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STRENGTH EVALUATION OF STRUT-PURLINS

by

Gerald L. Hatch[1], *W. Samuel Easterling*[2], *and Thomas M. Murray*[3]

SUMMARY

Diaphragm braced strut-purlins are commonly used in the roof systems of metal buildings. However, the design problem of combined uplift and axial loads on these members is not adequately addressed in the 1986 AISI Specification. The objective of this paper is to provide experimental evidence that strut-purlins can be designed with an existing interaction equation.

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INTRODUCTION

Strut-purlins are commonly used as secondary framing members which exist as part of the wind bracing system in the roof structure of metal buildings. In addition to resisting gravity loads, strut-purlins act in resisting uplift and axial loads introduced by the wind. With this latter type of loading, the bottom flange of the purlin is in compression and has little lateral bracing. The rotational support provided by the purlin to roof deck connection provides some limited lateral bracing.

Metal building roof systems are typically designed utilizing guidelines from the Metal Building Manufacturers Association (MBMA) (Low Rise 1986) and specification requirements of the American Iron and Steel Institute (AISI) (Specification 1986). MBMA recognizes the uplift and axial loading condition but does not provide a method of analysis. AISI does not yet recognize this loading combination.

The objective of this paper is to present design criteria, with supporting experimental data, for strut-purlins subject to uplift and axial loads.

DEVELOPMENT OF DESIGN CRITERIA

The most logical choice of models to reflect the beam-column response of strut-purlins is an interaction equation. Interaction equations are simple, convenient and have a broad range of application. They have been analytically and experimentally proven to predict capacity for elastic, inelastic and torsional flexural buckling problems of stand-alone and intermittently-braced beam-columns with various end conditions. The research in this paper is presented to broaden that range to include diaphragm-braced strut-purlins subject to uplift and axial loads.

The current AISI interaction equation (C5-1) is the basis of the proposed design criteria:

$$\frac{P}{P_a} + \frac{C_{mx}M_x}{M_{ax}\alpha_x} + \frac{C_{my}M_y}{M_{ay}\alpha_y} \leq 1.0 \qquad \text{(AISI C5-1)}$$

with

P = Applied axial load

M_x and M_y = Applied moments with respect to the centroidal axes

P_a = Axial load capacity

M_{ax} and M_{ay} = Moment capacity about the centroidal axes

$1/\alpha_x$ and $1/\alpha_y$ = Magnification factors

= $1/[1 - (\Omega_c P/P_{cr})]$

Ω_c = Factor of safety used in determining P_a

$$P_{cr} = \frac{\pi^2 E I_b}{(k_b L_b)^2}$$

I_b = Moment of inertia of full, unreduced cross section about axis of bending

L_b = Actual unbraced length in the plane of bending

k_b = Effective length factor in the plane of bending

C_{mx} and C_{my} = Moment reduction factors = 1.0 for this study

For the purpose of this study, the third term of the equation is neglected, that is constrained bending is assumed. The axial load, P_a, the Euler buckling load, P_{cr}, and the strong axis moment capacity, M_{ax}, were determined as follows.

The axial load, P_a, is calculated using the method defined in the work by Simaan (1973). He developed a general procedure and applied it specifically to metal wall studs. Simaan's method is complicated and requires the aid of a computer program to be of practical use. The method also relies on experimental data obtained from shear rigidity and rotational stiffness tests. For the same components, the rotational stiffness can vary widely, significantly affecting the results. This is because the rotational stiffness is strongly influenced by the location of the purlin-to-deck fasteners. Other factors that influence rotational stiffness are fastener type and spacing, and type of insulation, decking and purlin used. These factors are discussed in detail by LaBoube (1986).

The elastic solution for P_a is substituted for P_{cr} in the amplification factor of the interaction equation. The factor of safety, Ω_c, is taken as 1.0.

The uplift moment capacity, M_{ax} of the purlin and decking system is a complicated analytical problem involving the torsional-flexural buckling mode. A number of methods have been developed to predict uplift moment capacity of C- and Z-purlins, such as the work by Pekoz (1973). This method is complicated and requires the aid of a computer program to be of practical use. A method developed by Pekoz and Soroushian (1982), presents simplified design equations based on allowable stresses to predict uplift moment capacity.

The method adopted for this research is simpler still and is presented in the 1989 revision to Section C3.1.3 of the AISI specification. This method defines uplift moment capacity as a fraction of the fully laterally supported moment capacity:

$$M_{ax} = R\, S_e\, F_y$$

with

R = 0.4 for single span C sections

= 0.5 for single span Z sections

S_e = Effective section modulus

F_y = Design yield stress

To verify the adequacy of the proposed criteria a series of experimental tests were conducted. One series was used to verify the method for determining the axial load capacity without uplift loading and three series were used to verify combined axial load and uplift effects.

