FEARS STRUCTURAL ENGINEERING LABORATORY

PURLIN STUDIES
Progress Report
STANDING SEAM ROOF SYSTEMS
ADDENDUM

by

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Sponsored by

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CHAPTER I

INTRODUCTION

A research program to study the behavior of metal building roof systems has been undertaken at the Fears Structural Engineering Laboratory, University of Oklahoma, under the sponsorship of Star Manufacturing Company. The portion of the research concerned with the experimental determination of the behavior of Z-purlin supported standing seam roof systems was described in a previous report, "Standing Seam Roof Systems", Research Report No. FSEL/STAR 82-03. The primary purpose of that report was to document the testing procedure, test specimen properties and test results. For preliminary comparison purposes, experimentally determined failure loads, without correction for dead load, were compared to predicted failure loads considering only bending failure. (Bending failure for the purpose of this report is defined as failure caused by local buckling of lip, flange or web elements due to normal stresses only or by lateral-torsional buckling between lateral brace locations).

This report presents corrected experimentally obtained failure loads which account for dead load effects and refined analytical predictions which include shear plus bending failure modes. In addition, further discussion of test results and conclusions is presented.

CHAPTER II

ANALYTICAL AND EXPERIMENTAL RESULTS

2.1 Experimental Results

"Actual" failure loads reported in Table 4 of the report represent the maximum applied loads before failure of the system and do not include the weight of the standing seam panels, clips or Z-purlins. For each test series, Z-purlin weight per linear foot, as calculated from measured dimensions, is shown in Table 1. From calculated panel dimensions the unit weight of the panel is 1.5 psf.

Table 2 shows total load on the test purlins at failure. These loads were calculated as follows: actual applied load from Table 4 of the original report plus panel unit weight (1.5 psf) times purlin spacing plus Z-purlin unit weight (Table 1). The increase in actual failure loads varied from 10.75 to 13.0 plf for the six test series.

2.2 Analytical Results

Predicted failure loads were calculated using Star Manufacturing Company's purlin design computer program. Measured dimensions were used to calculate section properties. An assumed yield stress of 55 ksi, based on results of coupon tests (Table 5 of the original report), was used for all calculations. For single span tests, Series I and IV, the predicted failure load was determined as that load which resulted in a bending unity check (u.c.) value of 1.67. For multi-span tests, Series II, III, V and VI, the

predicted failure load was determined as the lowest load for a bending or shear plus bending unity check value of 1.67. A unity check value is defined as the ratio of the calculated maximum stress to the allowable stress or the value from an interaction equation as in the case of shear plus bending.

The resulting predicted failure loads are shown in Table 2. For single span tests, Series I and IV, only bending is applicable. For multi-span tests, Series II, III, V and VI, both bending and shear plus bending are applicable.

From Table 2, shear plus bending controlled for the two-span tests, Series II and III, and bending controlled for the three-span tests, Series V and VI, except Test 5-A where shear plus bending controlled.

2.3 Comparison of Analytical and Experimental Results

Table 2 shows the ratio of the experimentally obtained failure load to the lowest predicted failure load using Star Manufacturing Company's purlin design program for a unity check value of 1.67. For configurations used by Star Manufacturing Company, e.g. Series I, II, III and Tests 4-A, 4-C, 5-A, the ratio of experimental failure load to predicted failure load varied from 78.7% to 127.8%. For the remaining tests which were conducted to learn more about the behavior of Z-purlin supported standing seam roof systems, the ratio varied from 97.1% to 507.8%.

In Series I, II and III, Test A was conducted before Test B. After Test A was completed only damaged material was replaced, e.g. the purlins that failed and possibly intermediate brace material or clips or selected panels. It is believed that this procedure adversely affected the load carrying capacity of the system. As can be seen from the data in Table 2, Test B results for Series I, II and III were consistently lower than Test A results.

Consequently, it is believed that the results for the B tests, in particular Test 1-B, do not reflect the true capacity of the roof system.

To eliminate bridging of the panel, the edge purlins were of lesser section than the test purlins so that approximately equal vertical deflections were obtained at the centerline of the edge and test purlins. In Tests 4-A and 4-C, the edge purlin failed first and transferred load to the test purlin as evidenced by the load versus vertical deflection plots found in Appendix D of the report. Thus, it is believed that the true capacity of this configuration was not achieved.

