EVALUATION OF THE BASE TEST METHOD FOR DETERMINING THE STRENGTH OF STANDING SEAM ROOF SYSTEMS UNDER GRAVITY LOADINGS

by

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(ABSTRACT)

The base test method has been proposed by Carballo, Holzer and Murray [5] as a means of determining the strength of standing seam roof systems under gravity loading. The objective of this thesis is to evaluate the accuracy of the base test method. To do this, eleven sets of tests were performed at Virginia Polytechnic Institute & State University (VPI&SU). Each test set consisted of a single span base test from which a failure load was predicted for the corresponding three span confirming test. Results of two test sets recorded in Reference [5] were also used to evaluate the method. A secondary objective of this thesis is to comment on the effects that system components (purlin orientation, clip type, bracing configuration, panel type, insulation and purlin type) have on the strength of the system. Results from proprietary tests conducted at VPI & SU were used in conjunction with the results from this research to accomplish the secondary objective.

ACKNOWLEDGEMENTS

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My friends and colleagues , , , and have my undying gratitude for their daily aid in performing the experiments. I also wish to express thanks to for her clerical skills and help.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Traditionally metal roofs have been used on residences, on private buildings and as the roof coverings of prefabricated metal buildings. Recently metal roofs have evolved into a form that has gained popularity as a roofing system for conventional commercial buildings such as shopping malls and low rise office complexes. One reason for this new market is the standing seam roof (SSR) system. This type of roof system has been found to be aesthetically pleasing, durable and easy to maintain.

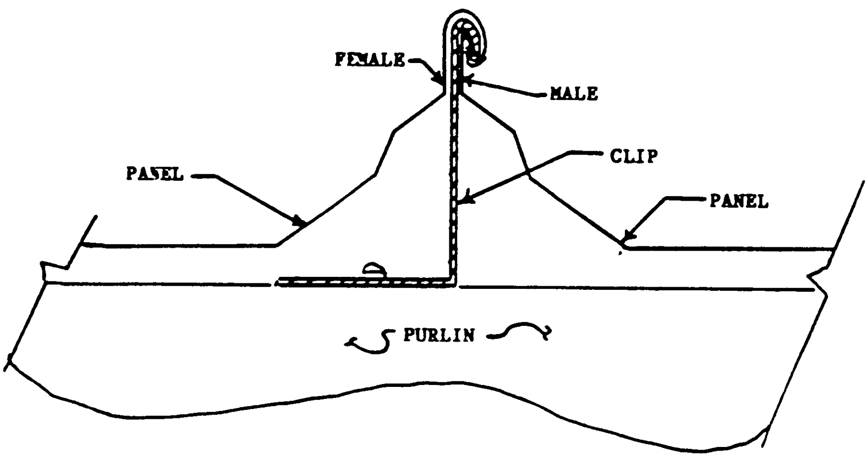
A conventional through-fastened system is the predecessor to the standing seam system. In the past, the conventional metal roof was looked upon as having a tendency to leak, corrode and disturb the aesthetics of the building [1]. Many of these problems have been solved by the development of the standing seam system. In addition, zinc coating of the panels has helped eliminate corrosion.

A through-fastened roof has a tendency to leak due to the manner in which it is constructed. The panels are attached to the purlins by means of a fastener through the deck. Expansion and contraction of the deck caused by temperature variations, allows the fastener holes to enlarge, permitting water to seep through the roof. The standing seam roof system eliminates the leakage problem by using a different type of connection between the panel and purlin. A clip is fastened to the purlin. The clip is then embedded in the seam or joint between adjacent panels (see Figure 1.1). In this manner there are no holes in the panel caused by fastener placement.

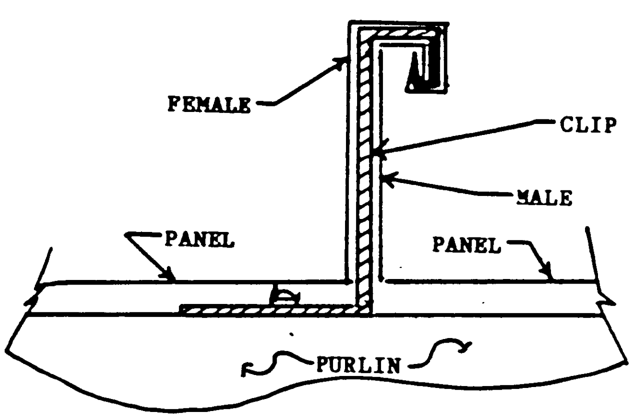
However, the clip seam combination does have disadvantages. In a conventional through-fastened system, the deck provides full lateral bracing to the purlin. In a standing seam system the deck provides only partial bracing. In essence the purlin is somewhere between a braced and unbraced condition.

Cold formed Z- and C- sections are usually used to support metal roofs. When attached to a conventional metal deck, the purlin may be assumed to be under a condition of constrained bending, meaning that it deflects only in the vertical direction. This allows the use of simple stress and deflection equations to determine the strength and deflections of the member.

A purlin supporting a standing seam roof, is only partially constrained because the deck no longer provides full lateral bracing. When a point symmetrical Z- section is loaded in a plane oblique to its principal axes and is not constrained, it will rotate as well as deflect both laterally and vertically (see Figure 1.2). A singly symmetrical C- section will rotate as well as deflect vertically and laterally when unconstrained (see Figure 1.3). These movements cause both normal and torsional stresses that are different from those found when the section is in a constrained bending mode. The complexity of the behavior of a standing seam roof system creates a design problem which has yet to be fully addressed.



a) Rib Panel



b) Pan Panel

Figure 1.1 Typical Standing Seam Joint Detail

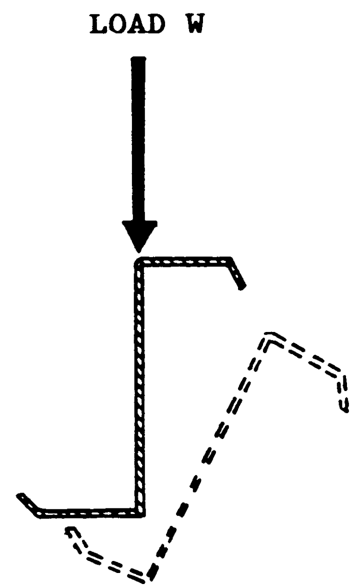


Figure 1.2 Deflection of Z-Purlin

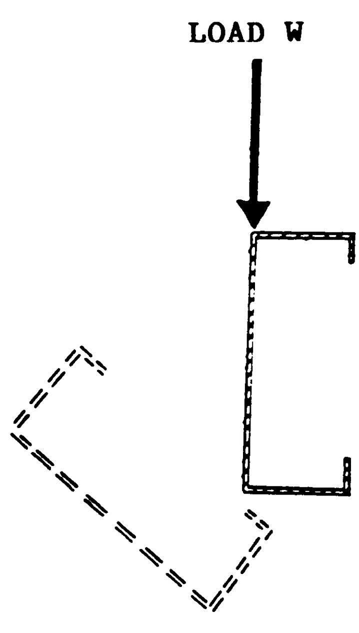


Figure 1.3 Deflection of C-Purlin

1.2 Literature Review

Standing seam roof systems are a relatively new product. For this reason very little research has been done.

Rivard and Murray [2] have conducted both analytical and experimental research to verify current design methods for predicting anchorage forces in Z-purlin supported standing seam roof systems. Their research also involved developing methods to predict the ultimate load of a standing seam roof system. The 1986 American Iron and Steel Institute (AISI) Specification [3] full lateral support and lateral buckling strength provisions were used to predict the ultimate failure loads. When the full lateral support equations were applied, the calculated values had an error range of -2% to -248%, as compared with the actual failure loads. The negative sign (-) indicated that the predicted load was unconservative. The 1986 AISI lateral buckling equations lead to a range of errors from -32% to +67%, when compared to the actual failure loads. The positive sign (+) indicates that the predicted value was conservative, and a negative sign again indicates an unconservative value. A third prediction method used a combination of the Structural Stability Research Council allowable stress equations [4] in conjunction with the 1986 AISI equations. In this method an unbraced length correction factor, K, was devised to modify the theoretical ultimate moment capacity in order to more accurately predict the failure load. The errors ranges from -12% to +31%.

The experimental test program [2] consisted of twelve tests: six were single span tests and six were three span continuous tests. Span lengths were 20 ft. for the single span tests and 23 ft. for the three span tests. Each test used an 8 in. Z-section with the top compression flanges facing in the same direction.

Both pan type panels and rib type panels were used. A pan type panel is defined as a panel where a single ninety degree bend is found at the seam between panels. A rib type panel is defined as a panel where several bends are found at the joint between panels. Bracing configurations were: bracing at the supports only, third point bracing and midpoint bracing.

Carballo, Holzer and Murray [5] reported on the strength of Z-purlin supported standing seam roof systems under gravity loadings. Four approaches to predict the failure loads were devised. In the first method, the 1986 AISI lateral buckling strength provisions were applied to the test results to provide a basis for comparing the degree of lateral support that a SSR system gives to the purlins. When the system was assumed to be laterally unbraced, the error was in the range of 37% to 86% conservative, depending on the bracing configuration. The data for the six single span tests from Rivard and Murray [2] were used to evaluate the method. When the system was assumed to be laterally braced, the 1986 AISI lateral support provisions gave errors ranging from 22% to 35% unconservative. Again the six single span test data were used to evaluate the method.