EXPERIMENTAL PROGRAM

Eight axial load only and 16 combined axial and uplift loading tests were conducted. Purlin spans ranging from 15 to 25 ft. (4.5 to 7.6 m) were used. Purlin depths ranged from 7 to 10 in. (178 to 254 mm) with thicknesses ranging from 0.08 to 0.104 in. (2 to 2.6 mm). Two facing purlin lines on 5 ft. centers were used in all tests. The purlins were simply supported in vertical bending. Some degree of horizontal bending and torsional restraint was present because of the method used to apply axial loads.

Decking, 7 ft. (2.1 m) wide, was fastened to the purlins with self- drilling screws. The entire roof system was constructed upsidedown in a sealed chamber. Air was evacuated to apply simulated uplift loading.

Axial loads were applied using spreader beams located over the supports. A load chain was installed between the spreader beams to pull the beams together, thus applying the axial load. The load chain consisted of loading straps, a calibrated load cell and a hydraulic ram as shown in Figure 1.

For the axial load only tests, load was applied incrementally to failure of the system. For the combined axial and uplift loading tests, an uplift load was applied incrementally to a pre-selected level and held constant for the remainder of the test. The axial load was then applied incrementally to failure of the system.

AXIAL TEST LOAD RESULTS

To verify the adequacy of Simaan's method for strut-purlin systems, a series of verification tests were performed and the results compared to theoretical calculations. The necessary shear rigidity data was obtained from the deck manufacturer. Rotational stiffness values were determined by test for each type of purlin and deck combination used.

The results of the experimental evaluation of the Simaan method for axial loaded only strut-purlins is summarized in Table 1. The ratios of actual to theoretical axial capacity are generally in the same range as those reported by Simaan for metal wall studs, indicating that his method is general enough to be applicable to strut-purlins.

The actual failure loads ranged between 87-107% of predicted values with one exception. One test failed at 82% of the predicted value.

In the Simaan method for determining axial capacity, the rotational stiffness of the connection is assumed constant along the member. To obtain constant rotational stiffness, the fasteners must be located in the same relative location the entire length of the flange. This will not occur in actual construction unless the purlin flanges are pre-punched at screw locations. In the axial load tests, the actual screw locations were measured and an average screw location was used to determine the allowable axial load.

Also, it was found, that the Simaan procedure, predicts axial capacities varying by as much as 95% based solely on the effect of fastener location on the flange of the purlin. Thus, the sensitivity of fastener location explains the scatter in the experimental results.

INTERACTION TEST RESULTS

Three series of interaction tests were performed to verify the adequacy of the proposed interaction equation. Two series were conducted using Z-purlins (nominally 8 in. and 10 in. deep) and the third series used nominally 10 in. deep C-purlins. The results are plotted along with interaction curves in Figures 2 through 6.

Each figure shows two interaction curves; one with and one without the moment amplification factor. The latter was plotted as reference. The interaction curves in Figures 2, 3 and 4 were constructed using P_a and M_{ax} values determined experimentally from tests conducted with axial load and no uplift loading and with no axial load and full uplift loading, respectively. The curves in Figures 5 and 6 were constructed using P_a values from Simaan's method and M_{ax} values from the 1989 revision to the AISI Specification Section C3.1.3.

Figures 2, 3 and 4 show conservative, but reasonable, results with respect to predicting failure.

Figures 5 and 6 show more conservative results, indicating that the analytical methods for determining P_a and M_{ax} are themselves conservative.

Also, error is introduced into the data from estimates of rotational stiffness, variation from assumed uplift moment capacity, conservative inaccuracy of the interaction equation and unavoidable eccentric loading of the C-purlins. Uplift moment capacity also relies on the rotational stiffness of the connection for part of its strength. Therefore, the uplift moment capacity can differ from the predicted value, based on screw location, which in turn influences the predicted axial failure load.

In all tests, the axial load is applied through the web of the purlins. For C-sections, this means an eccentric axial load is being applied about the Y-axis since the centroid does not lie on the web. On the other hand, the purlin is assumed simply supported with respect to Y-axis bending but actually has some degree of fixity. Based on the results of the axial tests, it is thought that these two effects tend to cancel each other.

CONCLUSIONS

This study has shown that the current AISI interaction equation, Simaan's method for determining the allowable axial load capacity and the 1989 revision to Section C3.1.3 of the AISI Specifications, together provide a rational design method for strut-purlins. The allowable axial load of a strut-purlin is significantly influenced by the rotational restraint of the connection. With this in mind and given the fact that strut-purlins will be erected with varying degrees of rotational restraint, even with the same components, a conservative value of rotational restraint must be assumed in design.