Test Series IV was an attempt to experimentally determine the relative contribution of intermediate braces, panel-to-purlin connection clips and panel "drape" to lateral restraint of the purlin compression flange. To accomplish this objective, tests were conducted using the standard configuration (Tests 4-A and 4-C), no intermediate bracing without clips installed (Test 4-B), intermediate bracing only at the midspan (Test 4-D), and no intermediate bracing with clips installed (Test 4-E).

Analyses for Test 4-B and 4-E were done assuming no lateral support between rafters. The predicted failure loads were 51 plf and 55 plf for Tests 4-B and 4-E, respectively. The respective experimental failure loads for these tests were 141 plf and 259 plf. Hence, the actual load for the test without intermediate bracing or clips was 256.4% of predicted and for the test without intermediate bracing but with clips was 507.8% of predicted. The actual failure load for configuration 4-E was 89.9% of the predicted failure load for Test 4-A and 82.5% for Test 4-C, the fully braced tests. From this data it is obvious that panel drape and clip friction provide significant lateral restraint

to the purlin compression chords.

Tests 5-B, 6-A and 6-B were conducted using only midspan intermediate braces. The ratio of actual to predicted failure loads for the three tests were 97.1%, 95.4%, and 99.7%. Although these ratios are below other test results, they are believed to be acceptable considering full scale structural systems were being tested. Further, on examining the test set-up for Test 6-A after failure, it was found that a nut on one intermediate brace had not been installed and that failure occurred at this location, invalidating the test.

Table 1
Z-Purlin Unit Weights

Test No.	Purlin Spacing (ft)	Panel Dead Load per Purlin (plf)	Purlin Weight (plf)	Total Dead Load (plf)
1A	5.0	7.5	4.0	11.5
1B	5.0	7.5	4.5	12.0
2A	5.0	7.5	3.0	10.5
2B	5.0	7.5	3.5	11.0
3A	5.0	7.5	5.0	12.5
3B	5.0	7.5	5.5	13.0
4A	4.83	7.25	5.5	12.75
4B	4.83	7.25	5.5	12.75
4C	4.83	7.25	5.5	12.75
4D	4.83	7.25	5.5	12.75
4E	4.83	7.25	5.5	12.75
5A	4.83	7.25	3.5	10.75
5B	4.83	7.25	3.5	10.75
6A	4.83	7.25	4.0	11.25
6B	4.83	7.25	4.5	11.75

*Based on 1.5 psf.

Table 2
Revised Summary of Test Results

Test No.	No. of Spans	Bracing	Design Load on Design Section (plf)	Failure Loads on Measured Sections			
				Star Predictions		Tested + Dead Load (plf)	Test / Star x 100
				Bending** (plf)	Shear & Bending** (plf)		
1-A	1@25'	1/3 PTS.	72	146	N/A	155	106.0
1-B	1@25'	1/3 PTS.	72	145	N/A	129	88.9
2-A	2@25'	1/3 PTS.	71	149	128	141	110.2
2-B	2@25'	1/3 PTS.	71	146	127	128	100.8
3-A	2@25'	1/3 PTS.	113	244	225	278	123.6
3-B	2@25'	1/3 PTS.	113	243	232	260	112.1
4-A	1@20'	1/3 PTS.	163	288	N/A	239	83.0
4-B	1@20'	None	*	55	N/A	141	256.4
4-C	1@20'	1/3 PTS.	163	314	N/A	247	78.7
4-D	1@20'	Midspan	*	216	N/A	262	121.7
4-E	1@20'	None	*	51	N/A	259	507.8
5-A	3@20'	1/3 PTS.	111	303	205	262	127.8
5-B	3@20'	Midspan	*	207	242	201	97.1
6-A	3@20'	Midspan	*	283	309	270	95.4
6-B	3@20'	Midspan	*	298	333	297	99.7

*Not standard design configuration
**At unity check = 1.67
N/A = not applicable

CHAPTER III

CONCLUSIONS

From the data presented in Table 2 and the discussion in the previous chapter, it is concluded that Star Manufacturing Company's purlin design program adequately predicts the structural strength of the Z-purlin supported standing seam roof system configurations used in this research program. For the standard multi-span configurations tested, the ratio of actual to predicted failure loads was less than 100% for only one test and this result is adequately explained because of the use of parts previously used in a test to failure. For the standard configuration single span tests, the reported failure loads were considerably less than predicted because of a defect in the test set-up. However, the adequacy of the design program for single span configurations is confirmed by the results of Test 4-D where only a midspan lateral brace was provided and the ratio of actual to predicted failure load was 121.7.

