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WIDE LIPS - A PROBLEM WITH THE 1986 AISI CODE

By Christopher T. Willis[1] and Benjamin J. Wallace[2]

ABSTRACT

Full-scale tests of cold-formed steel C-purlins designed with wider than usual flange stiffening lips using the 1986 AISI specification resulted in lower failure loads than expected. The suspected reason for this lower than expected capacity was local buckling of the wide stiffener lips, which then caused local buckling of the compression flange. To experimentally determine the effect of the compression flange stiffener lip width on the bending capacity of the purlins, three simple span tests were conducted on 8 inch deep C-sections. The second and third test specimens had compression lips approximately 1/8 inch (3.2mm) and 1/4 inch (6.4mm) narrower than the first specimen. These tests show an increase in load capacity with decreasing compression lip width.

A modified shape was then developed which used the same width of flat steel to form a section with the same depth, wider flanges, and narrower lips than the previous section. Purlins of this shape were tested and found to have more capacity than any of the previous shapes. The test capacity of the modified shape is in good agreement with predictions calculated using the 1986 AISI code.

From these tests, it appears that the 1986 AISI code provisions do not properly account for the behavior of wide lips. This was not a problem with previous versions of the code which used an allowable stress concept for wide lips which significantly reduced the predicted capacity of the section. A comparison of the two codes' predicted capacities of sections with various stiffener widths shows that the new code predicts larger bending capacities than the previous code for sections with wide lips. Currently, a limitation of the w:t ratio of stiffener lips to not more than 14 is being suggested by the AISI code committee until additional work is done to verify this problem.

INTRODUCTION

Cold-formed steel sections are commonly used as purlins and girts in metal buildings because of their economy in this relatively light load and medium span situation. C- and Z-sections with simple lip stiffeners at the outer edge of the flanges are the most common shapes due to their ease of cold-forming, efficiency, and ease of erection. The compression lip stiffeners in these sections must be sufficiently stiff to provide an edge stiffener to the compression flange, while also resisting local buckling as an unstiffened element themselves. In the U.S., these sections are usually designed in accordance with

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provisions published by the American Iron and Steel Institute (AISI). The most recent revision of the AISI specification was published in 1986 (1) and uses a different method of accounting for the effects of wide stiffening lips than the previous specification which was published in 1980 (2).

Experimental results of tests on C-section purlins are presented which indicate that the design procedure in the 1986 AISI specification (1) over-predicts the bending capacity of sections containing wide stiffener lips. Additional experimental results are included which show that when the wide compression lip is narrowed while all other section dimensions remain constant, the bending capacity is increased, which is contrary to predictions based on the 1986 AISI Specification and consistent with predictions based on the 1980 specification. Finally, a comparison of the two specifications is made which shows that purlin capacities predicted using the 1986 specification are more conservative for sections with narrow stiffener lips and less conservative for sections with wide stiffener lips than predictions based on the 1980 specification.

TEST SETUP AND INSTRUMENTATION

The gravity load test setup consisted of two C-section purlins supporting a conventional roof deck which had a one foot (305mm) rib spacing. The roof deck consisted of seven foot (2.1m) long sheets which were fastened to each of the two purlins with self-drilling fasteners spaced at one foot (305mm) intervals. This deck provided continuous lateral support to the purlins and provided a platform to place the concrete blocks, which were used to apply the gravity load. The two purlins in each specimen were placed in opposing positions, so that no lateral forces were generated which would have to be resisted by the deck. These purlins were spaced 5 feet (1.52m) apart, measured between the purlin webs as shown in Figure 1.

The purlins were supported by typical metal building rafter sections. Each rafter section was supported by two short beams which rested on the laboratory floor. One rafter section was rigidly connected to the support beams while the other rafter section was allowed to pivot on the support beams so that catenary forces would not be developed on the purlins. Angle stiffeners were bolted to the purlin webs at each support to avoid web crippling.

Data collected included vertical and horizontal deflection of each purlin at midspan. These measurements were made with wire and linear potentiometers connected to a microcomputer controlled data acquisition system. These devices were connected close to the web-bottom flange intersection as possible. Some early tests included vertical deflection measurements at the support rafters which were used to correct the vertical midspan deflection to that of the purlin only. These rafter deflections were found to be insignificant, so they were discontinued on later tests. Downward vertical deflections of the purlins were defined as positive. Positive horizontal deflections of the bottom flanges were defined to be an inward movement as shown in Figure 2.

TEST SPECIMENS AND PROCEDURE

Purlins for the first three specimens were roll-formed from the same steel coil during the same production run. The compression lip of the second and third specimens was narrowed using a portable electric shear fitted with a guide.