The second method was based on deflection correlation. This method made use of the fact that the deflection of conventional and standing seam roof systems at ultimate load are the same. A mathematical model was developed to predict the stiffness of the standing seam system. The model was used to give the load vs. deflection curve for the standing seam system. The 1986 AISI Specification [3] provides the means for predicting the deflection at the failure load of a conventional system. The load of the standing seam system corresponding to the deflection at failure load of the conventional system is the predicted failure load. The error range was from 3% to 28 % unconservative when the method was used to predict the failure load of the six single span tests performed by Rivard and Murray [2].

The third method used stress correlation to predict the failure load. The approach predicted the failure load by using the stresses calculated from the allowable flexural capacity of the cross section and the general flexural formula. The allowable flexural capacity was based on the local buckling sections of the 1986 AISI specifications. These stresses were used to scale the actual stresses of the cross section which were also calculated using the general stress formula. The error ranged from 0% to 22% conservative.

The final method used by Carballo, Holzer and Murray [5] was the base test method. This method predicts the ultimate load of a multiple span system by scaling the failure load of a single span test. The method requires the user to perform actual full scale tests to find the single span failure load. A test is required for each different combination of deck, clip and purlin size. Carballo, Holzer and Murray [5] performed two sets of tests and used previous results and data from Rivard and Murray [2] to evaluate the methods. These tests consisted of single, two and three span tests using Z-purlins and standing seam roof panels. The procedure predicted loads that were -3% to +27% of the actual failure loads. Of the four methods proposed, the base test method proved to be the most favorable.

1.3 Scope of Research

The partially braced condition that exists when a standing seam roof system is used is not covered by the 1986 AISI Specifications [3]. Without the use of a design procedure, a designer is faced with two options. The first option is to assume that the unbraced length is equal to the span length. This assumption generally results in conservative designs. The second option is to assume full lateral support, which may result in unconservative designs.

From the work of Carballo, Holzer and Murray [5], the base test method appears to be the best available method to determine the strength of standing seam roof systems. The primary purpose of this research is to evaluate the ability of the base test method to predict the failure load of multiple span, multiple purlin line Z- and C-purlin supported standing seam roof systems. Two sets of test data from research done by Carballo, Holzer and Murray [5] will be used in conjunction with the results of this research. Each of the tests consisted of a single span base test and a two span confirming test.

The secondary purpose of this study is to gain insight into the effects that the different system components (clip, deck, purlin size and inclusion or omission of insulation) have on the ultimate strength of the system. For the latter purpose, available data from a proprietary test program being conducted at Virginia Polytechnic Institute and State University, are used in conjunction with the data and results from this research.

1.4 Overview of Thesis

Chapter II of this thesis describes in detail the base test method proposed by Carballo, Holzer and Murray [5]. The background for the method and descriptions of the steps involved are given. General restrictions imposed on the method are covered in the final section of Chapter II.

Chapter III and Chapter IV explain test details and results respectively. The test details in Chapter III include an outline of the test program and a discussion of the different components used in the individual tests. A description of the test setup is also included in this chapter. An explanation of the test designation system is included in Chapter VI. Chapter VI also includes the coupon test results, as well as a discussions and tabulations of results from the tests performed.

Chapter V describes the generalizations and insights that may be made concerning the effects of the individual components on the strength of the system. Chapter VI contains a detailed design procedure and example for implementing the base test method. Chapter VII is a summary of the project and contains recommendations on the method and future research.

CHAPTER II

BASE TEST METHOD

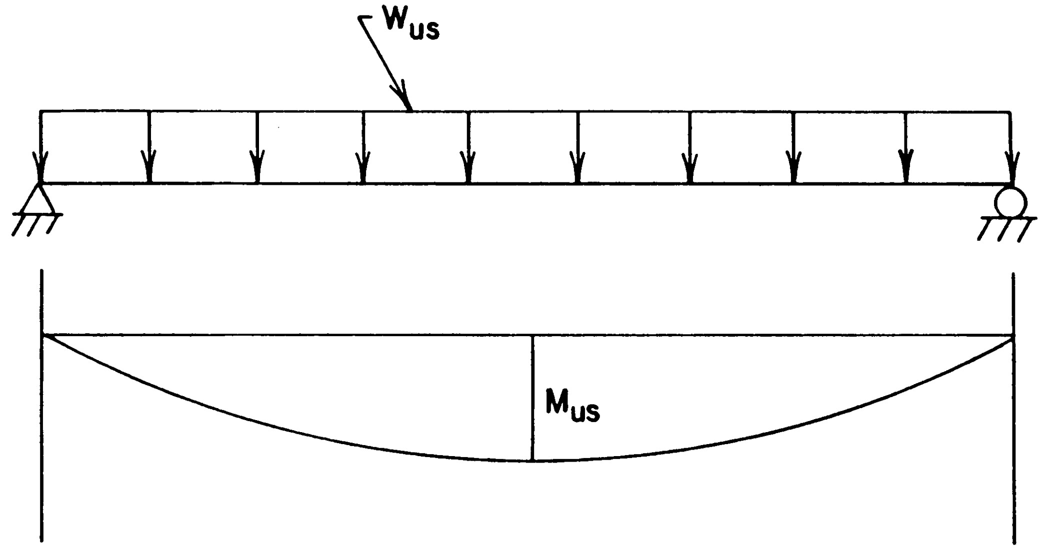
2.1 Background

Due to the complex structural behavior of Z- and C-purlin supported standing seam roof systems, an experimental procedure to determine system strength under gravity loading was proposed by Carballo, Holzer and Murray [5]. The procedure is referred to as the base test method and uses the results of single span tests to predict the capacity of continuous multiple span, multiple purlin line systems.

2.2 The Base Test Method

The basic concept of the base test method is to predict the flexural failure load of a multiple span, multiple purlin line standing seam roof system from the experimental failure load of a single span, two purlin line system. The basic component of the method is the failure moment of the single span base (see Figure 2.1). This phase of the method must be completed in the laboratory by loading a full scale single span, two purlin line system to failure.

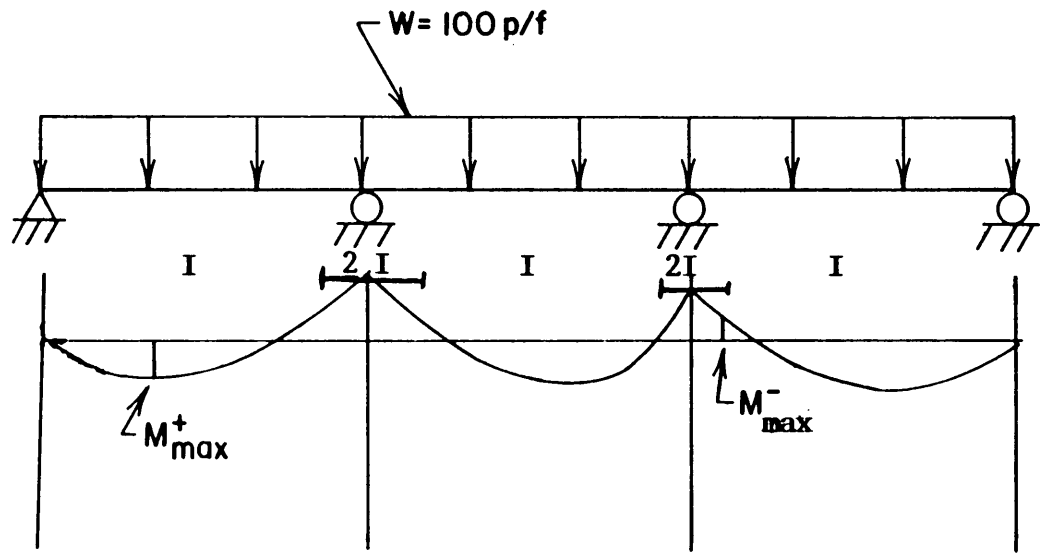
A stiffness analysis with a nominal uniform load (say 100 plf) on a multiple span system is the second step of the method. The stiffness analysis results in maximum positive and maximum negative moments (see Figure 2.2). For gravity loading, a positive moment is defined as a moment which causes compression in



W_{us} = FAILURE LOAD OF SINGLE SPAN TEST

M_{us} = MAXIMUM MOMENT OF SINGLE SPAN CORRESPONDING TO W_{us}

Figure 2.1 Single Span Base Test



M^+_{max} = MAXIMUM POSITIVE MOMENT AT A NOMINAL LOAD OF 100 p/f

M^-_{max} = MAXIMUM NEGATIVE MOMENT AT A NOMINAL LOAD OF 100p/f LOCATED AT EITHER THE INTERIOR OR EXTERIOR OF THE LAP SPLICE.

Figure 2.2 Multiple Span Stiffness Analysis the purlin flange which is attached to the roof panel. A negative moment is a moment which causes tension in the same purlin flange.

The final component of the method is the theoretical flexural capacity of the fully braced cross section calculated using the 1986 AISI specification [3] with the factor of safety removed and assuming constrained bending.

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

$$W_{p3} = \text{minimum of} \left| \begin{array}{l} \dfrac{M_{US}}{M^{+}_{max}} \text{ X } 100 \text{ plf} \\ \\ \dfrac{M_{AISI}}{M^{-}_{max}} \text{ X } 100 \text{ plf} \end{array} \right. \qquad (2.1)$$

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

M_{AISI} = 1986 AISI allowable flexural capacity X 1.67.

M^{+}_{max} = Maximum positive moment from stiffness analysis.

M^{-}_{max} = Maximum negative moment from stiffness analysis.

2.3 Restrictions on Method

Restriction applied to the method are: the panels, clips, purlins, and bracing configuration used in the base test must be nominally identical to those which are used in the multiple span systems. For this reason, a base test must be performed for each combination of deck, clip, bracing, and purlin size that will be designed using the method.