It is further concluded that the design program is adequate for configurations using only a midspan intermediate brace. Of the configurations tested for which valid data was obtained, Tests 4-D, 5-B and 6-B, the lowest ratio of actual to predicted failure load was 97.1%. Since the predicted failure loads were based on a unity check value of 1.67, which is based on an "ideal" structural system and includes provisions for inaccuracies (not errors) in design, fabrication and erection, and the fact that large scale, complete systems were tested with such unavoidable inaccuracies, the analytical and experimental results are considered to be in excellent agreement. Hence, the

design program is found to be adequate for these configurations.

From the tests conducted in Series IV, it was found that considerable lateral restraint is provided by the phenomenon of panel drape and clip friction. It is possible that an economically feasible system can be designed without intermediate braces. However, it is not recommended that such systems be used without additional testing to verify the adequacy of lateral restraint provided by the panel/clip combination.

APPENDIX G

REVISED TEST SUMMARY SHEETS

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 1A

Test Date: 5/28/81

Purpose: Base Test

Span(s): 25'-0" Single Span

Thickness: 0.083 Moment of Inertia: 13.589 in^4

Parameters: Intermediate Bracing @ 1/3 pt.

Clips in place.

No insulation

Spacing @ 5'-0"

Failure Load: 143.0 plf applied load

Failure Mode: Local buckling of the compression flange & lip at midspan.

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 146 plf Bending

Method _____ Load _____

Method _____ Load _____

Discussion:

-At the onset of this test very poor load vs. deflection results were observed. After several tests to working load and an analysis of the test set-up as a grid, it was concluded that due to the stiffness of the deck and the strength of the clip the deck was transferring load to the outside purlin. All purlins in the set-up were identical and, since the tributary area for this purlin was only one-half of the interior purlins, reserve capacity existed.

-Ribs of the deck were cut close to the interior purlins to allow the test purlin to deflect independently of adjacent purlins.

-After this modification, the load vs. deflection curve showed good agreement with the deflection predicted through constrained bending analysis.

-Failure occurred because of local buckling of the compression flange and lip at the center line of the span.

-The test failure load was 38.0% less than that predicted using constrained bending theory and AISI criteria.

-The Star Manufacturing Company failure load prediction was 6% less than the test load. This prediction was based on a laterally unbraced span equal to the intermediate bracing spacing.

-The stress distribution over the cross-section at working load is close to constrained bending.

-The maximum stress at failure load was 39.6 ksi at the bottom flange to web junction.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 1B

Test Date: 6/3/81

Purpose: Base Test

Span(s): 25'-0" Single Span

Thickness: 0.083 Moment of Inertia: 12.929 in^4

Parameters: Intermediate Bracing @ 1/3 pt. $I_{x_{star}}$ = 12.334 in^4

Clips in place.

No insulation.

Spacing @ 5'-0"

Failure Load: 117 plf applied load

Failure Mode: Local buckling of the compression flange & lip @ B

Predicted Failure Loads:

Method Star (u.c. 1.669) Load 145 plf Bending

Method _____ Load _____

Method _____ Load _____

Discussion:

-This test is identical to Test 1A; only the test purlin was replaced.

-Deflection of the purlin adjacent to the test purlin was observed to be greater than that of the test purlin. Premature failure of this purlin may have influenced the test.

-Failure occurred because of local buckling of the compression flange and lip at the centerline of the span.

-The measured load vs. deflection curve for the tet purlin was in good agreement with the constrained bending prediction.

-The predicted constrained bending AISI failure load was 66.7% higher than the test failure load.

-The Star predicted failure load was 12.4% higher than the test failure load. This prediction was based on lateral buckling.

-The maximum stress on the purlin was at the top flange to web junction and was 42.6 ksi comp.

-Intermediate brace forces were relatively consistent. Braces near the ridge were in compression and those near the eave in tension. Only the brace near the ridge showed significant load.

