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SHEAR PLUS BENDING IN LAPPED Z-PURLINS

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Summary

Six two purlin line, three span continuous Z-purlin tests were conducted to show that combined shear plus bending is a possible failure mode immediately outside the lapped portion of the purlin lines. AISI Specification provisions predicted that combined shear plus bending was the controlling limit state. Strain gage data showed that local buckling occurred immediately outside of the lapped portion of the purlins lines prior to failure which caused moment to redistribute to the positive moment region. It is concluded that shear plus bending is a possible controlling limit state for continuous lapped purlins.

1. Introduction

The failure mode for continuous purlin systems constructed of lapped Z-purlins and subjected to gravity loading commonly appears to be local lip/flange/web buckling in the positive moment region of the exterior bay purlins. (Positive moment is defined here as a moment which causes compression in the top flange under gravity loading.) However, the AISI Specification for the Design of Cold-Formed Member (Specification 1996) provisions usually do not predict this observed limit state. The failure load of the system is usually predicted to be shear plus bending of a single purlin immediately outside of the lapped portion of the continuous purlins. An explanation for the difference between the observed failure mode and the predicted limit state is that local buckling first occurs immediately outside of the lapped portion of the purlin line, which, in turn, causes moment to redistribute to the positive moment region of the system resulting in the observed failure.

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To determine if, in fact, combined shear plus bending is a controlling limit state for lapped Z-purlin systems a set of tests was conducted with fully instrumented purlins. The experimentally determined failure loads were then compared to the provisions of Section C.3.3.2 LRFD Method of the AISI Specifications (Specifications 1996). This section states:

> *For beams with unreinforced webs, the required flexural strength, M_u and required shear strength, V_u, shall satisfy the following interaction equation:*

$$\left(\frac{M_u}{M_{nox}}\right)^2 + \left(\frac{V_u}{V_n}\right)^2 \leq 1.0 \qquad (1)$$

> *Where M_{nxo} = Nominal flexural strength about the centroidal x-axis determined in accordance with Section C3.1.1 and V_n = Nominal shear strength when shear alone exists.*

2. Methodology

In attempt to show that shear plus bending is a controlling limit state for continuous lapped Z-purlins, six , three span continuous tests were conducted. Three, two purlin, tests were conducted with three spans of 20 ft. (6.10 m) each and two tests with spans of 25 ft. (7.62 m) each. All tests used 8.5 in. (216 mm) deep purlins with the top flanges facing inward, that is, opposed purlins. Unequal lap lengths were used so that the predicted limit state was shear plus bending immediately outside the laps in the exterior bays of all tests. Through fastened deck was used. Table 1 shows the test designations, purlin size in each bay, and lap lengths into each bay. The last two digits of the purlin designation represent the nominal thickness of the purlin in thousands of an inch. Thus, an 8.5Z64 is an 8.5 in. deep Z-purlin having a nominal thickness of 0.064 in. Standard tensile coupon test results for the purlins are shown in Table 2.

The test setups were constructed inside a vacuum chamber. Polyethylene sheeting was placed over the completed assemblies and sealed to the chamber walls. Air was evacuated from the vacuum chamber to simulate gravity loading. The differential air pressure was measured using two U-tube manometers.

Instrumentation consisted of displacement transducers and strain gages. Vertical deflection was measured at the theoretical point of maximum deflection in each exterior span. Strain gages were placed on one purlin of each purlin line immediately outside the lap and at the point of maximum moment in the exterior span as shown in Figure 1.

The test setups were loaded in initial increments of 0.5 in. of water or 2.6 psf. Smaller increments were used near the failure load of the system. All data, except, that from the U-tube manometers was recorded using a PC-based data acquisition system.

3. Results

Each system was analyzed using measured section and material properties. A standard stiffness analysis, assuming full continuity between the purlins within the laps, was first conducted. From these analyses, M_u and V_u values were determined for the recorded failure load for each test. Next, M_{nxo} and V_n values were determined using the AISI Specification provisions. The purlins were assumed to be continuously laterally braced except between the end of the lap and the inflection point in the exterior bay. That is, the inflection point was assumed to be a brace point. Finally, the shear plus bending interaction equation was used to predict the failure load immediately outside of the lap in the exterior bay.