CHAPTER III

TEST DETAILS

3.1 Test Program

A test program was established to verify the accuracy of the base test method. The program consisted of two sequences of tests categorized by distinct bracing locations. The first sequence used purlins laterally braced at the rafters only and included six sets of tests, one with opposed Z-purlins, four with Z-purlins facing the same direction, and one with C-purlins facing the same direction. The second sequence of tests used purlins laterally braced at the rafters and at the third points and included three sets of tests with Z-purlins facing the same direction. Each set of tests consisted of a single span test and a three span test. Test details, test results, and conclusions are found in later sections.

3.2 Test Components

Components used in the testing were supplied by manufacturers belonging to the Metal Building Manufacturers Association (MBMA). However, identical panels, clips, and purlins were used in constructing the single span and three span tests that composed each test set. Table 3.1 shows the configurations used in the test program.

Purlins. Two types of purlins were used in the test sequences; Z-purlins and C-purlins. Depth, flange width, edge stiffener, length, thickness and other dimensions varied between test sets. Measured purlin dimensions for the

TABLE 3.1

MATRIX OF TEST CONFIGURATIONS

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

*Bracing at rafters and intermediate third points of span.

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

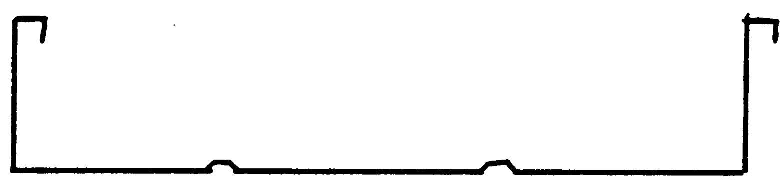
individual purlins from each test are contained in Appendices A and B of the research report by Brooks and Murray [6]. Tensile coupon tests were conducted using material taken from the web area of representative purlins for each set of tests.

Panels. The panels used in the tests were of two basic configurations; "pan" type panels, Figure 3.1 (a), or "rib" type panels, Figure 3.1 (b). The panel widths, depths, corrugations, joint details, and seaming requirements varied from test set to test set. The panel lengths were 7 ft. 0 in. for the single spans and 14 ft. 4 3/4 in. for the three span tests. The panel lengths were calculated so that the applied load would be equally distributed among the purlin lines.

Clips. The "standing seam clips" used in the tests were of two types; one piece fixed clips and two piece sliding clips. The exact clip detail varied among the sets of tests; representative configurations are shown in Figure 3.2.

Bracing. The bracing at the rafters consisted of 1/2 in. diameter rods connected to the purlin webs near the top flange and anchored to a rigid stand fastened to the rafter. Figure 3.3 shows details of the rafter bracing system.

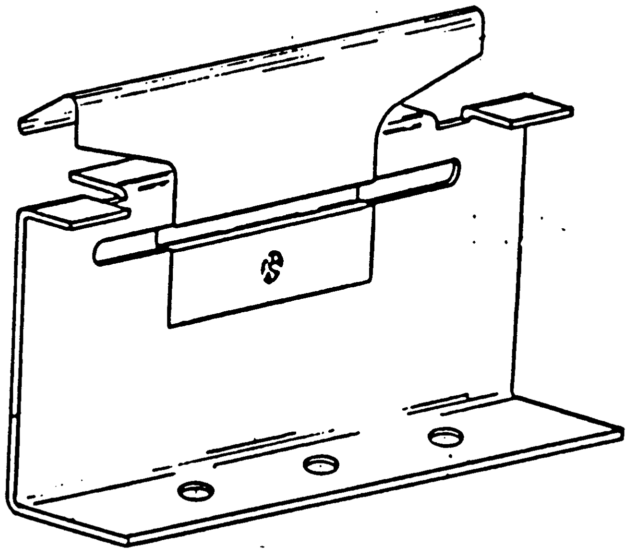
Bracing used in the interior of the spans consisted of a continuous single angle bolted to the bottom flanges of the purlins. A set of rollers was attached to each end of the angles. The rollers were restricted to vertical movement by channels anchored to the laboratory floor. This system allowed the purlins to deflect in a vertical direction while providing lateral bracing at the third points of the spans. Figure 3.4 is a schematic of the bracing system. Bracing locations are shown in Figures 3.5 and 3.6.



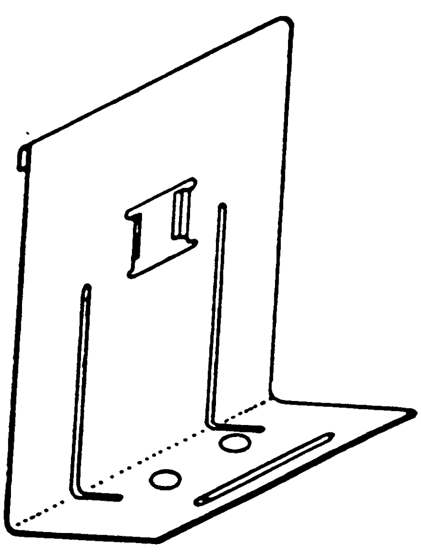
a) Typical Pan Type Panel

b) Typical Rib Type Panel

Figure 3.1 Typical Panel Configurations



a) Two Piece Sliding Clip



b) One Piece Fixed Clip

Figure 3.2 Representative Clip Configurations

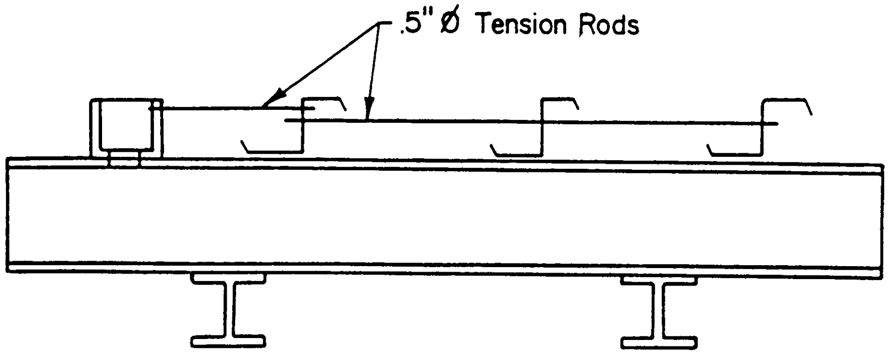


Figure 3.3 Rafter Bracing Details

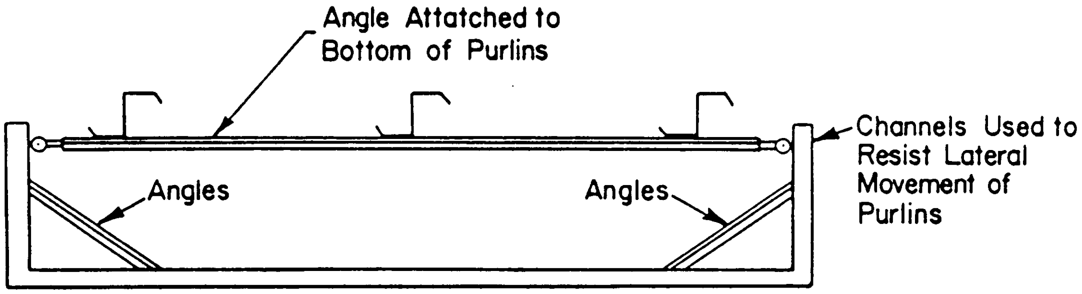
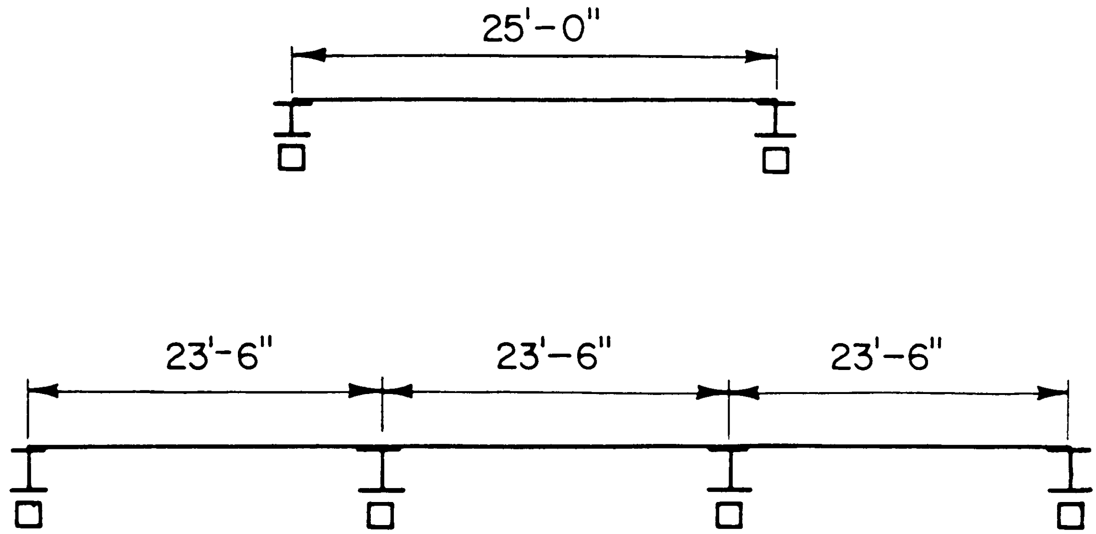
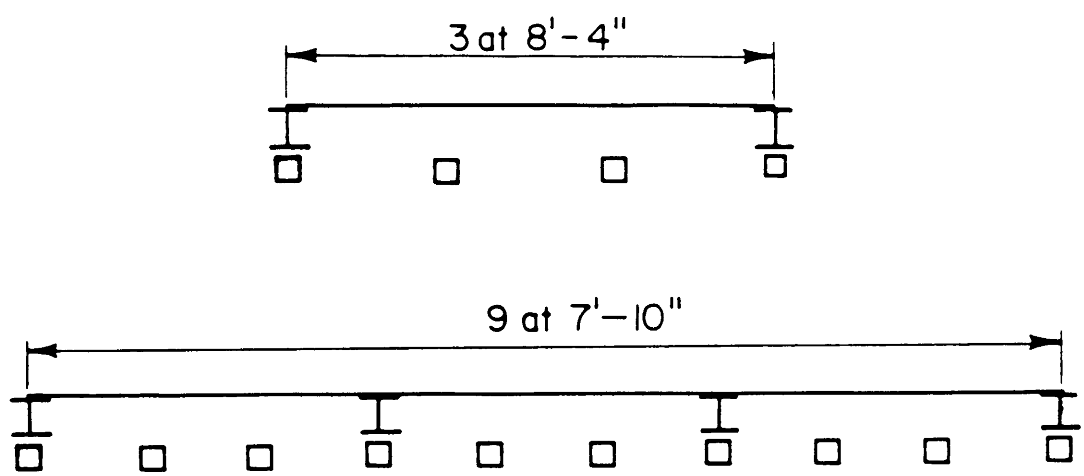