-The top flange lateral displacement was higher than the bottom flange up to 80 plf at which point bottom flange changed direction and moved the same magnitude as the top flange.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 2-A

Test Date: 7/17/81

Purpose: Base Test

Span(s): 2 @ 25'-0"

Thickness: N=0.66", s=0.64" Moment of Inertia: N=10.34 in^4, S=10.315 in^4

Parameters: Intermediate Braces @ 1/3 pt. Star (N=0.814 in^4, S=9.825 in^4)

Clips in place.

No insulation

Spacing @ 5'-0"

Failure Load: 130 plf

Failure Mode: Local buckling

Predicted Failure Loads:

Method Star (U.C. = 1.67) Load 128 plf Shear plus Bending

Method Star (U.C. = 1.67) Load 149 plf Bending

Method Load

Discussion:

-The failure mode was local buckling of the compression flange immediately outside the lap.

-The rib of the deck was cut as was done in Tests 1A and 1B.

-The predicted load vs. deflection (assuming constrained bending) curve was in good agreement with test data.

-The Star predicted failure load was 9.3% lower than the test value.

-The AISI predicted, constrained bending failure load was higher than tested.

-A purlin cross-section immediately outside of the lap was strain gaged.

-The stress distribution over the cross section at working load shows max. stress on the tension side at the web to top flange junction.

-The stress distribution over the cross section near the failure load shows maximum stress at the outside of the lip and at the flange to lip junction both on the compression side.

-Only the exterior line of intermediate braces in one span was instrumented.

-Brace forces were found to be as high as 650 lb. compressions at the ridge.

-Brace forces decreased in the direction of the eave and were in tension adjacent to the eave.

-The top and bottom flange lateral displacements were in the same direction and had about the same magnitude until 105 plf at which point the bottom flange began to move more than the top flange and the top flange changed in direction.

-The maximum lateral displacement was 1.05 in. @ the bottom flange.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 2B

Test Date: 7/24/81

Purpose: Base Test

Span(s): 2 @ 25'-0"

Thickness: N=0.065", S=0.065" Moment of Inertia: N=0.85 in^4, S=10.08 in^4

Parameters: Intermediate bracing @ 1/3 pt.
Clips in place
No insulation
Spacing @ 5'-0"

Failure Load: 117 plf

Failure Mode: Local buckling of compression flange and lip at lap.

Predicted Failure Loads:

Method	Star (u.c. = 1.67)	Load	127 plf shear plus bending
Method	Star (u.c. = 1.67)	Load	146 plf bending
Method		Load	

Discussion:

-The failure mode of the test purlin was local buckling of the compression lip and flange immediately outside of the lap.

-This test was similar to 2A. The deck ribs were cut near each purlin.

-Test data was in good agreement with the predicted (constrained bending) load vs. deflection relationship.

-The down hill purlin showed more deflection than the test purlin and it is possible that this purlin failed first.

-The Star predicted failure load was 0.8% lower than the experimental load.

-The AISI predicted failure load was higher than the experimental load.

-A section immediately outside of the lap was strain gaged.

-The maximum stress on the gaged cross section at working load was 31.4 ksi tension at the web to flange junction.

-The maximum stress on the gaged cross-section at failure load was 46.6 ksi tension at the web to flange junction.

-The distribution of brace forces was similar to Test 2A. The magnitudes were considerably less than in Test 2A.

-The top and bottom flange lateral displacements were in the same direction and were of approximately the same magnitude until 90 plf at which point the displacement of the top flange changed in direction.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 3A

Test Date: 7/30/81

Purpose: Base Test

Span(s): 2 @ 25'-0"

Thickness: N=.099", S=.097" Moment of Inertia: N=15.81 in^4, S=15.47 in^4

Parameters: Intermediate Bracing @ 1/3 pt.
Clips in place
No insulation
Spacing @ 5'-0"

Failure Load: 265.2 plf applied load

Failure Mode: Local buckling at compression flange and lip at lap.

Predicted Failure Loads:

Method Star (u.c. 1.67) Load 225 plf shear plus bending

Method Star (u.c. 1.67) Load 244 plf bending

Method _____ Load _____

Discussion:

-Failure mode was local buckling of the lip and flange just outside of the lip.

-Load vs. deflection plot showed good agreement between constrained bending and test data.

