

Design Example for Analytical Modeling of a Curtainwall and Considering the Effects of Bridging (All-Steel Design Approach)

RESEARCH REPORT RP18-2

August 2018

Committee on Specifications
for the Design of Cold-Formed
Steel Structural Members



American Iron and Steel Institute

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DESIGN EXAMPLE FOR ANALYTICAL MODELING OF A CURTAINWALL AND CONSIDERING THE EFFECTS OF BRIDGING (ALL-STEEL DESIGN APPROACH)

INTRODUCTION

This example illustrates how to apply the provisions in AISI S100-16, *North American Specification for the Design of Cold-Formed Steel Structural Members*, in a practical example by analytically modeling a curtainwall and considering the effects of bridging. The modeling procedure may also be applicable to other framing systems. The following two software packages are used in this example:

1. MASTAN2, a structural analysis program, which is capable of considering warping torsion and also second-order effects. MASTAN2 is used to predict the elastic critical global buckling force, the warping torsion present in the studs, and also the second-order forces in the bridging elements. MASTAN2 can be downloaded from www.mastan2.com.
2. CUFSM, a cold-formed steel member finite strip analysis program. CUFSM is utilized in this example to determine the elastic critical local and distortional buckling forces. CUFSM can be downloaded from www.ce.jhu.edu/~bschafer/cufsm.

This example is based on AISI S100-16. All symbols used in the example are defined in AISI S100-16 unless otherwise noted. Input files for the software analyses are provided in Appendix 1.

The materials set forth herein are for general information only. They are not a substitute for competent professional advice. Application of this information to a specific project should be reviewed by a registered professional engineer.

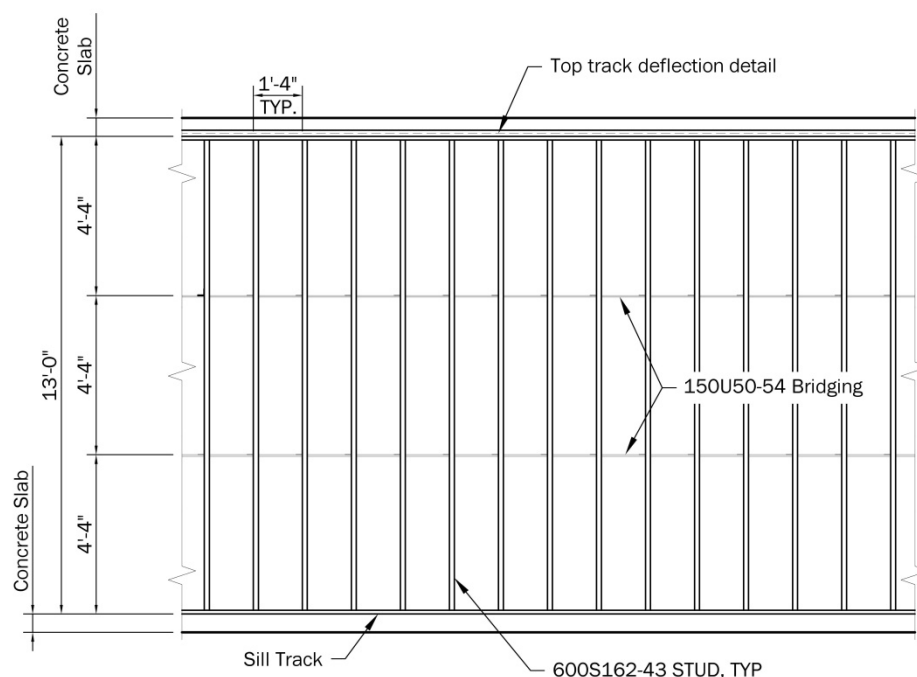


Figure 1: Typical Wall Elevation

Given:

1. Wind bearing infill wall with an unsheathed design approach as shown in Figure 1.
2. Steel: $F_y = 33$ ksi, $F_u = 45$ ksi
3. Sections: 600S162-43 studs and 150U50-54 bridging as shown above with section properties per Table 1.
4. Each stud is subject to a uniform wind load applied in line with the web centerline of 37.3 plf using ASD load combinations.
5. Gravity load on wall is negligible.
6. Bridging is anchored at its ends and provides bracing to the studs.
7. Holes are present only at bridging locations and have a length of 4.5 in. and a width of 1.5 in.

Required:

1. Using MASTAN2 and AISI S100 Section F2.1.1, perform an analysis to determine the critical elastic lateral-torsional buckling stress for a typical stud.
2. Using CUFSM, perform an analysis to determine the critical elastic local and distortional buckling stresses for the studs.
3. Using MASTAN2, determine the warping torsion present in the studs due to the shear center eccentricity.
4. Verify the strength of the studs considering warping, bracing from the bridging, and the critical elastic buckling stresses.
5. Using MASTAN2, perform a second-order analysis to determine the maximum moment in the bridging.

Table 1: Cross Section Properties

Property	600S162-43	150U50-54
A (in. ²)	0.447	0.130
r_y (in.)	0.576	0.146
r_o (in.)	2.58	0.625
J (in. ⁴)	0.000303	0.000138
C_w (in. ⁶)	1.10	0.000915
S_f (in. ³)	0.772	0.0521
m (in.)	0.670	0.164
I_x (in. ⁴)	2.32	0.0390
$C_{w,net}$ (in. ⁶)	1.09	N/A

Solution:

1. Critical Elastic Global (Lateral-Torsional) Buckling Stress

Determination of the critical elastic lateral-torsional buckling stress, F_{cre} , is required in order to evaluate the limit state of yielding and global buckling according to AISI S100 Section F2. F_{cre} may be determined using the theoretical equations in AISI S100 Section F2.1.1 or by an analysis in accordance with AISI S100 Appendix 2, Section 2.2. Both methods are evaluated in the following sections and comparisons are made.