Figure 3.4 Third Point Bracing Details



□ Indicates Location of Brace

Figure 3.5 Rafter Only Bracing Locations



□ Indicates Location of Brace

Figure 3.6 Rafter and Third Point Bracing Locations

3.3 Test Setup

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

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

The single span base tests consisted of two lines of purlins 5 ft. 0 in. on center with a span of 25 ft. 0 in. The purlins were bolted through the bottom flanges to the rafter. The panels used were 7 ft. 0 in. in length. This permitted a 1 ft. 0 in. overhang beyond the webs of the purlins. The panel-to-purlin clips were either attached with self drilling screws or bolted to the purlins with 1/4" bolts to simplify removal of the panels after testing. A cold-formed angle was attached continuously to one edge of the panels to simulate the stiffness provided by an eave strut. Figure 3.7 is a cross section of the single span test.

The three span tests consisted of three or four lines of purlins depending on whether the purlin flanges were facing the same direction or opposing each other, respectively. Each of the three spans were 23 ft. 6 in. between rafters. The lap splices over the interior rafters varied between tests and were set by the manufacturer of the purlins (see Table 3.1). The purlins were connected through their bottom flanges to the rafter. The panels were 14 ft. 4-3/4 in. in length. When three lines of purlins were used, the purlins were spaced 5 ft. 0 in. on center with a 2 ft. 2-3/8 in. overhang of the panels. When four purlin lines were used, the purlins were on a 3 ft. 7 in. spacing with an overhang of 1 ft. 9-3/4 in. The clips either attached with self drilling screws or bolted to the purlins with 1/4 in. bolts to simplify removal of the panels after testing. A cold-formed angle was attached continuously to one edge of the panels to act as an eave. Figure 3.8 is a cross section of the three span test setup.

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

Linear displacement transducers were used to measure the midspan vertical deflections of the purlins. Measurements were made for both purlins in the single span tests and all purlins in both exterior bays of the three span tests. Both exterior purlins and one interior purlin was measured in the end bays when four purlin lines were used. No measurements were taken for the purlins in the interior bay of the multiple span tests.

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

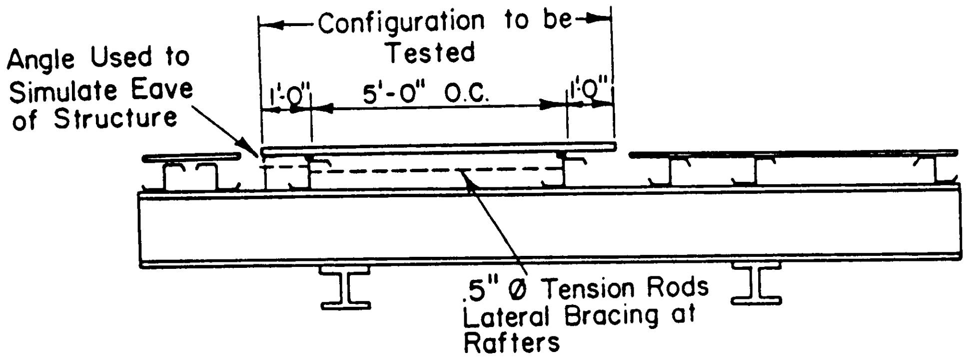


Figure 3.7 Cross-Section of Single Span Base Test Setup

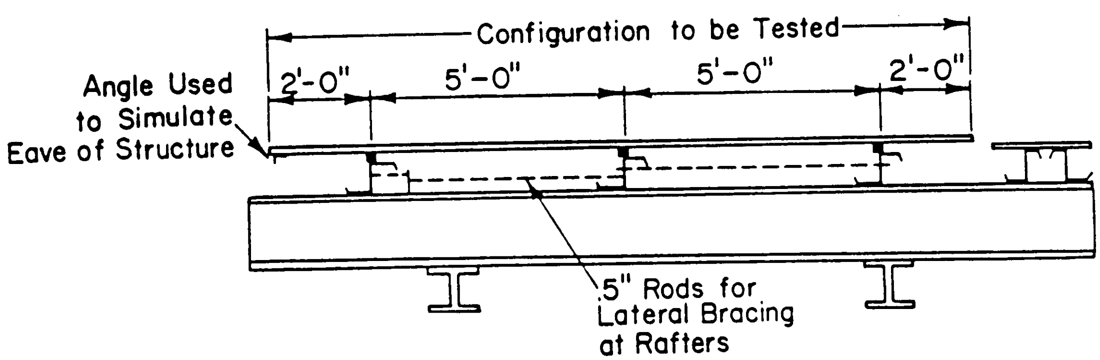


Figure 3.8 Cross-Section of Three Span Continuous Test Setup

CHAPTER IV

TEST RESULTS

4.1 General

Individual results for each set of single span and three span tests are found in Appendices A and B of the report by Brooks and Murray [6]. Each set of results includes a test summary sheet, measured cross-section dimensions, the allowable flexural capacity as computed according to the 1986 AISI Specification [3], plots of the load vs. midspan deflection, and plots of load vs. lateral movement. Examples of the plots are included in later sections.

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

4.2 Test Identification System.

The following are examples of the method used to identify each of the tests from the two sequences.

Example 1 C-R-R/S-1

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

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

4.3 Coupon Test Results

Standard ASTM tensile coupon tests were conducted by Butler Manufacturing Company using material taken from the web area of representative purlins used in each test. Two tests were made for each removed sample. Average values of measured yield stress, tensile strength and elongation are found in Table 4.1.

4.4 Rafters Braced Test Results

The sequence of tests with bracing at the rafters only, consisted of six sets of tests with each set of tests consisting of a single span base test and a three span confirming test. The bracing of the system was as shown in Figure 3.3 at the locations shown in Figure 3.5.

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

TABLE 4.1

COUPON TEST RESULTS

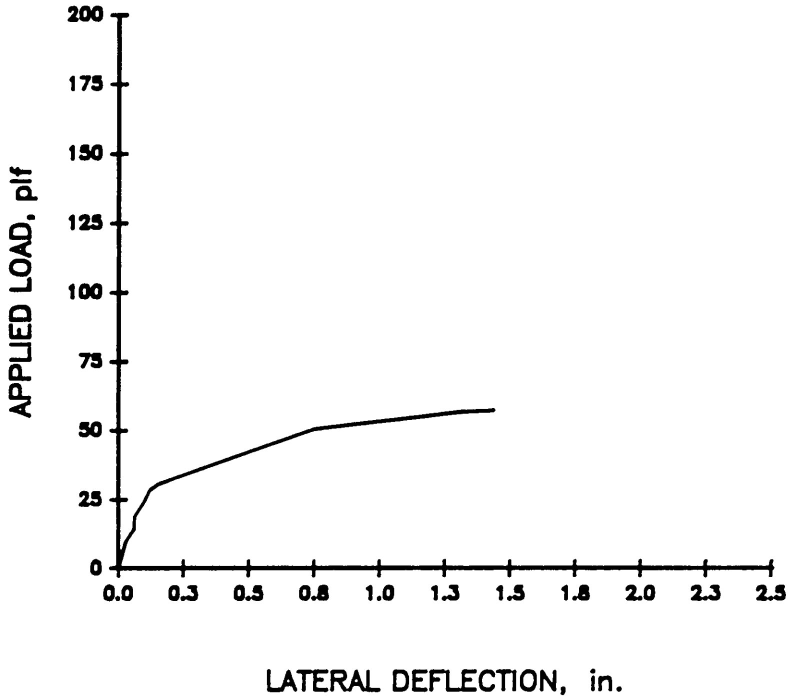
Identification	Thickness (in.)	Yield Stress* (ksi)	Tensile Strength* (ksi)	Elongation %
Z-R-R/S-1	0.078	63.21	79.27	22.75
Z-R-R/S-3	0.078	59.80	77.28	23.40
Z-R-R/F-1	0.058	67.53	85.52	21.50
Z-R-R/F-3	0.059	68.51	87.11	20.50
Z-R-P/F-1	0.060	57.61	80.35	20.25
Z-R-P/F-3	0.059	59.93	81.71	20.75
Z-R-P/S-1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

*Average of two tests.