-The Star predicted failure load was 19.1% lower than the experimental failure load.

-The AISI predicted failure load was 13.5% lower than the experimental failure load.

-The stress at working load showed a max. stress of 38.5 ksi comp. at the flange to web junction.

-The stress at failure load showed yield stress at both the top and bottom web to flange junctions.

-The magnitude of the compressive force in brace #1 & #2 were approximately the same. Brace forces #3 and #4 were approximately the same until approximately 120 plf at which point brace #3's compressive force increased while #4's went from compression to tension.

-The maximum brace force for all the braces is as follows: #1, 1089 lbs compression; #2, 1000 lbs compression; #3, 398 lbs compression; #4, 346 lbs tension.

-The lateral movement of the top and bottom flanges was in the same direction. The top flange of the purlin displaced more than the bottom flange.

-The maximum lateral displacement of the top and bottom flanges was 1.169 in. and 0.945 in., respectively.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 3B

Test Date: 8/3/81

Purpose: Base Test

Span(s): 2 @ 25'-0"

Thickness: N=.099", S=.097" Moment of Inertia: N= 15.665 in^4, S=15.758 in^4

Parameters: Intermediate Bracing @ 1/3 pt. Star N=15.144; S=15.278

Clips in place

No insulation

Spacing @ 5'-0"

Failure Load: 247 plf applied load

Failure Mode: Local buckling of compression flange and lip at lap.

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 232 plf shear plus bending

Method Star (u.c. 1.67) Load 243 plf bending

Method Load

Discussion:

-Failure mode was local buckling of lip and flange.

-Load vs. deflection curve showed good agreement up to about 180 plf then the experimental curve began to deviate from theoretical predictions.

-It was observed that the displacement of the downhill purlin was more in this test than in test 3A. This could explain the failure load being lower than that of test 3A.

-The Star predicted failure load was 10.7% lower than the experimental failure load.

-The AISI predicted failure load was 8.3% higher than the experimental failure load.

-The stress on the cross section at working load shows a maximum stress of 42.6 ksi tension at the top flange to web junction.

-The stress on the cross section at failure load shows yield stress at both top and bottom flange to web junctions.

-The brace forces in braces #1 and @2 were similar to test 3A. Brace #4 was in tension from the onset of the test and showed very little load throughout the test.

-The maximum brace forces are as follows: #1, 714 lbs compression; #2, 500 lbs compression; #3, 108 lbs compression; #4, 247 lbs tension.

-Top horizontal displacement transducer was not working at the time of testing.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 4-A

Test Date: 1/18/82

Purpose: Test 4A w/o Insulation

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

Thickness: 0.094" Moment of Inertia: 14.484 in^4

Parameters: Intermediate Braces @ 1/3 pt.

Clips in place

No insulation

Spacing 4'-9"*

Strain gages @ ℄ of purlin

Failure Load: 225.6 plf applied load

Failure Mode: Compression buckling of flange @ flange & web node.

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 288 plf Bending

Method _____ Load _____

Method _____ Load _____

Discussion:

-The purlins were spaced @ 4'9" to provide more room on the outside of the test set-up so that the ridge purlin would not hit the chamber wall.

-The failure mode was local buckling of the compression flange and web at the center of the span.

-There was good agreement between the predicted and experimental load vs. deflection curves.

-From the load deflection curve, deflection of the test purlin seems to be linear up to the point of failure. It would appear that the ridge purlin again failed before the test purlin.

-The AISI predicted failure load was 47.2% higher than the experimental failure load.

-From the stress plot @ failure load the max. stress was 47.8 ksi compression at the flange to web junction.

-With the adjustment in the test set-up the brace forces did not reduce in magnitude at higher loads.

-Brace forces increased approximately linearily.

-At 31.2 psf the ratio of brace forces was 1:1.79:3.09 (in the direction of ridge to eave). The ratio of tributary areas was 1:3:5.

-At 31.2 psf the brace forces as a percentage of stabilized vertical load was 19.8%, 18.9% and 17.2% in the direction of ridge to eave.

-The top and bottom flanges moved laterally in the same direction. The top flange moved more than the bottom flange.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 4B

Test Date: December 3, 1981

Purpose: Effect of panel "hugging" on lateral restraint.