ACKNOWLEDGEMENTS

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APPENDIX -- NOTATION

C_{mx} and C_{my} = Moment reduction factors

E = Modulus of elasticity

F_y = Design yield stress

I_b = Moment of inertia of full, unreduced cross-section about axis of bending

k_b = Effective length factor in the plane of bending

L_b = Actual unbraced length in the plane of bending

M_x and M_y = Applied moments with respect to the centroidal axes

M_{ax} and M_{ay} = Moment capacity about the centroidal axes

P = Applied axial load

P_a = Axial load capacity

P_{cr} = $\dfrac{\pi^2 E I_b}{(k_b L_b)^2}$

R = Reduction factor

S_e = Effective section modulus

$1/\alpha_x$ and $1/\alpha_y$ = Magnification factors, $1/[1 - (\Omega_c P/P_{cr})]$

Ω_c = Factor of safety used in determining P_a

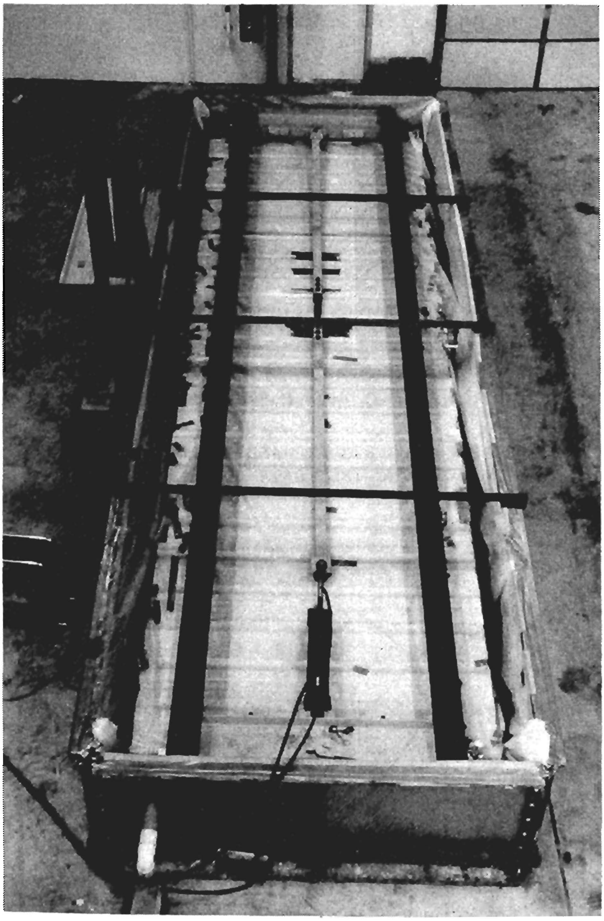

FIGURE 1. PHOTOGRAPH OF TEST SET-UP

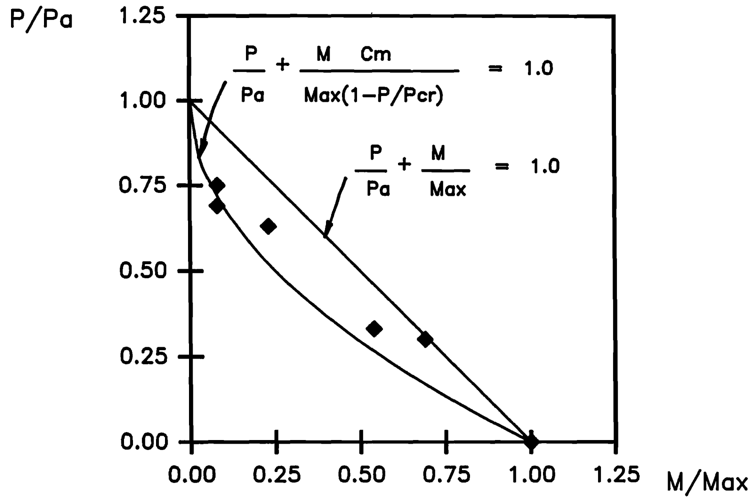

FIGURE 2. TEST RESULTS AND INTERACTION CURVE USING TEST DATA FOR 8 IN. Z-PURLINS

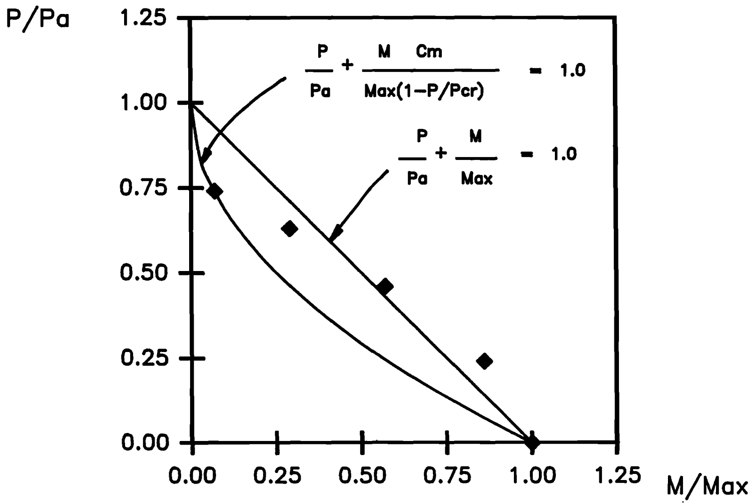

FIGURE 3. TEST RESULTS AND INTERACTION CURVE USING TEST DATA FOR 10 IN. Z-PURLINS

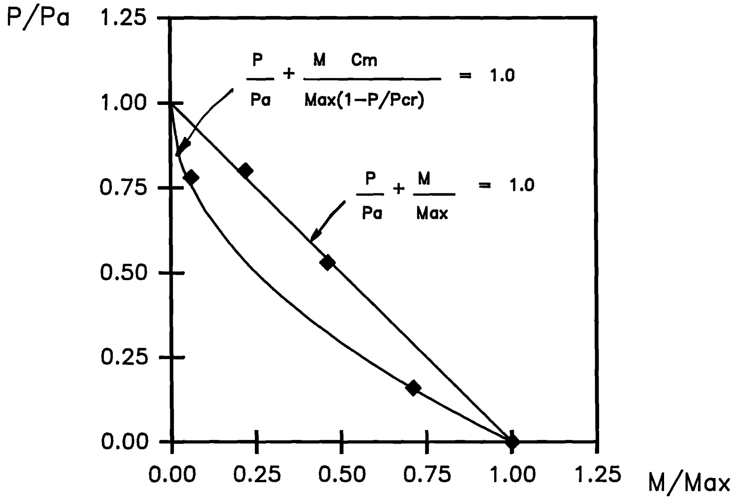

FIGURE 4. TEST RESULTS AND INTERACTION CURVE USING TEST DATA FOR 10 IN. C-PURLINS

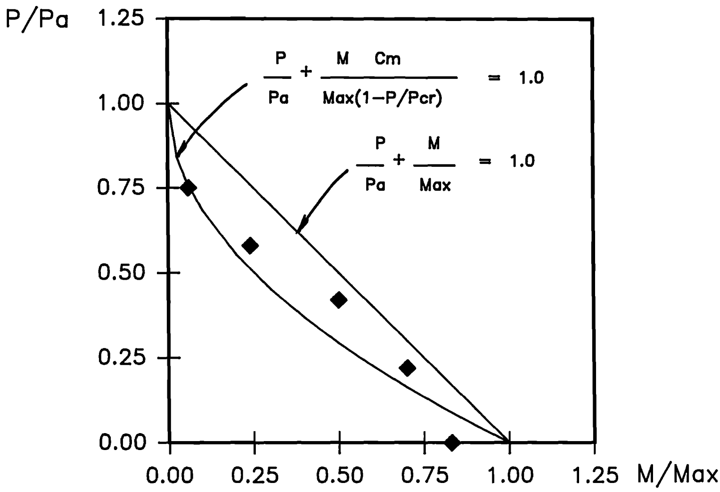

FIGURE 5. TEST RESULTS AND INTERACTION CURVE USING THEORETICAL DATA FOR 10 IN. Z-PURLINS

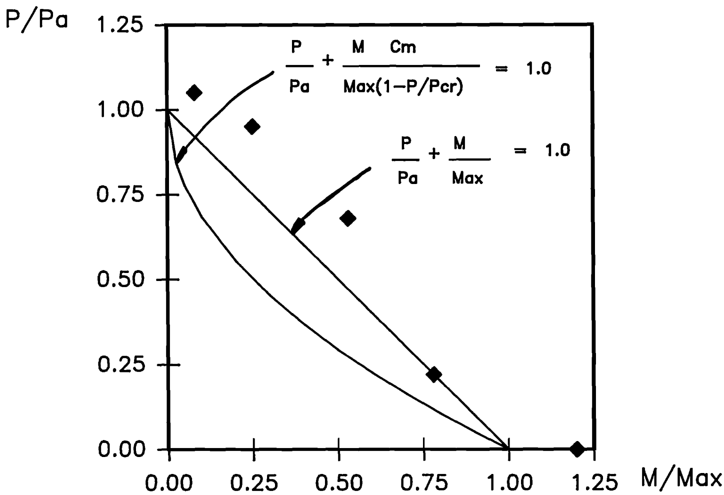

FIGURE 6. TEST RESULTS AND INTERACTION CURVE USING THEORETICAL DATA FOR 10 IN. C-PURLINS