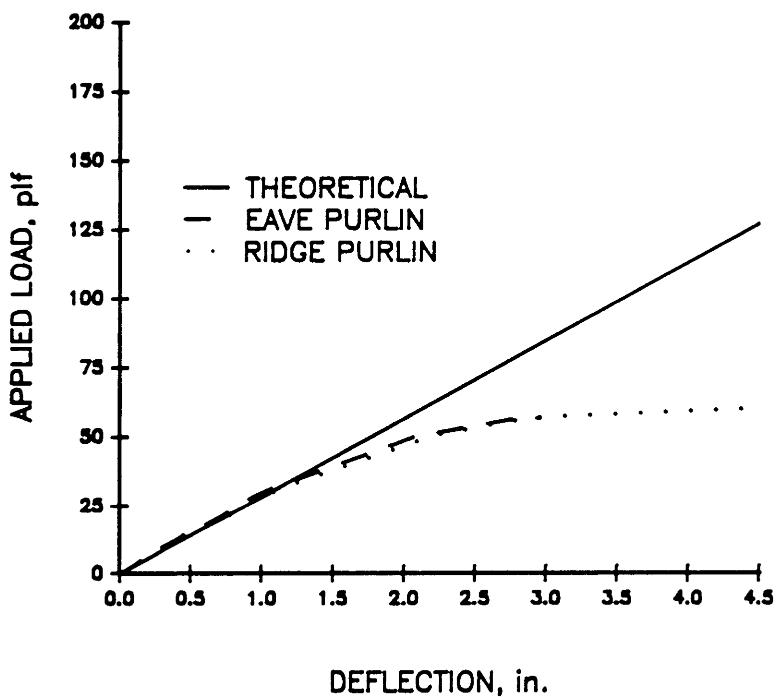
three span tests. The sixth set of tests used opposed Z-purlins. For this test, two purlin lines were used in the single span test and four lines of purlins in the three span test.

Figure 4.1 shows examples of the load vs. deflection plots for the single span, rafter only braced tests using Z-purlins with flanges facing the same direction. Figure 4.2 shows the load vs. deflection plots for the single span C-purlin test. Figure 4.3 contains load vs. deflection plots for the single span opposed Z-purlin test. Figure 4.4 contains example plots of load vs. deflection for a three span, rafter only braced test. Appendix A in Brooks and Murray [6], contains complete test results of the rafter braced tests. Table 4.2 shows the failure load and failure mode for each test.

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

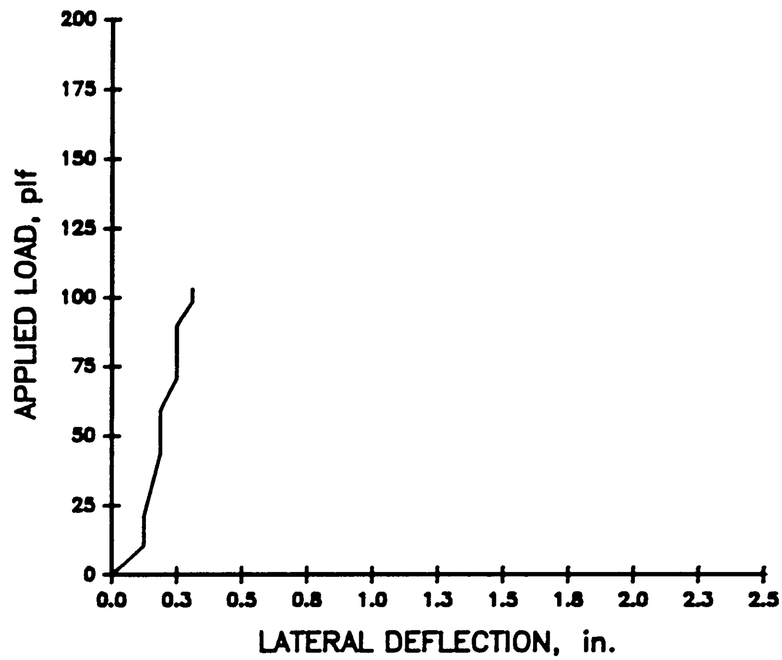


a) Load vs. Lateral Deflection, Test Z–R–P/F–1

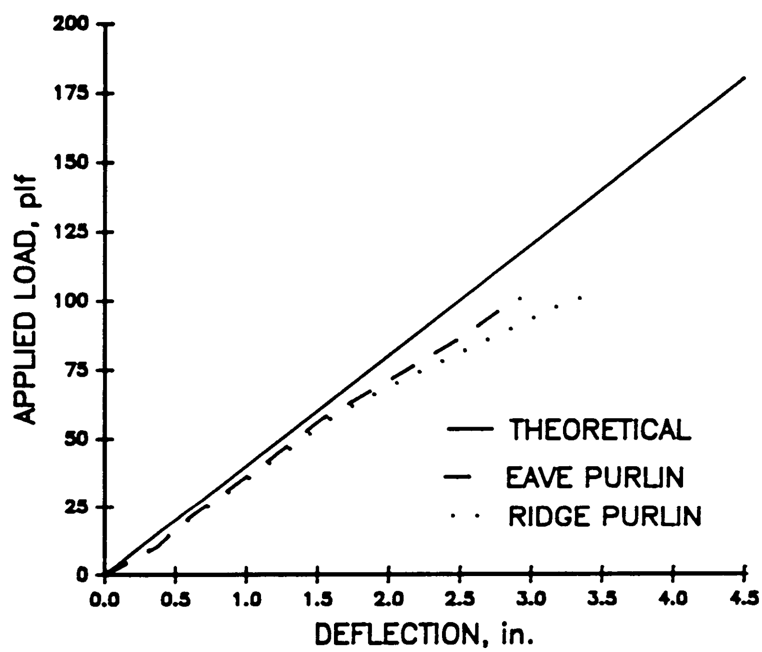


b) Load vs. Deflection, Test Z–R–P/F–1

Figure 4.1 Typical Load vs. Deflection Plots For Single Span, Rafter Only Braced Z-Purlin Test

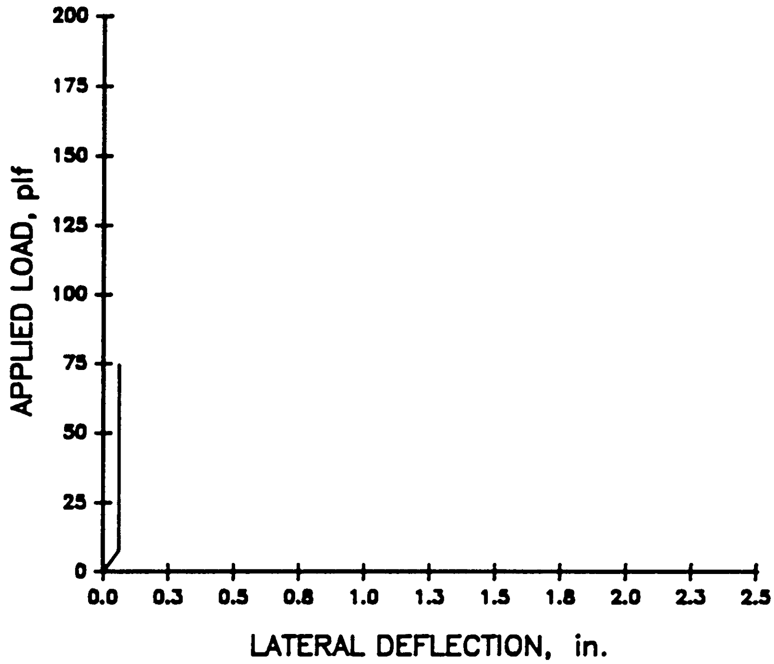


a) Load vs. Lateral Deflection, Test C-R-P/S-1

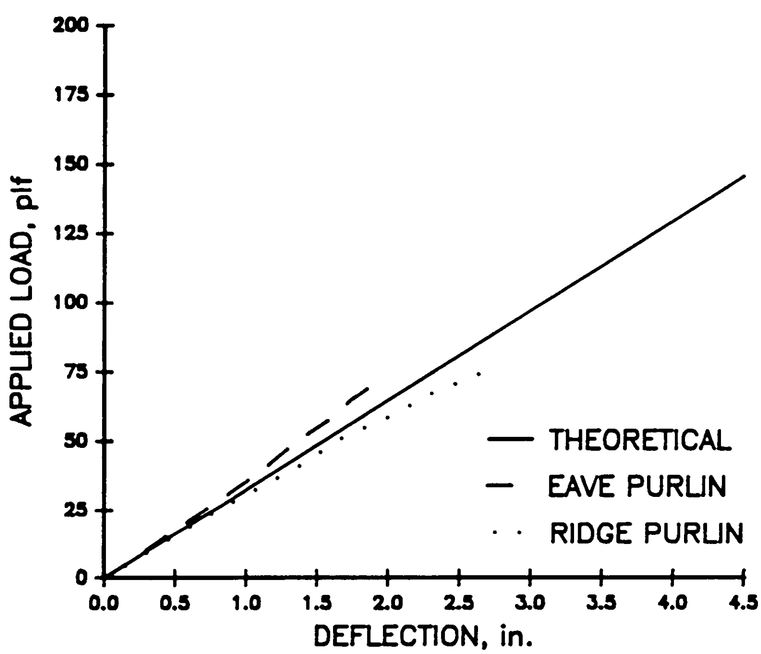


b) Load vs. Deflection, Test C-R-P/S-1

Figure 4.2 Typical Load vs. Deflection Plots For Single Span, Rafter Only Braced C-Purlin Test

