.0	0	0	0.000	0.000	0.000	0.000
2	41.106	2.0	0.005	0.038	-0.004	0.026	-0.004	0.022
3	63.271	3.1	0.008	0.049	-0.007	0.033	-0.006	0.031
4	72.540	3.6	0.01	0.054	-0.009	0.035	-0.008	0.033
5	81.406	4.0	0.013	0.061	-0.012	0.036	-0.009	0.036
6	91.481	4.5	0.017	0.068	-0.014	0.040	-0.010	0.041
7	99.944	5.0	0.022	0.077	-0.015	0.047	-0.010	0.049
8	106.795	5.3	0.029	0.087	-0.016	0.054	-0.010	0.059
9	114.855	5.7	0.037	0.1	-0.015	0.064	-0.009	0.069
10	121.706	6.0	0.049	0.113	-0.013	0.075	-0.006	0.081
11	131.378	6.5	0.063	0.135	0.002	0.094	0.012	0.103
12	139.841	6.9	0.088	0.154	0.021	0.110	0.034	0.121
13	146.289	7.3	0.127	0.182	0.074	0.133	0.101	0.146
14	154.349	7.7	0.19	0.219	0.148	0.157	0.174	0.171
15	161.200	8.0						

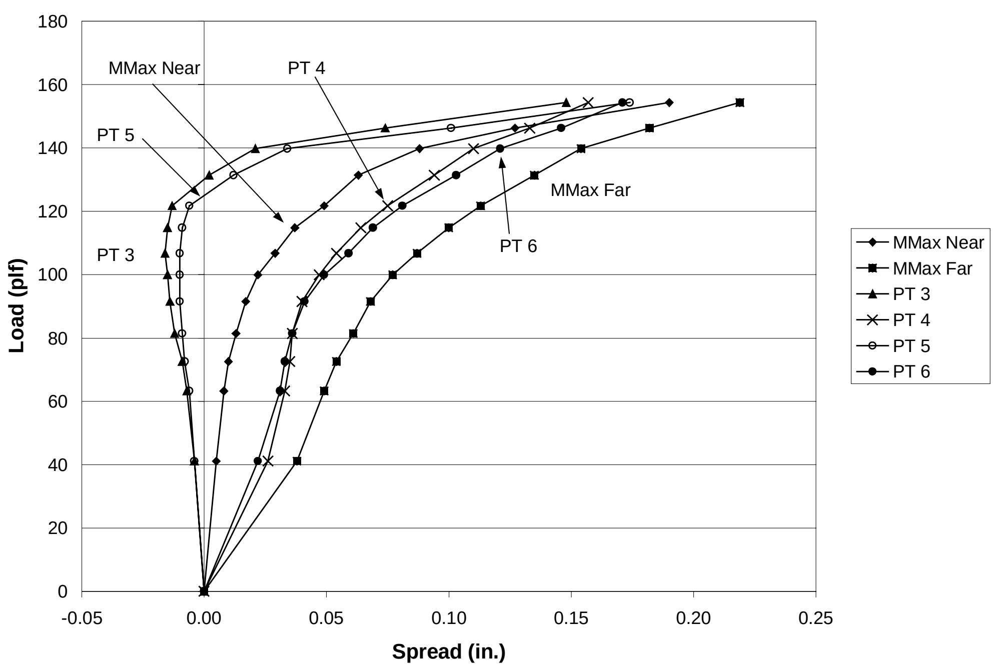
Properties	w_d, Deck Weight	d, Depth	t, Thickness	Top Flange Width	Bottom Flange Width
Units	plf	in.	in.	in.	in.
IP9	4.00	8.50	0.078	2.496	2.493

A_g, Area	w_o, Self Weight	w_{ts}	S_{et}	F_y
in^2	plf	plf	in^3	ksi
1.18	8.02	169.2238	2.66	69.6

Notes: Opposed Purlins
Through Fastened Panel



I. P. Test 3 Z–TF Load vs. Vertical Deflection



I. P. Test 3 Z–TF Load vs. Spread

VITA

Michael R. Bryant was born in Woodlawn, Virginia on February 11, 1974. After graduating from high school in 1992 he entered the engineering program at Virginia Polytechnic Institute and State University. In 1997 he attained a Bachelor of Science Degree in Civil Engineering and enrolled in the graduate program in the Civil Engineering Department at Virginia Polytechnic Institute and State University, Blacksburg, Virginia.