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Estimating Uplift Capacity of Light Steel Roof System

By R. A. LaBoube,[1] Member, ASCE

Introduction

The economy of a preengineered metal building is due much in part to the favorable strength to weight ratio of its roof system. A typical light steel roof system is composed of a roof panel, cold-rolled from 24-gage or 26-gage sheet steel, attached by screws through the panel to a structural member. The structural member, or purlin, is roll-formed from sheet steel, 0.06–0.12-in. (1.5–3-mm) thick, having either a *C*- or *Z*-shaped cross section (Fig. 1); the purlin span typically ranges from 20 ft to 30 ft (6–9 m).

This paper presents an emperically based design approach for evaluating the load capacity of a light steel roof system subjected to wind uplift loading.

Moment-Capacity Evaluation

Because the tension flange of the purlin is attached to a roof sheet by a mechanical fastener, i.e., a self-drilling or self-tapping screw, the purlin will have some resistance to lateral translation or twist. Therefore, the nominal moment strength, M_n, may be expressed as a reduction in the full moment capacity by the following equation:

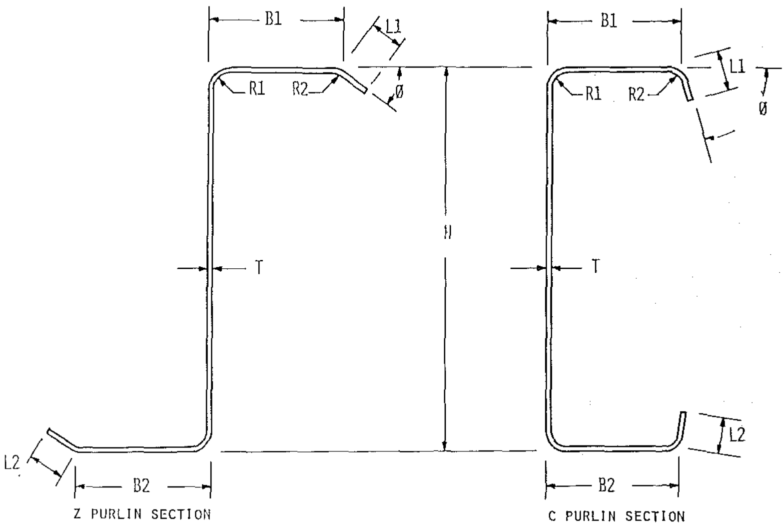

FIG. 1. Typical Purlin Cross Sections

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$$M_n = R\,M_y \qquad (1)$$

where $M_y = S_e F_y$; S_e = the elastic section modulus of the effective section calculated in accordance with the AISI specification (*Cold-formed* 1989) when the extreme compression fiber is at the yield stress of the material, F_y; and R = a factor that accounts for the reduction in moment capacity of the section from the full yield moment.

Summary of Test Results

The factor R is an empirical quantity that reflects the relationship between the tested moment capacity, M_t, and the yield moment capacity, M_y, i.e., $R = M_t/M_y$. The tested moment capacity was calculated using the failure load in conjunction with linearly elastic beam theory. This value of R varies with the purlin cross-section type, i.e., C- or Z-shape, and the member boundary conditions, i.e., simple versus continuous span.

A total of 25 full-scale tests were conducted for purlin roof systems consisting of simple span members having tension flanges attached to a deck or sheathing, and compression flanges laterally unbraced. The test procedure and test parameters for 16 test specimens have been discussed by Pekoz and Soroushian (1982). Additional tests were conducted by the author, and are summarized in Table 1.

Table 2 lists the corresponding R value for each specimen. For Z-shaped members, the mean value of R is 0.51, and the standard deviation is 0.06, whereas for the C-shaped members, the mean and corresponding standard deviations for R are 0.46 and 0.12, respectively. For the C-section data, one test specimen, the C 7.00 × 0.075, developed an R value that was significantly greater than the other data. Because this data point was skewing the mean and standard deviation, it was omitted from the evaluation. The resulting mean and standard deviation are 0.42 and 0.04.

A total of 19 full-scale, continuous span, purlin systems were tested. These full-scale tests considered both C- and Z-shaped purlin sections, continuous over three spans and affixed to roof panels (LaBoube et al. 1988). Table 3 presents the tested R value for each of the 19 test specimens. For Z-shaped members the mean value of the tested R is 0.70 with a standard deviation

TABLE 1. Cross-Section Dimensions

Specimen (1)	t (in.) (2)	H (in.) (3)	$B1$ (in.) (4)	$B2$ (in.) (5)	$L1$ (in.) (6)	$L2$ (in.) (7)
Z9.50 × 0.071	0.071	9.50	2.75	2.81	0.88	0.88
Z9.50 × 0.071	0.071	9.50	2.75	2.75	0.81	0.81
Z9.63 × 0.071	0.071	9.63	2.81	2.75	0.75	0.81
Z9.44 × 0.106	0.106	9.44	2.88	2.81	0.81	0.81
Z9.56 × 0.106	0.106	9.56	2.81	2.88	0.88	0.81
C9.56 × 0.071	0.071	9.56	2.81	2.81	0.75	0.81
C9.50 × 0.071	0.071	9.50	2.81	2.75	0.81	0.81
C9.50 × 0.106	0.106	9.50	2.81	2.81	0.81	0.81
C9.50 × 0.106	0.106	9.50	2.88	2.81	0.81	0.81

Notes: See Fig. 1 for definition of symbols; all corner radii are 0.313 in; for all edge stiffeners, ϕ = 90°; F_y = 64.47 ksi for all specimens; 1 in. = 25.4 mm; 1 ksi = 6.895 MPa.