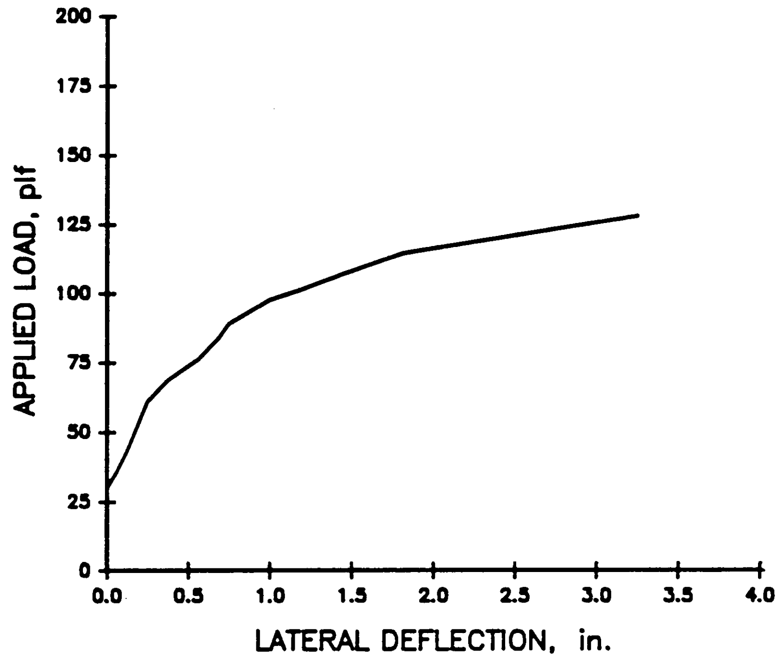


a) Load vs. Lateral Deflection, Test Z–R–R/F–1 (O)

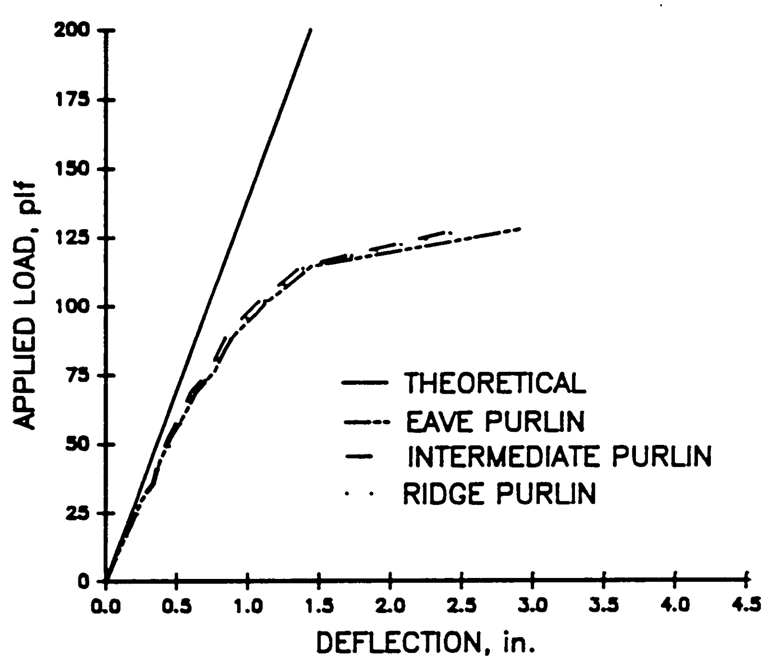


b) Load vs. Deflection, Test Z–R–R/F–1 (O)

Figure 4.3 Typical Load vs. Deflection Plots For Single Span, Rafter Only Braced Opposed Z-Purlin Test



a) Load vs. Lateral Deflection, Test Z–R–P/S–3, West Span



b) Load vs. Deflection, Test Z–R–P/S–3, West Span

Figure 4.4 Typical Load vs. Deflection Plots For Three Span, Rafter Only Braced Z-Purlin Test

TABLE 4.2

SUMMARY OF RAFTER BRACED TEST RESULTS

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

LB = Local buckling of lip, flange, web.

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

4.5 Third Point Braced Test Results

The sequence of tests with third point bracing consisted of three sets of tests with each set containing a single span base test and a three span confirming test. The bracing of the systems was as shown in Figures 3.3 and 3.4 at located shown in Figure 3.6.

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

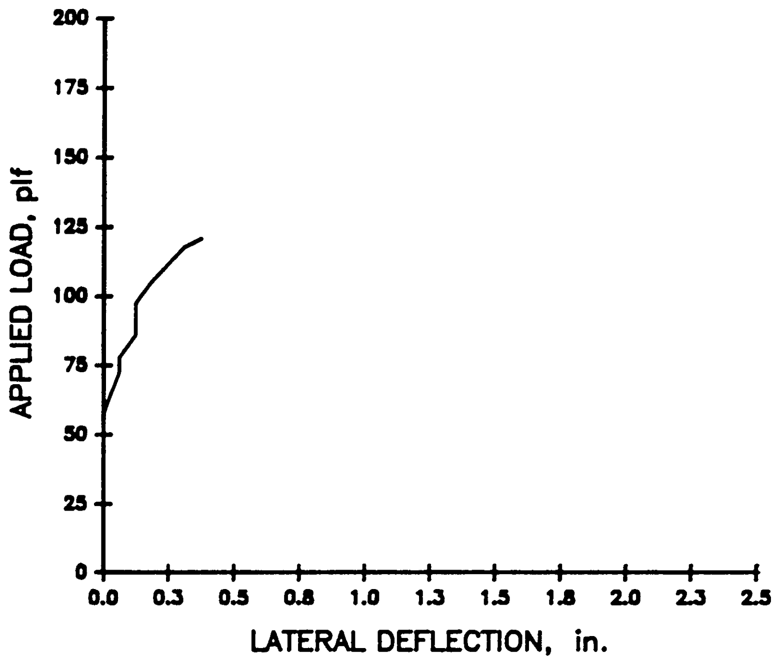
Figure 4.5 shows examples of the load vs. deflection plots for single span, third point braced tests. Figure 4.6 contains example plots of load vs. deflection for a three span, third point braced test. Appendix B in the report by Brooks and Murray [6], contains complete test results for the third point braced tests. Table 4.3 is a summary of the test results, showing failure loads and failure modes.

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

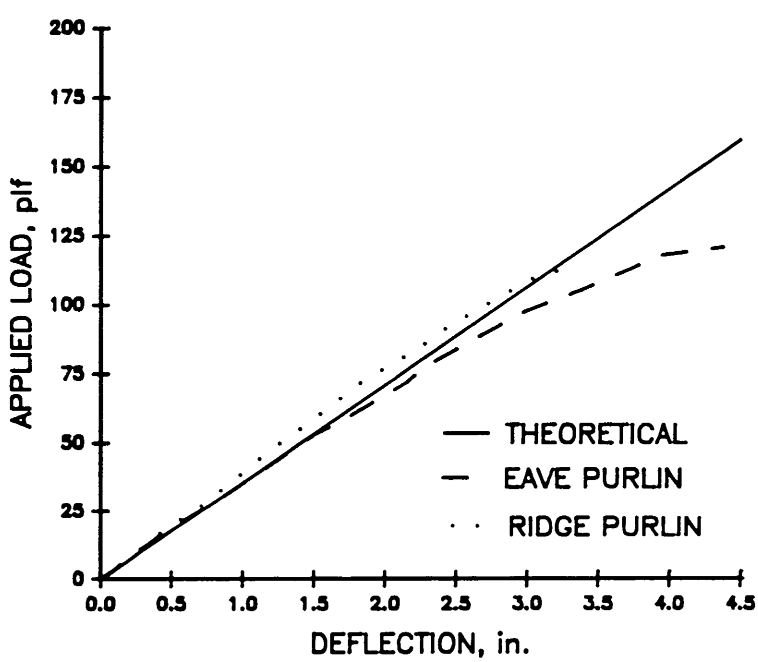
The failure mode for the confirming three span tests Z-T-P/F and Z-T-R/S was local lip/flange/web buckling after some lateral movement. In confirming test Z-T-P/S, a lateral brace-to-purlin flange connection failed causing premature failure of the system.

4.6 Evaluation of Method

Tables 4.4 and 4.5 show the predicted three continuous span failure loads, the actual failure loads, and the ratio of actual-to-predicted failure loads. The predicted failure loads were calculated using the procedure described in Chapter II. For all tests, the predicted failure location was at the maximum moment