Purlins for the last specimen discussed were roll-formed at a later date. Dimensions and properties of the purlins are listed in Table 1. Each line in this table corresponds to one test, with each test given a specific test number. The first digit indicates the test number. The second character indicates that the test was a "C" section as opposed to a "Z" section. The third digit indicates the number of spans, which was one for the results presented in this paper. Tensile coupons were cut from the ends of the failed purlins and tested to obtain the yield strengths listed in this table. Each purlin was measured in at least three locations, and the resulting measurements were averaged to obtain the results shown in Table 1. The length of each element of the purlin was taken as the outside to outside distance between the intersections of lines tangent to each element as shown in Figure 3. All purlins were tested at a span of 20 feet (6.1 m).

Failure loads and working load deflections are given in Table 2. The predicted failure loads were calculated by multiplying the allowable load, which was calculated from the measured specimen dimensions and yield strength using the 1986 AISI specification, by the implied factor of safety of 1.67. The experimental failure load was defined as the load at which complete failure occurred. All failures were characterized by severe local buckling of the compression lip and flange. The predicted vertical deflections were calculated using the measured section properties and the allowable load described above. The experimental deflections listed are the deflections measured while the specimens were loaded to the same allowable load.

A uniformly distributed load was applied to each test specimen using concrete blocks placed on the decking. The average weight of each block was determined by weighing randomly selected blocks. This weight was used along with the average number of block per length of purlin to determine the load applied. The load was applied in increments which varied from one complete block per foot (0.305m) of purlin length during the early stages of the test to one block every four or eight feet (1.2m or 2.4m) as the failure load was approached. After each load increment was placed, the specimen was allowed time to stabilize and the deflection data was stored. Real-time plots of the load versus deflection results were displayed by the data acquisition system so that the load increments could be reduced as the failure load was approached.

TEST RESULTS

Figure 4 is a graph of the load versus deflection behavior of the four test specimens. Specimen 1C2 was the original design with rather wide stiffener lips which was predicted to be more efficient by the 1986 AISI specification. This specimen failed by premature local lip buckling and subsequent local flange buckling. Specimens 1C3 and 1C4 were from the same batch of purlins, with their top lips trimmed approximately 1/8 and 1/4 inches (3.2 and 6.4mm) respectively. By comparing the load versus deflection curves from these three tests, it can be seen that as material is removed from the compression lip, the strength of the section is increased. This is the opposite trend than predicted by the 1986 AISI specification.

After the tests of specimens 1C2, 1C3, and 1C4, another section was designed which uses the same width of steel sheet to make a purlin with the same depth, wider flanges, and narrower lips than the first design. Test specimen 1C5 was constructed of these sections and the resulting load versus displacement behavior is plotted in Figure 4. By comparing this curve to those of the earlier specimens, it can be seen that the later section is stronger and therefore more efficient.

COMPARISON OF CODE PREDICTIONS AND EXPERIMENTAL RESULTS

As stated previously, the 1986 AISI specification appears to over-predict the capacity of sections with wide compression lips. This problem was not recognized as a weakness of the previous, 1980, specification. To compare the effects of the two code provisions on predicted purlin capacity, sections with the same geometry and yield stress as the first test specimens except with varying compression lip widths were analyzed using both specifications. The resulting capacity predictions for a 20 foot (6.1m) span are plotted versus compression lip width to thickness (D:t) ratio in Figure 5. In this figure the 1986 code is seen to predict smaller bending capacities than the 1980 code for sections with traditional lip widths, and larger bending capacities for sections with wider lips.

Also shown in Figure 5 are the test results from specimens 1C2, 1C3, and 1C4. It can be seen that these test results follow the predictions given by the 1980 AISI specification in the region of large D:t ratios. It is believed that if additional tests with smaller D:t ratios were conducted, the results would follow the predictions of the 1986 AISI specification, as the specification was compared with a significant number of previous purlin test results on specimens in that D:t range before adoption.

SUMMARY AND CONCLUSIONS

Test results are given which show that the 1986 AISI specification predicts unconservatively large capacities for purlins with wide compression flange stiffener lips. Experimental results indicate that sections with narrower lips, which are predicted to have a lower capacity by the 1986 specification, actually had a higher capacity. This behavior of the experimental results is consistent with the previous (1980) specification and also work done by Desmond, Pekoz, and Winter (3), where lip width to flange width (D:W) ratios larger than 0.4 were found to cause destabilization of the compression flange due to premature buckling of the lip.