Span(s): Single span 20'-0"

Thickness: 0.094 in. Moment of Inertia: 14.44 in^4

Parameters: No intermediate bracing Star I_x = 13.769 in^4

No clips

No insulation

Spacing 7'-3"

Failure Load: 128.2 plf applied load

Failure Mode: Extreme lateral displacement

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 55 plf unbraced (bending)

Method Load

Method Load

Discussion:

-Top flange lateral displacements were very large.

-Test was stopped when it was determined that the outside purlins were taking the load. (See load vs. displacement curve.)

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 4C

Test Date: November 3, 1981

Purpose: Base Test

Span(s): Single Span 20'-0"

Thickness: 0.096" Moment of Inertia: 15.695 in^4 (Gross)

Parameters: Intermediate Bracing at 1/3 pts. Star I_x = 15.024 in^4

Clips installed

No insulation

Spacing 4'-10"

Failure Load: 233.7 plf applied load

Failure Mode: Local buckling

Predicted Failure Loads:

Method Star u.c. = 1.67) Load 314 plf Bending

Method Load

Method Load

Discussion:

-Failure occurred because of local buckling of the compression flange near the centerline at 233.7 plf.

-Vertical deflections were approximately 25% greater than constrained bending predictions.

-Measured vertical deflections were approximately linear.

-From lateral displacement and intermediate brace vs. load plots, it appears that the system deflected into the west side of the vacuum chamber and was then restrained by the chamber wall.

-No strain measurements were made.

-Brace forces were reasonably consistent until contact with the chamber wall.

-Brace forces increased approximately linearily.

-At 31.2 psf (6 in. of H_2O) the ratio of brace forces was 1:2.32:2.82 (in the direction of ridge to eave). At 10.4 the ratio was 1:2.03:2.55. The ratio of tributary areas was 1:3:5.

-When tributary areas are considered it is evident that the brace forces did not accumulate in proportion to tributary area.

-At 31.2 psf, the brace forces as a percentage of stabilized vertical load were 17.3%, 13.4% and 9.7% in the direction of ridge to eave and at 10.4 psf, 24.0%, 16.2% and 12.2%.

-Maximum centerline horizontal displacement of the top flange of the test purlin was approximately 0.5 in.

-The top and bottom flanges of the test purlin moved in the same direction.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 4D

Test Date: November 19, 1981

Purpose: Adequacy of single brace at midspan

Span(s): Single span 20'-0"

Thickness: 0.099 in. Moment of Inertia: 15.23 in^4 / Star I_x = 14.680 in^4

Parameters: Intermediate bracing at centerline
Clips installed
No insulation
Spacing 4'-10"

Failure Load: 248.8 plf applied load

Failure Mode: Local buckling

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 216 plf Bending

Method ____ Load ____

Method ____ Load ____

Discussion:

-Failure occurred due to local buckling of the compression flange at 248.8 plf.

-Vertical deflections were 15-20% greater than predicted by constrained bending.

-No strain measurements were made.

-From the plot of intermediate brace force vs. load it appears that the system deflected into the west chamber wall and was then restrained.

-Brace forces increased approximately linearily until contact was made with the chamber wall.

-At 26.3 psf (5 in. of water) the ratio of brace forces was 1:3.0:5.39 (in the direction of ridge to eave). At 10.9 psf (2 in. of water) the ratio was 1:1.5:3.36. The ratio of tributary areas was 1:3:5.

-Brace forces appear to accumulate in proportion to the tributary area at higher loads.

-At 26.3 psf, the brace forces as a percentage of stabilized vertical load were 5.7%, 4.7% and 5.5% in the direction of ridge to eave and at 10.9 psf 7.8%, 4.9% and 5.2%.

-Maximum horizontal displacement of the top flange of the test purlin was approximately 1 in.

-The top and bottom flanges of the test purlin moved in the same direction.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 4E

Test Date: November 25, 1981

Purpose: Adequacy of clips as lateral braces

Span(s): Single span 20'-0"

Thickness: 0.099 in. Moment of Inertia: 15.08 in^4

Parameters: No intermediate braces
Clips installed
No insulation
Spacing 4'-10"

Failure Load: 246.3 plf applied load

Failure Mode: Lateral buckling

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 51 plf unbraced (bending)

Method _____ Load _____

Method _____ Load _____

Discussion:

-Failure occurred due to lateral buckling of the top flange at 246.3 plf.