Table 3 shows the results for the shear plus bending calculations. In this table the "unity check" value is the ratio of M_u/M_n in the positive moment region and the result from Equation 1 in the negative moment region. A value less than one indicates that the result is conservative with respect to the AISI Specification provision. From this data it is clear that neither positive moment or negative moment alone is the predicted failure mode since all unity check values are significantly less than 1.0. When combined shear plus bending is considered, the results are much closer to 1.0.

Table 4 shows the actual and predicted failure loads for the six tests. In Tests FV20-1 and –2, a purlin failed at an exterior support and in Test FV25-2 the compression flanges of lapped purlins buckled at an intermediate support. For the remaining three tests, the actual failure load was predicted within 9% assuming the shear plus bending limit state, as shown in Table 4.

As expected, the collapsed purlins were severely buckling near the point of maximum moment. However, examination of the strain gage data clearly shows that buckling at the instrumented section immediately outside of the lap began before buckling at the point of maximum positive moment. Figure 2 shows stress (measured strain multiplied by the modulus of elasticity, 29,500 ksi) versus applied load for the two instrumented locations of Test FV20-3A. It is evident from the figure that web buckling occurred at the lap location between 250 and 300 plf and that there is no evidence of buckling at the maximum positive moment location until very near failure. Figure 3 shows similar results for test FV25-1

4. Conclusions

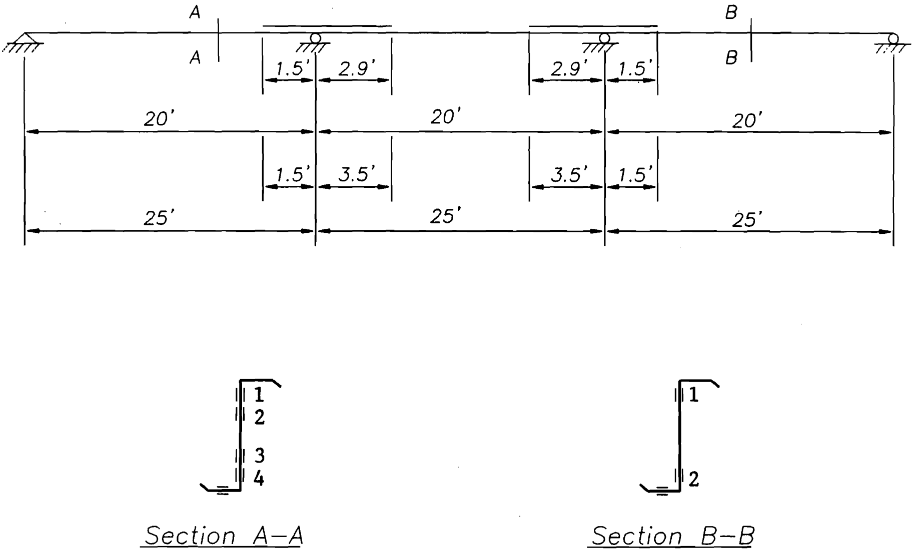
From the results of the limited study reported here, it is concluded that shear plus bending is a possible limit state for continuous lapped Z-purlin systems and that the current AISI Specification provisions for shear plus bending accurately predict the failure load.

5. References

"Specification for the Design of Cold-Formed Steel Structural Members," (1996), American Iron and Steel Institute, Washington D.C.

6. Acknowledgements

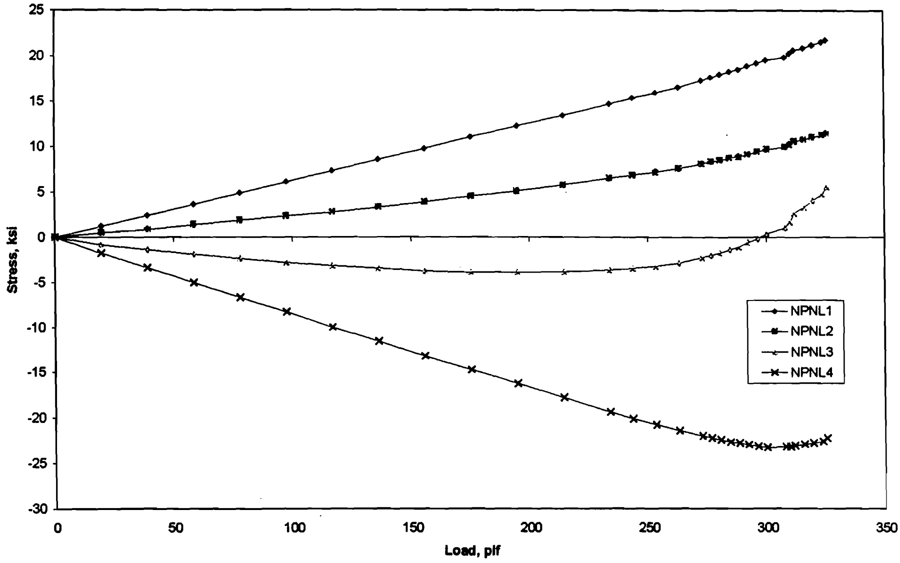
The research reported here was sponsored by the American Iron and Steel Institute and the Metal Building Manufacturers Association.