From these observations, it is concluded that the 1986 AISI specification should be amended to properly address the strength of sections with wide stiffener lips. One possible solution, which is currently suggested by the AISI code committee, is to limit the stiffener width to thickness ratio, D:t, to not more than 14. Another parameter which might be used to avoid this problem is to limit the stiffener width to flange width, D:w, to not more than 0.4 or 0.45. It is recommended that work on this problem consider both parameters to find the most appropriate one. It is also recommended that the AISI code committee's recommendation of limiting lip D:t ratios to not more than 14 be followed until the code is ammended to address this problem.

TABLE 1. MEASURED DIMENSIONS AND PROPERTIES OF PURLINS TESTED

	TOP			BOTTOM					
TEST NUMBER	LIP WIDTH D_C in. (mm)	LIP ANGLE Q_C deg. (mm)	FLANGE WIDTH W_C in. (mm)	LIP WIDTH D_T in. (mm)	LIP ANGLE Q_T deg. (mm)	FLANGE WIDTH W_T in. (mm)	DEPTH H in. (mm)	THICKNES T in. (mm)	YIELD STRESS Fy ksi (MPa)
1C2	1.063 (27.0)	86.5	2.313 (58.8)	1.063 (27.0)	87.0	2.313 (58.8)	8.000 (203)	0.061 (1.55)	53.9 (372)
1C3	0.969 (24.6)	88.5	2.313 (58.8)	1.094 (27.8)	85.5	2.313 (58.8)	8.000 (203)	0.061 (1.55)	53.9 (372)
1C4	0.844 (21.4)	88.5	2.313 (58.8)	1.094 (27.8)	85.5	2.313 (58.8)	8.000 (203)	0.061 (1.55)	53.9 (372)
1C5	0.875 (22.2)	88.5	2.500 (63.5)	0.938 (23.8)	89.5	2.500 (63.5)	7.938 (202)	0.063 (1.60)	60.0 (414)

TABLE 2. MEASURED AND PREDICTED TEST LOADS AND DEFLECTIONS

	PREDICTIONS		EXPERIMENTAL			
TEST NUMBER	Pult plf (N/m)	VERT. Δall in. (mm)	Pult plf (N/m)	VERT. Δall in. (mm)	HORZ. Δmax in. (mm)	Pult (exp) / Pult (pred)
1C2	168.4 (2459)	1.48 (37.6)	144.3 (2107)	1.47 (37.3)	0.63 (16.0)	0.857
1C3	169.7 (2478)	1.48 (37.6)	156.0 (2278)	1.49 (37.8)	1.21 (30.7)	0.919
1C4	162.8 (2377)	1.45 (36.8)	161.6 (2359)	1.44 (36.6)	1.23 (31.2)	0.993
1C5	187.6 (2739)	1.64 (41.7)	191.8 (2800)	1.52 (38.6)	0.73 (18.5)	1.022

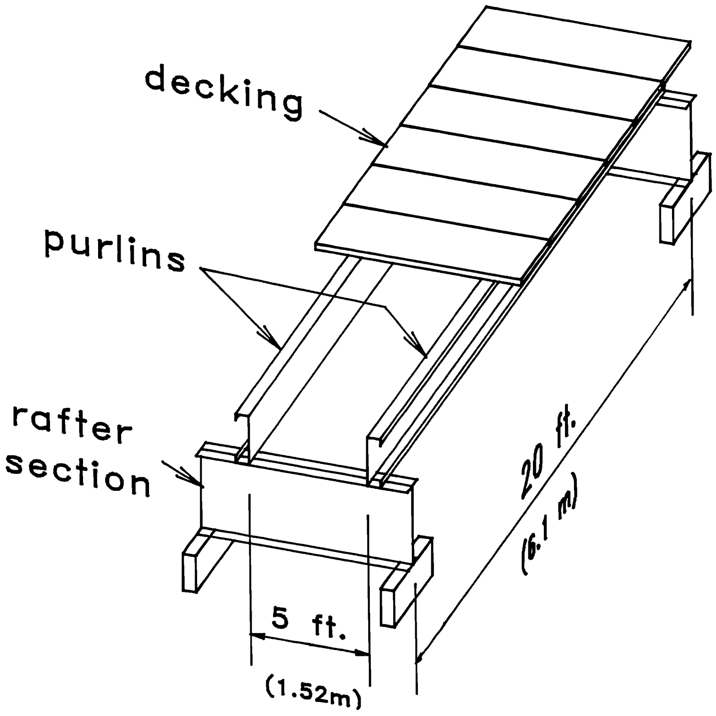

Figure 1. Test specimen and supports.