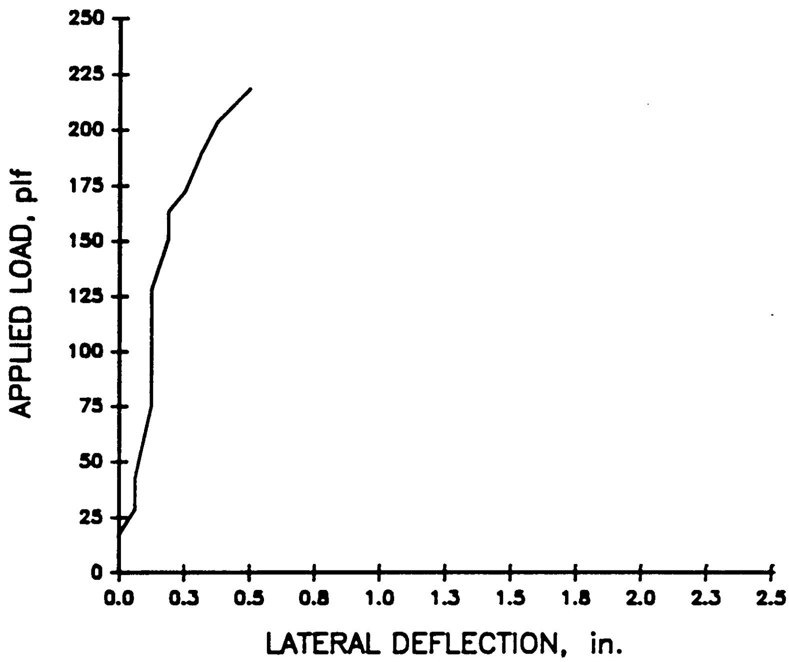


a) Load vs. Lateral Deflection, Test Z–T–P/F–1

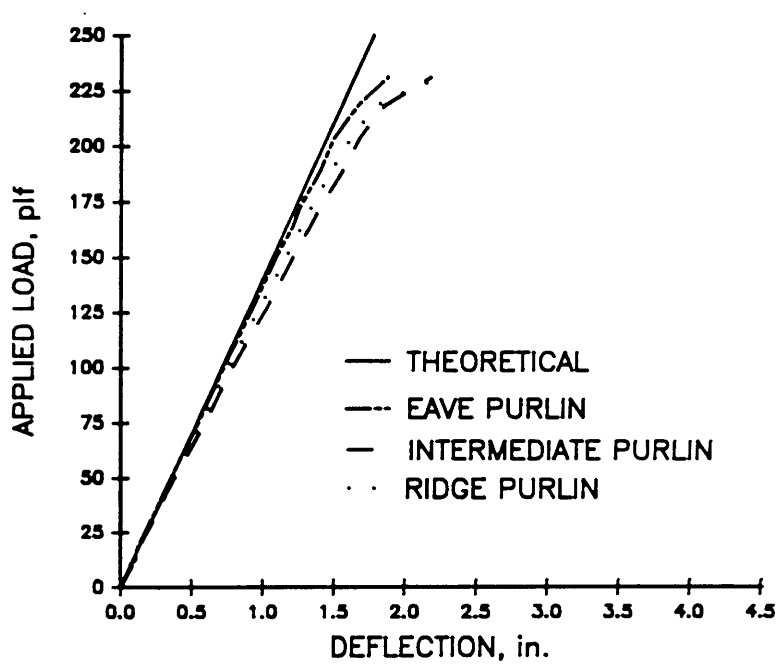


b) Load vs. Deflection, Test Z–T–P/F–1

Figure 4.5 Typical Load vs. Deflection Plots For Single Span, Third Point Braced Z-Purlin test



a) Load vs. Lateral Deflection, Test Z–T–R/S–3, West Span



b) Load vs. Deflection, Test Z–T–R/S–3, West Span

Figure 4.6 Typical Load vs. Deflection Plots For Three Span, Third Point Braced Z-Purlin Test

TABLE 4.3

SUMMARY OF THIRD POINTS BRACED TEST RESULTS

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

LB = Local buckling of lip, flange, web.

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

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

TABLE 4.4

ACTUAL AND PREDICTED RAFTER BRACED TEST RESULTS

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

*Assumed yield stress.

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

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

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

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

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

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

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

W_u = actual failure load

TABLE 4.5

ACTUAL AND PREDICTED THIRD POINT BRACED TEST RESULTS

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

*Assumed yield stress.

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

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

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

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

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

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

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

W_u = actual failure load

location in the exterior spans of the three span confirming tests, that is, in the positive moment region. This location is also the location of the actual point of failure except for tests Z-R-R/S and Z-T-P/S. Except for these test sets, the ratio of actual-to-predicted failure loads was between 0.87 and 1.02 with an average value of 0.95. As described in Chapter IV, the failure modes for the three span continuous tests in sets Z-R-R/S and Z-T-P/S were unrelated to the purposes of this study and not considered in the final evaluation.

Data from Carballo, Holzer and Murray [5] was also evaluated using the base test method. Table 4.6 shows results for two sets of base/confirming tests as reported in Reference 5. The confirming tests were two span continuous tests. The failure mode for all four tests was cross-section failure after considerable lateral movement. The failure location was near midspan, that is, in the positive moment region, for all tests. The ratio of actual-to-predicted failure load for the two sets of tests was 0.92.

In summary, from the results of the nine valid sets of base/confirming tests, excluding the two test sets containing tests not considered in the final evaluation, the range of the ratio of actual-to-predicted failure loads was 0.87 to 1.02 with an average value of 0.94. This average includes the ratios calculated from the seven valid tests in this thesis and the two tests taken from reference 3 (see Table 4.6).

TABLE 4.6

ACTUAL AND PREDICTED TEST RESULTS FROM REFERENCE 5

	BASE TEST		TWO SPAN TEST									
Test Designation	w_u (plf)	M_{us} (in. kips)	F_y (ksi)	M_{AISI} (in. kips)	M_{max}^- (in. kips)	M_{max}^+ (in. kips)	w_{p2}^- (plf)	w_{p2}^+ (plf)	w_{p2} (plf)	w_u (plf)	w_u/w_{p2}
10Z14-P-1-1	91.0	85.31	56.5	206.13	79.30	50.50	259.9	168.9	168.9	155.0	0.92
10Z14-R-1-1	86.0	80.63	56.5	211.47	79.30	51.70	266.7	156.0	156.0	144.0	0.92

*Assumed yield stress.

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

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

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

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

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

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

W_{p2} = minimum of W_{p3}^- and W_{p3}^+, e.g. predicted failure load

W_u = actual failure load

CHAPTER V

EFFECTS OF COMPONENTS ON ULTIMATE STRENGTH

5.1 General

The complex interactions between the clip, deck, purlins and insulation is such that an analytical model to predict the failure load of a base test cannot be formulated with the available data. However, from that data, trends and general statements can be made, to describe what effects the components have on the capacity of the system.

The majority of the data used comes from the tests that were performed to substantiate the premise of this thesis. Data from proprietary tests, presently being conducted at Virginia Polytechnic Institute and State University, are used to gain insight into the component interactions.

Certain variables were seen to have a major role in determining the strength of the system. These variables are the orientation of the section, clip type, panel type, presence of insulation, the bracing configuration and the section shape, C- or Z-purlin. Each variable is discussed in later sections. The parameter used to compare the systems and components is the through fastened capacity (AISI full lateral braced capacity) of the section.

Table 5.1 contains data from the research presented in this thesis. The test designation, the number of spans, actual failure loads, 1986 AISI predicted failure loads and the ratio of actual to through fastened capacity for each of the tests performed for this research are listed in Table 5.1.

Table 5.2 contains data generated from the proprietary test program. All of the proprietary tests were 25 ft. single span tests. A single manufacturer provided the rib type decking for all of the tests. Eight tests used 14 gage purlins and four tests used 12 gage purlins. The primary emphasis of this research was to quantify the effects that different clip types, bracing conditions, use of insulation and rafter shear clips have on the strength of standing seam roof systems.

5.2 Orientation of Section

Test sets Z-R-R/F and Z-R-R/F (O) have 1986 AISI capacities differing by seven percent, indicating that the sections were similar in size. The same nominal type of clip and deck was used for each test. Therefore, the only difference between the two tests was that the compression flanges were facing the same direction in the first test and opposed in the second. The ratio of actual to through fastened capacity obtained, shows an increase of sixteen percent, when the flanges are opposed.

For the opposed purlin test set lateral movement was less than 0.3 in. for both the single and three span test setups. For the test set with the flanges facing the same direction, the lateral movement was over 1.5 in. for the single span and 2.5 in. for the three span test. The significant decrease in lateral movement when the purlins were opposed is the reason for the corresponding increase in strength.

TABLE 5.1

GRAVITY LOADING TESTS

(Actual failure load compared to through fastened failure load)

Test Designation	Spans	Failure Load (plf)	AISI Load (plf)	w_u/w_{AISI} (%)
10Z14-P-1	1	91.00	219.9	41
	2	155.0	259.9	60
10Z14-R-1	1	86.00	225.6	38
	2	144.00	266.7	54
Z-R-R/S	1	136.5	216.8	63
	3	152.9	388.6	39
Z-R-R/F	1	64.50	114.8	56
	3	107.1	213.8	50
Z-R-P/F	1	60.50	105.5	57
	3	102.5	205.8	50
Z-R-P/S	1	80.00	174.1	46
	3	128.2	341.4	38
C-R-P/S	1	119.0	150.3	79
	3	217.0	284.1	76
Z-R/R/F (0)	1	87.00	123.07	71
	3	158.0	230.7	68
Z-T-P/F	1	126.0	140.9	89
	3	223.0	265.3	84
Z-T-P/S	1	120.0	187.9	64
	3	188.0	350.7	54
Z-T-R/S	1	126.0	212.2	60
	3	238.0	388.2	61

TABLE 5.2

PROPRIETARY GRAVITY LOADING TESTS

(Actual failure load compared to through fastened faliure load)

Test Designation	Clip Type	Bracing	Insulation	Failure Loads (plf)	% Fully Braced
N-Z-14-SF-1	Short Fixed	TR @ Rafter	No	112.0	56.5
N-Z-14-SS-1	Short Sliding	TR @ Rafter	No	103.0	53.0
N-Z-14-TS-1	Tall Sliding	TR @ Rafter	No	100.0	51.0
N-Z-14-TF-1	Tall Fixed	TR @ Rafter	No	99.7	48.9
N-ZI-14-SF-1-2	Short Fixed	TR @ Rafter	Yes	124.1	58.8
N-ZI-14-SS-1	Short Sliding	TR @ Rafter	Yes	122.0	57.3
N-ZI-14-TS-1	Tall Sliding	TR @ Rafter	Yes	100.5	50.2
N-ZI-14-TF-1	Tall Fixed	TR @ Rafter	Yes	96.0	44.6
N-ZIS-12-SF-1	Short Fixed	S.C./ Third Point	Yes	193.0	70.0
N-ZIS-12-SS-1	Short Sliding	S.C./ Third Point	Yes	142.0	50.7
N-ZIS-12-TF-1	Tall Fixed	S.C./ Third Point	Yes	153.5	55.5
N-ZIS-12-TS-1	Tall Sliding	S.C./ Third Point	Yes	157.4	54.7

Notes: TR = torsional restraints at rafter.
S.C. = shear clip at rafter.