-Vertical displacements of the test purlin were 10-15% greater than predicted by constrained bending until near failure when the displacement increased at a rapid rate.

-No strain measurements were made.

-Horizontal displacement of the top flange increased in "jumps" at 35.4 and 41.6 psf indicating slip due to breaking of friction at the clips.

-Maximum centerline lateral deflection of the test purlin top flange exceeded 1 in.

-Lateral deflections of the top and bottom flanges were in the same direction with the top flange showing more deflection than the bottom.

TEST SUMMARY

Project: Star Purlin Study

Test No.: 5-A

Test Date: April 22, 1982

Purpose: Star Standard Brace System

Span(s): 3 @ 20' = 60'

Thickness: .066 & .055 Moment of Inertia: I_x = 9.947 in^4 & I_x=8.310 in^4

Parameters: Standard Braces @ 1/3 pts.

Clips are in place

No Insulation

Spacing 4'9"

Failure Load: 251.3 plf applied load

Failure Mode: Local buckling of compression flange and lip at lap.

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 205 plf shear plus bending

Method Star (u.c. = 1.67) Load 303 plf bending

Method Load

Discussion:

-Failure occurred by compression buckling of the flange web node just outside the lap at the north interior support.

-Web crippling was also observed at the south exterior support.

-The load-deflection curve showed very good agreement with that predicted by stiffness analysis and assuming constrained bending.

-The failure was clearly marked by an increase in the deflection with no increase in load.

-The Star Manufacturing Company design program predicted a failure load of 205 plf. The AISI constrained bending failure load predicted was 310.6 plf.

-The plot of the experimental stress distribution on the cross-section did not compare well with constrained bending assumptions. At failure load the stress plot indicated buckling of the compression flange and lip.

-At 20.7 psf (working load) the ratio of brace forces was: 1:2.08:3.59 for the exterior row of the exterior bay; 1:1.24:1.96 for the interior row of the exterior bay; 1:2.77:4.22 for the north row of the interior bay; and 1:2.53:4.07 for the south row of the interior bay. The ratio of tributary areas was 1:3:5.

-At 52.8 psf (failure load) the ratio of brace forces was: 1:2.70:5.94 for the exterior row of the exterior bay; 1:1.67:2.57 for the interior row of the exterior bay; 1:3.15:5.32 for the north row of the interior bay; and 1:2.77:5.07 for the south row of the interior bay. The ratio of tributary areas was 1:3:5.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 5-B

Test Date: May 17, 1982

Purpose: Center line brace only

Span(s): 3 @ 20' = 60'

Thickness: .055 & .059 Moment of Inertia: 10.02 in^4 & 8.658 in^4

Parameters: Internal braces @ b

Clips in place

No insulation

Spacing @ 4'9"

Failure Load: 190.5 plf applied load

Failure Mode: Web crippling at north exterior support

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 207 plf Bending

Method Star (u.c. = 1.67) Load 242 plf shear plus bending

Method _____ Load _____

Discussion:

-Failure occurred well above design load by web crippling. However, the load-deflection curve showed a nonlinear change before the web crippling occurred.

-The load deflection curve began to show a nonlinear change after a load of 141.6 plf was obtained.

-The Star Manufacturing Company's predicted failure load was 3% higher than the test failure load.

-The AISI predicted constrained bending failure load was 96% higher than the test failure load.

-The experimental stress distribution looked like an unconstrained bending distribution.

-From stiffness analysis (constrained bending) the moment at 123.5 plf was 3.29 k-ft while the experimental moment measured from strain gages was 2.44 k-ft.

-The moment about the y axis was -0.42 k-ft.

-The brace forces in the exterior bay are higher than those in the interior bay.

-At 19.8 psf (working load) the ratio of brace forces was 1:2.10:2.30 for the exterior bay and 1:2.10:2.75 for the interior bay. The ratio of tributary areas was 1:3:5.

-At 40.11 psf (failure load) the ratio of brace forces was 1:1.48:1.84 for the exterior bay and 1:2.83:4.06 for the interior bay.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 6-A

Test Date: 2/18/82

Purpose: Test w/only L bracing

Span(s): 3 @ 20'

Thickness: Outside 0.084" Inside 0.064" Moment of Inertia: $I=13.499\ in^4$, $I=9.837\ in^4$, $I=12.565\ in^4$

Parameters: Intermediate Braces @ L

Clips in place

No insulation

Spacing 4'-9"

Strain Gages 3" outside of lap.