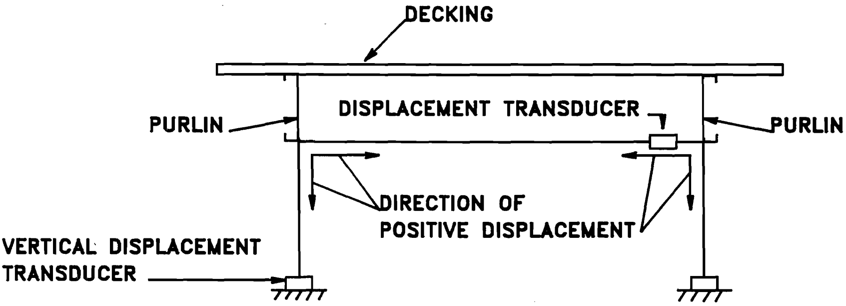

Figure 2. Displacement instrumentation.

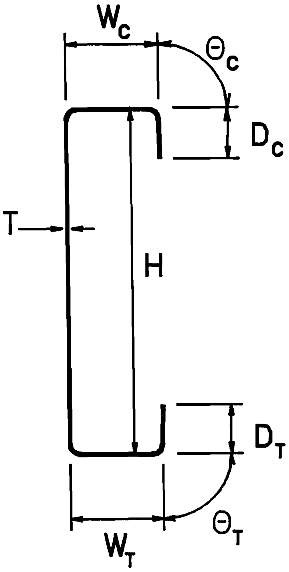

Figure 3. Section dimensions measured.

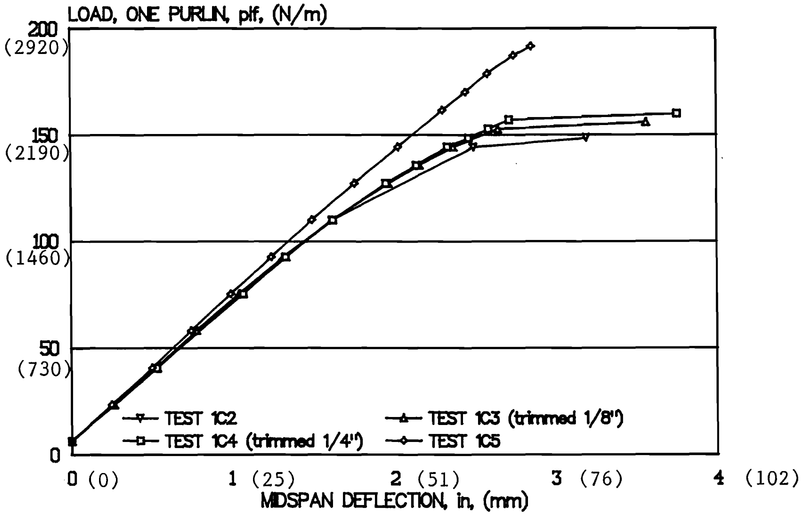

Figure 4. Experimental load vs. deflection results.

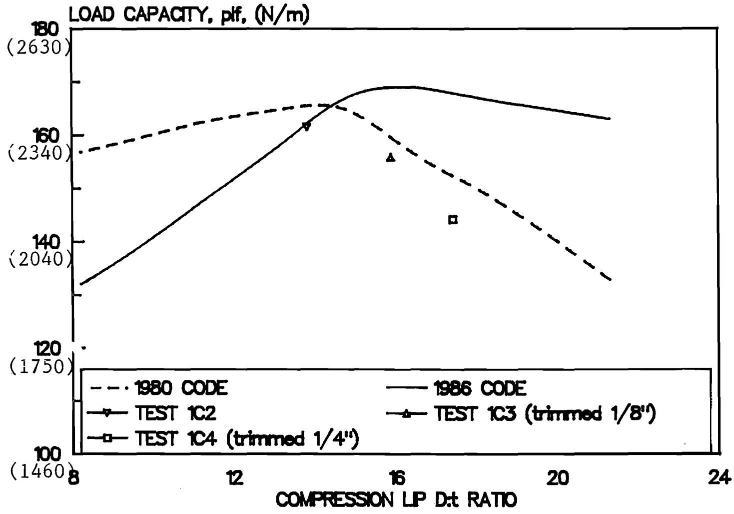

Figure 5. Effect of compression lip width on purlin capacity.

APPENDIX -- REFERENCES

1 American Iron and Steel Institute, (1986). Specification for the Design of Cold-Formed Steel Structural Members August 19, 1986, 1st Printing, W.P. Reyman Associates, INC. New York.

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3 Desmond, T. P., Pekoz, T., and Winter, G. (1981) "Edge Stiffeners for Thin-Walled Members." Journal of the Structural Division, ASCE, Vol. 107, NO.ST2, February, 1981.