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TABLE 2. *R* **Values for Simple Span Tests**

Specimen (1)	*R* (2)
$Z8.00 \times 0.059$	0.49[a]
$Z7.92 \times 0.060$	0.49[a]
$Z8.06 \times 0.063$	0.54[a]
$Z7.97 \times 0.070$	0.50[a]
$Z8.00 \times 0.075$	0.55[a]
$Z8.03 \times 0.088$	0.55[a]
$Z8.00 \times 0.089$	0.51[a]
$Z7.94 \times 0.114$	0.56[a]
$Z7.93 \times 0.115$	0.42[a]
$Z9.63 \times 0.062$	0.49[a]
$Z9.45 \times 0.063$	0.54[a]
$Z9.58 \times 0.106$	0.66[a]
$Z9.49 \times 0.109$	0.45[a]
$Z9.50 \times 0.071$	0.44[b]
$Z9.50 \times 0.071$	0.49[b]
$Z9.63 \times 0.071$	0.43[b]
$Z9.44 \times 0.106$	0.51[b]
$Z9.46 \times 0.106$	0.51[b]
Mean for Z	0.51
Standard deviation for Z	0.06
$C7.00 \times 0.075$	0.73[a]
$C9.00 \times 0.075$	0.47[a]
$C9.00 \times 0.077$	0.41[a]
$C9.56 \times 0.071$	0.38[b]
$C9.50 \times 0.071$	0.36[b]
$C9.50 \times 0.106$	0.42[b]
$C9.50 \times 0.106$	0.45[b]
Mean for C	0.46
Standard deviation for C	0.12
Mean without $C7.00 \times 0.075$	0.42
Standard deviation without $C7.00 \times 0.075$	0.04

[a]Pekoz and Soroushian (1982) data.
[b]Table 1 data.

of 0.06, and for the C-shaped members, the mean and standard deviations are 0.61 and 0.05, respectively.

Design Provision

Based on the available full-scale test data, the following calculation method has been adopted by the AISI specification (*Cold-formed* 1989).

The nominal moment capacity of a C- or Z-shaped section loaded in the plane parallel to the web, with its tension flange attached to deck or sheathing and with its compression flange laterally unbraced shall be determined as follows:

$$M_n = R\, S_e\, F_y \quad \text{(2)}$$

where $R = 0.40$ for simple-span C section; 0.50 for simple-span Z sections;

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TABLE 3. R Values for Continuous Span Tests (LaBoube 1988)

Specimen (1)	R (2)
$Z9.50 \times 0.071$	0.72
$Z9.50 \times 0.101$	0.83
$Z9.50 \times 0.070$	0.72
$Z9.50 \times 0.100$	0.80
$Z9.50 \times 0.070$	0.67
$Z6.50 \times 0.059$	0.64
$Z6.50 \times 0.061$	0.65
$Z6.50 \times 0.060$	0.68
$Z6.50 \times 0.059$	0.70
$Z8.50 \times 0.085$	0.62
$Z8.50 \times 0.085$	0.69
$Z10.0 \times 0.083$	0.72
$Z8.50 \times 0.061$	0.72
$Z9.50 \times 0.067$	0.59
Mean	0.70
Standard deviation	0.06
$C9.00 \times 0.061$	0.60
$C7.00 \times 0.060$	0.68
$C8.50 \times 0.090$	0.64
$C8.50 \times 0.056$	0.54
$C8.50 \times 0.090$	0.61
Mean	0.61
Standard deviation	0.05

0.60 for continuous-span C sections; and 0.70 for continuous-span Z sections.

Because this calculation method is empirically based, its application must be limited to the scope of the test programs. Thus the specification provision is very specific that the method is limited to roof and wall assemblies that meet the conditions of the test programs.

Although (2) is limited in application, the test parameters were chosen such that a majority of the roof systems using a through-fastened roof panel attached to a C- or Z-shaped cold-formed steel member could be evaluated by the equation. However, recognizing that there will be exceptions, the specification also permits performance of full-scale tests, or application of another rational analysis procedure, when a parameter of the roof system falls outside any of the stated test limits.

CONCLUSIONS

The behavior of a light steel roof system is a very complex phenomenon because of the numerous parameters, i.e., purlin shape and stiffness, panel stiffness, fastener attachment of the purlin to the panel, and the interaction of these parameters. The calculation of the strength of such a roof system does not easily lend itself to routine design. Therefore, a simplified, empirical design method has been developed that can be easily applied in the design office. The design method is applicable to a majority of the roof systems in the United States that are constructed using cold-formed steel

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panels and purlin sections, when the panel is through-fastened to the purlin using either a self-drilling or self-tapping screw.

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Appendix I. References

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Appendix II. Notations

The following symbols are used in this paper:

M_n = nominal moment capacity;
M_t = tested moment capacity;
M_y = yield moment; and
R = moment reduction factor.

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