The opposed test failed by local buckling of the compression lip, flange and web, which is the mode of failure for a braced system. The other test set had a failure mode caused by excessive lateral movement, which is the type of failure expected in an unbraced purlin.

5.3 Clip Type

The data from Tables 5.1 and 5.2 was analyzed for clip type, fixed or sliding, excluding any test with an excessively high or low percentage of braced capacity and finding the average. For tests with sliding clips the average was 52.8% of full capacity; for fixed clips the average was 55.6%.

These averages indicate that a fixed clip gives slightly more lateral support to the purlin than a sliding clip. The 2.8% difference suggests that clip type has little effect on the strength of the system. The load vs. lateral movement plots shown in Brooks and Murray [6] shows that a sliding clip moves more at the onset of the loading cycle than does a fixed clip. However, the final lateral movement is of the same magnitude for both clip types.

5.4 Panel Type

The first six sets of tests listed in Table 5.1 were used to determine the effect of panel type on strength. Only these test sets were used to keep the number of variables to a minimum. The procedure in Section 5.3 was used to obtain the average percentage of full laterally braced strength for each panel type. An average of 52% was found for the test sets using pan type panels, and 55.8% for rib type panels.

These average percentages show that rib type panels provide slightly more support than pan type panels by 3.8%. One reason for the increase is that the joint between rib panels provides more torsional restraint to the purlin than the joint between pan type panels. Lateral movement plots show no perceptible difference in movement between tests using either panel type.

5.5 Insulation

The first two groups of tests in Table 5.2 are identical except that insulation was placed between the deck and purlins in the second group. With insulation, the average percentage was 52.7%, without insulation the percentage was 52.4%. With a difference of only 0.03%, it is safe to assume that insulation has no effect on the strength of the system.

5.6 Bracing Configuration

The two types of bracing used in the tests were rafter only bracing and third point plus rafter bracing (see Figures 3.3 thru 3.6). The average percentages for the two bracing configurations were calculated as in previous sections. For rafter only bracing and third point plus rafter bracing, the average percentages of fully braced strength were 53.2% and 64.3% respectively. An increase of 11% was gained by using third point bracing in addition to rafter bracing.

Both lateral and vertical deflections at failure were smaller for the third point plus rafter bracing tests when compared to the rafter only braced tests. The deflections are recorded in Appendices A and B of Brooks and Murray [6]. The actual vertical deflections of the third point braced tests closely followed the theoretical predictions until failure. The actual vertical deflections moved away from the theoretical line and reached a plateau prior to failure for the rafter only braced tests. Lateral movement of the third point braced test systems was negligible when compared to the rafter only braced systems.

5.7 Purlin Type

Two types of purlins were used during testing, Z- and C-purlins. The C-purlin test set (flanges facing same direction) used rafter only bracing, so it was compared to the Z-purlin test sets (flanges facing same direction) with rafter only bracing. The average percentage of the through fastened capacity for the Z-purlins was 53.2%. For the C-purlin test set the average percentage of fully braced strength was 78%, an increase of 24.8% over the Z-purlin tests.

Comparison of the lateral and vertical deflection plots in Brooks and Murray [6] shows that the C-purlin tests act as a braced system. The lateral deflections of the C-purlin tests are small when compared to the Z-purlin tests. Also, the actual vertical deflections plotted close to the theoretical curve prior to failure for the C-purlin tests. However, since the C-purlin data is limited to only one test set, a more accurate statement comparing C- and Z-purlin strength cannot be made.

5.8 Summary

Purlin type had the greatest impact on the strength of the system. However, with limited data, no general statement comparing C- and Z-purlins can be made. Excluding purlin type, purlin orientation and bracing configuration had the largest effect on the strength, with an average increase of 10% to 15%. The other four variables had little effect on the strength, with an average increase of less than 5%.

In summary, for a single span test using standing seam deck supported by Z-purlins facing the same direction and with bracing at the rafters only, a conservative ultimate capacity is 50% of the 1986 AISI full laterally braced ultimate capacity. This percentage can be increased to 60% when third point braces are added.

CHAPTER VI

DESIGN PROCEDURE

6.1 Methodology

A design procedure implementing the base test method is given in this section. The steps listed below must be followed if a safe and efficient design is to be obtained. The procedure is as follows:

1. Perform a single span base test by applying a uniform load in increments to the system until failure.

2. Calculate the ultimate failure moment corresponding to the failure load found in step 1 (see Figure 2.1). Divide the moment by a F.S. = 1.67 to calculate the allowable moment.

3. Next perform a stiffness analysis of the multiple continuous span system that is to be built using a nominal uniform load.

4. From the analysis two moments are derived. The first is the maximum positive moment. The second is the maximum negative moment located at either the interior or exterior of the lap splice (see Figure 2.2).

5. The ratio of the failure moment from the single span base test divided by the maximum positive moment from the stiffness analysis is calculated and multiplied by the nominal uniform load applied in step 3. The result is a possible failure load (see Equation 2.1).

6. The ratio of the cross-section flexural capacity calculated assuming constrained bending and using 1986 AISI provisions, divided by the maximum negative moment from the stiffness analysis is calculated and multiplied by the nominal uniform load applied in step 3. A second possible failure load results (see equation 2.1).

7. The predicted failure load for the system is the minimum of the two failure loads calculated in steps 5 and 6.

6.2 Limitations on the Method

The method is based on an experimental procedure and is used to describe the interaction of a very complex system of components; an interaction that is not fully understood at this time. For these reasons, limitations must be placed on the method to insure that safety requirements are met when it is used. The limitations are:

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

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

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

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

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

6.3 Example Calculations

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

A simple span base test was conducted using two purlin lines spaced 5 ft. 0 in. on center. The purlins were oriented with top flanges facing in the same direction. A cold-formed base angle was attached at the "eave" end of the panels using self-drilling fasteners at 12 in. on center. The base angle was used to simulate eave strut effects. The base test was constructed using standing seam panels, clips and insulation nominally identical to what will be used in the proposed building. The base test span was 25 ft. and the failure load per purlin line was 110 plf. The corresponding failure moment is $110\ (25)^2/8$ = 8.594 ft-lbs = 103.1 in-kips. The allowable capacity is then 103.1/1.67 = 61.7 in-kips.

The flexural cross-section strength was determined using the provisions of the 1986 AISI specification [3]. The allowable moment capacity for the section is 82.1 in-kips.

Next, a stiffness analysis of a four span purlin line was conducted using 100 plf loading. The controlling positive moment is 57.9 in-kips and the controlling negative moment is 64.9 in-kips both per purlin. These moments are located as shown in Figure 2.2. Using the base test method, the allowable capacity of the proposed roof system is then:

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

Assuming the positive moment region controls (106.6 plf), the negative moment region capacity is recalculated considering shear plus bending effects and is found to be 119.7 plf which is greater than the positive moment region capacity. Thus, the capacity of the proposed standing seam roof system per purlin line is 106.6 plf. Round off, and design for an allowable load of 106 plf.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

7.1 Summary

The primary objective of this thesis was to evaluate the accuracy of the base test method as a means of predicting the ultimate capacity of multiple span standing seam roof systems under gravity loadings. To do this a total of nine test sets were conducted, with each set consisting of a single span and three span test. Data from previous research [5] was also used to evaluate the method. The average ratio of actual to predicted failure loads for the tests performed was 94%. The base test method appears to be an effective and accurate means of determining the strength of multiple span standing seam roof systems. Considering the complex nature of a standing seam system, the base test method also has the advantage of being a relatively simple and straight forward design procedure.

The data from this study is not sufficient to build an analytical or empirical mathematical model for predicting the failure load of a standing seam system. However, when combined with data from other proprietary tests, insight was gained into the way the system components affect the capacity.

By comparing the actual strength to the theoretical through fastened capacity, it was seen that purlin orientation and bracing configuration contributed the most to increased strength, an increase in the range of 10% to 15%. A fixed clip increased the strength by an average of less than 3% over a system using a sliding clip. Inclusion or omission of insulation had no effect on the strength. Average percentages indicated that rib panels increased the capacity of the system by less than 4% when compared to pan type panels. The single C-purlin test set indicated that C-purlins were more efficient than Z-purlins with an increase in strength of approximately 25%. However, more tests using C-purlins need to be conducted before a generalized statement can be made.

In summary, the base test method is highly accurate, easy to implement and cost efficient to the producer.

7.2 Recommendations

The base test method is a viable means of predicting the ultimate capacity of multiple span, multiple line, continuous Z- or C-purlin standing seam roof systems under gravity loading. However, the limitations as discussed in Chapter VI must be strictly enforced to obtain safe, accurate results.

Future research should be conducted to substantiate the effectiveness of opposing the purlin flanges, and of bracing configurations, as both were major factors in strength increase. It is suggested that future test programs include midpoint bracing in order to create a broader spectrum of data concerning bracing configurations.

The capacities and percentages from the single C-purlin test set were encouraging, in that they were much higher than similar Z-purlin results. However, more tests should be performed using C-purlins to clarify this matter.

The next step in refining the base test method should be to develop an analytical model for the single span base test, ending the necessity of full scale testing. In addition, it is suggested that a test program be devised that would keep all variables constant except the one in question. As an example, one set of tests should be conducted using identical clips and purlins, while varying the deck type. This would result in more accurate data pertaining to panel effects on the through fastened capacity. It is suggested that future test programs consider the effects of uncertainties in material properties, member dimensions and erection techniques on the capacity of the system.

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