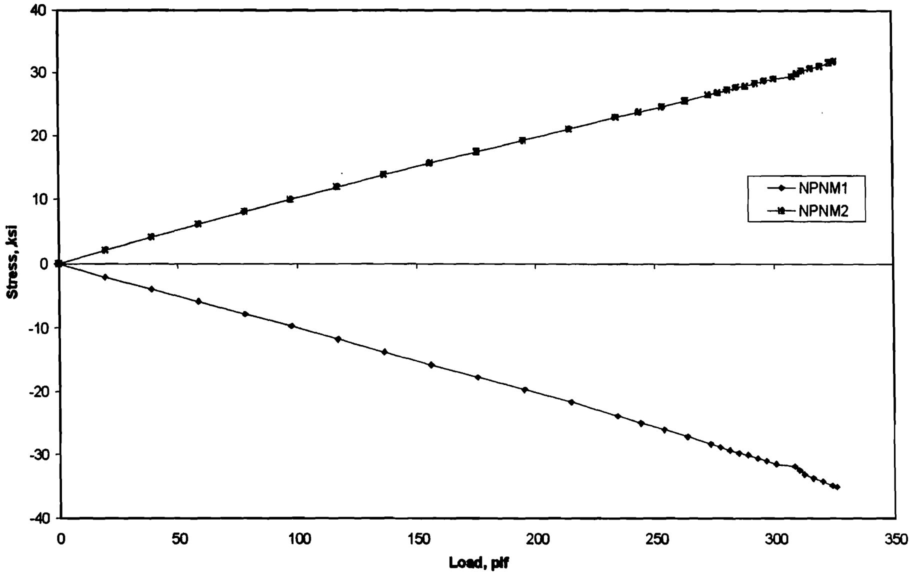
Section A–A

Section B–B

Figure 1. Layout and Strain Gage Locations

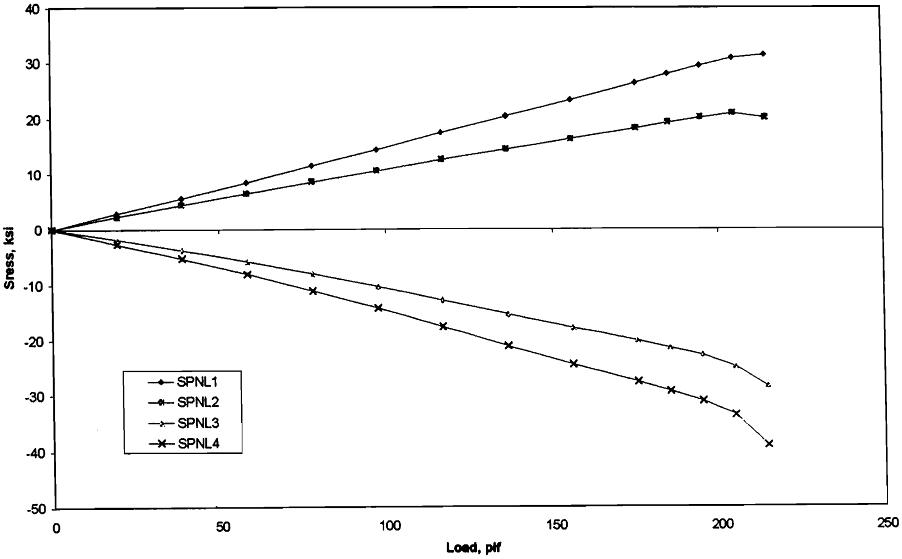


(a) Stresses Outside of Lap-North Purlin

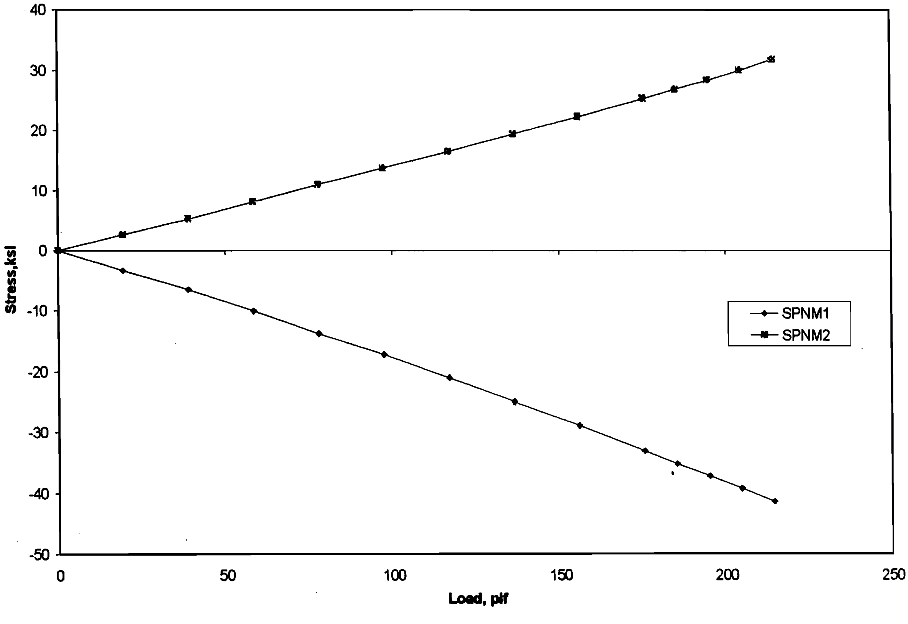


(b) Stresses at Maximum Moment-North Purlin

Figure 2. Purlin Stresses – Test FV20-3A



a) Stresses Outside of Lap-South Purlin



b) Stresses at Maximum Moment-South Purlin

Figure 3. Purlin Stresses – Test FV25-1

Table 1
Test Matrix

Test Identification	Purlin Size	Span (ft)	Lap Length (ft)
FV20-1, -2, -3, -4	8.5Z64 8.5Z57 8.5Z64	20.0 20.0 20.0	1.500 2.8958 1.500
FV25-5, -6	8.5Z72 8.5Z64 8.5Z72	25.0 25.0 25.0	1.500 3.500 1.500

Table 2
Tensile Test Results

Test Identification	Thickness (in.)	Yield Stress (ksi)	Tensile Strength (ksi)	Elongation (%)
FV20-1	0.065	64.7	77.1	21.78
FV20-2	0.065	65.8	78.7	20.58
FV20-3	0.069	64.4	75.3	20.06
FV20-4	0.070	65.6	75.1	19.38
FV25-1	0.072	69.5	78.4	18.12
FV25-2	0.079	69.5	75.5	22.58

Table 3