Failure Load: 259.4 lb/ft applied load

Failure Mode: Lateral buckling of the ridge purlin

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 283 plf Bending

Method Star (u.c. = 1.67) Load 309 plf Shear plus bending

Method _____ Load _____

Discussion:

-The failure of the ridge purlin was due to a lack of bracing. The intermediate brace at the centerline was not attached properly. The bracing given to the purlin from the deck was not enough to restrain the purlin.

-The experimental deflections were much higher than predicted curve.

-From the experimental stress plot it was determined that the test was no good due to a lack of bracing.

-At 37 psf the brace forces in the interior span as a percentage of stabilized vertical load were: 11.4%, 5.9%, and 6.5% and at 53 psf they were 13.6%, 7.1% and 7.2%.

-At 37 psf the ratio of brace forces in the interior span was: 1:1.55:2.88 and at 53 psf 1:1.57:2.66 in the direction of ridge to eave. The ratio of tributary area was 1:3:5.

-At 37 psf the brace forces in the interior span as a percentage of stabilized vertical load were 11.4% and 12.2% with the ridge brace force not taken. At 53 psf they were 9.2% and 11.5% in the direction of ridge to eave with the ridge brace force not taken.

-The lateral displacement of the test purlin was about 1 in at the top flange. The top and bottom flanges moved in the same direction.

TEST SUMMARY

Project: Star Manufacturing Company

Test No.: 6B

Test Date: March 8, 1982

Purpose: Adequacy of single brace at midspan

Span(s): 3 @ 20'

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

Parameters: Intermediate braces at L

Clips installed

No insulation

Spacing 4' 9"

Failure Load: 284.5 plf applied load

Failure Mode: Local buckling

Predicted Failure Loads:

Method Star (u.c. = 1.67) Load 298 plf Bending

Method Star (u.c. = 1.67) Load 333 plf Shear plus bending

Method _____ Load _____

Discussion:

-Failure occurred by local buckling of the bottom (compression flange) in the interior span immediately outside the lap. Buckling of the compression flange in the outside bay at midspan followed.

-Measured vertical deflections were greater than theoretical predictions.

-The moment of inertia of the eave purlin was 79.6% of that of the test purlin. It was not possible to determine if the eave purlin failed first.

-The strain gages, which were mounted 3" from the end of the lap on the north outside purlin, did not indicate yield strain near failure.

-Stress plots indicate unconstrained bending.

-At 37 psf, the brace forces in the interior spans as a percentage of stabilized vertical load were 9.1%, 5.6%, and 5.1% in the direction of ridge to eave and at 60 psf they were 11.7%, 5.9% and 4.3%.

-At 37 psf the brace forces in the exterior span as a percentage of stabilized vertical load were 14.2%, 9.1%, 9.2% and at 60 psf they were 14.3%, 8.3% and 7.7% in the direction of ridge to eave.

-For the intermediate brace location in the exterior span at 37 psf, the ratio of brace forces was 1.0:1.92:3.24 and at 60 psf the ratio was 1.0:1.73:3.34. The ratio of tributary areas was 1:3:5.

-At 37 psf, the ratio of brace forces at the intermediate brace location in the interior span was 1.0:1.84:2.81 and at 60 psf the ratio was 1.0:1.53:2.24. The ratio of the tributary areas was 1:3:5.

APPENDIX H

ERRATA

Errata
PURLIN STUDIES
Progress Report
STANDING SEAM ROOF SYSTEMS
FSEL/STAR 82-03

The following corrections should be made to the original report:

Page 38 Actual Failure Load for Test 3A should read 265 instead of 235.

Page A.4 Radius at lower flange/web should read 3/8" instead of 13/16".

Page A.14 Radius at upper flange/lip should read 1/2" instead of 13/32".

Page A.14 Radius at upper flange/web should read 13/32" instead of 1/2".

Page B.3 For both purlins, upper lip angle with horizontal should read 42^{o}.

Page F.18 North span purlin, upper lip angle with horizontal should read 41^{o}.

Page F.18 Center span purlin, lower flange width should read 2.71" instead of 2.94".