Unity Check Calculation Results

Test No.	Positive Moment			Negative Moment						
	M_u (ft-kips)	M_{nxo} (ft-kips)	Unity Check	M_u (ft-kips)	M_{nxo} (ft-kips)	$\frac{M_u}{M_n}$	V_u (kips)	V_n (kips)	$\frac{V_u}{V_n}$	Unity Check
20-1	4.70	10.59	0.44	6.86	10.72	0.64	2.76	4.59	0.60	0.77
20-2	4.73	10.45	0.45	6.91	10.73	0.64	2.78	4.59	0.61	0.78
20-3	6.11	11.68	0.52	8.89	11.41	0.78	3.60	5.74	0.63	1.00
20-4	5.70	11.94	0.48	8.34	11.42	0.73	3.37	5.74	0.59	0.88
25-1	6.69	12.40	0.54	10.62	13.44	0.79	3.19	6.26	0.51	0.88
25-2	6.87	15.22	0.45	10.69	15.39	0.69	3.26	8.67	0.38	0.62

Table 4
Summary of Test Results

Test Identification	Actual Failure Load (plf)	Predicted Failure Load (plf)	Percent of Predicted Load	Expected Failure Mode
FV20-1	259.6	297.1	87.4	No[1]
FV20-2	261.5	298.3	87.7	No[1]
FV20-3	339.6	340.2	99.8	Yes
FV20-4	317.4	339.4	93.5	Yes
FV25-1	234.1	254.9	91.8	Yes
FV25-2	240.1	302.5	79.4	No[2]

[1] Purlin failed at exterior support

[2] Bottom flanges of lapped purlins buckled over support