1a. AISI S100 Section F2.1.1 Method

The equations contained in AISI S100 Section F2.1.1 apply to singly- or doubly-symmetric sections bending about their symmetric axis such as the studs in this example. The bridging is considered to brace the stud and the effect of moment gradient is accounted for using Eq. F2.1.1-2. By calculations not shown, the controlling unbraced segment is the unbraced segment between the bridging lines. The moment gradient factor, C_b , is calculated based on a unit uniformly distributed load, w , for the middle segment as follows:

$$\begin{aligned}
 M_{\max} &= (1/8)wL^2 \\
 M_A &= \frac{w(5L/12)}{2}(L - 5L/12) = (35/288)wL^2 \\
 M_B &= (1/8)wL^2 \\
 M_C &= \frac{w(7L/12)}{2}(L - 7L/12) = (35/288)wL^2 \\
 C_b &= \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C} = \frac{12.5(1/8)}{2.5(1/8) + 3(35/288) + 4(1/8) + 3(35/288)} = 1.01
 \end{aligned}$$

(Eq. F2.1.1-2)

Since the anchored bridging is considered to provide both lateral and torsional bracing:

$$\begin{aligned}
 K_y L_y &= K_t L_t = 52.0 \text{ in.} \\
 \sigma_{ey} &= \frac{\pi^2 E}{(K_y L_y / r_y)^2} = \frac{\pi^2 (29500)}{(52.0 / 0.576)^2} = 35.72 \text{ ksi}
 \end{aligned}$$

(Eq. F2.1.1-4)

$$\begin{aligned}
 \sigma_t &= \frac{1}{A r_o^2} \left[GJ + \frac{\pi^2 E C_w}{(K_t L_t)^2} \right] \\
 &= \frac{1}{(0.447)(2.58)^2} \left[(11300)(0.000303) + \frac{\pi^2 (29500)(1.10)}{(52.0)^2} \right] = 40.96 \text{ ksi}
 \end{aligned}$$

(Eq. F2.1.1-5)

$$F_{cre} = \frac{C_b r_o A}{S_f} \sqrt{\sigma_{ey} \sigma_t} = \frac{(1.01)(2.58)(0.447)}{0.772} \sqrt{(35.72)(40.96)} = 57.71 \text{ ksi}$$

(Eq. F2.1.1-1)

1b. AISI S100 Appendix 2, Section 2.2 Method

It is permitted to calculate the critical elastic lateral-torsional buckling stress using a numerical solution according to AISI S100 Appendix 2, Section 2.2. One such numerical solution is to

perform a global elastic buckling analysis using software that implements the finite element method. It is important that the formulation used by the software properly accounts for the interaction of bending and torsion as described in the user notes contained in AISI S100 Appendix 2, Section 2.2.

An analysis model is created in the software package MASTAN2 (Ziemian and McGuire, 2010) as shown in Figure 2 for a representative portion of the wall. In this model, the studs and the bridging are modeled using beam elements which have the capability to account for warping. Each of the studs are subdivided at 4 in. increments to facilitate the application of torques along the length of the stud. The studs are considered to have warping continuity along their length. Fixity at each end of the stud is released for flexural moments and warping torsion. However, each end of the stud is restrained for torsion and translation. The bridging is also considered to be continuous along its length. Torsion in the studs is able to be resisted by the bridging. Full, unreduced section properties are used in this analysis.

Holes are present only at the third-points of the studs where the bridging passes through the stud. The cumulative length of these holes relative to the overall length of the stud is small and therefore assumed to have a negligible effect on the global buckling of the stud. One rational approach of accounting for the effect of holes on global buckling is to assign net section properties to portions of the MASTAN beam elements where the holes exist. This method reflects the variation in stiffness along the member resulting from the holes. For this example, if 4 in. long holes would be added every 24 in., then every sixth, 4 in. element would contain the properties for the net section and the remainder of the elements would contain the properties for the gross section. However, analogous to the recommendations in AISI S100 Appendix 2, Section 2.3.4.1, $C_{w,net}$ would rationally be assigned to the whole member to account for the disruption in warping stiffness at the holes, especially since the warping continuity is relied upon in this analysis at the hole locations. For this example, the difference between C_w and $C_{w,net}$ is minimal and therefore neglected.

The nominal modulus of elasticity is used in this analysis (1.0E). No initial imperfection is considered. The uniform wind load is applied to each stud and an elastic buckling (elastic critical load) analysis is performed to determine the eigenvalue at which elastic buckling of the studs will occur when subjected to the uniform wind loads.

After the elastic buckling analysis is performed, the deflected shape for the first, lowest, buckling mode can be viewed (see Figure 3). It can be observed from the deflected shape that lateral-torsional buckling has occurred since nodal displacements exhibit both translation and rotation. It can also be observed from the deflected shape that the bridging was effective in restricting the movement of the stud where the bridging was attached to the stud. The applied load ratio (eigenvalue) given by MASTAN2 is the multiplier of the applied loading that corresponds to the global elastic buckling mode in the deflected mode shape. In this case, the multiplier for the lowest mode is 6.33. This value considers the effect of moment gradient, the bracing provided by the anchored bridging, and the continuity of the stud.

The maximum moment in the uniformly loaded, simply supported stud under the applied loading is calculated by:

$$M = wL^2/8 = (37.3)(13)^2/8 = 788.0 \text{ lb-ft} = 9.46 \text{ kip-in.}$$

$$M_{cre} = M(\text{Applied Load Ratio}) = (9.46)(6.33) = 59.88 \text{ kip-in.}$$

$$F_{cre} = M_{cre}/S_f = 59.88/0.772 = 77.56 \text{ ksi}$$

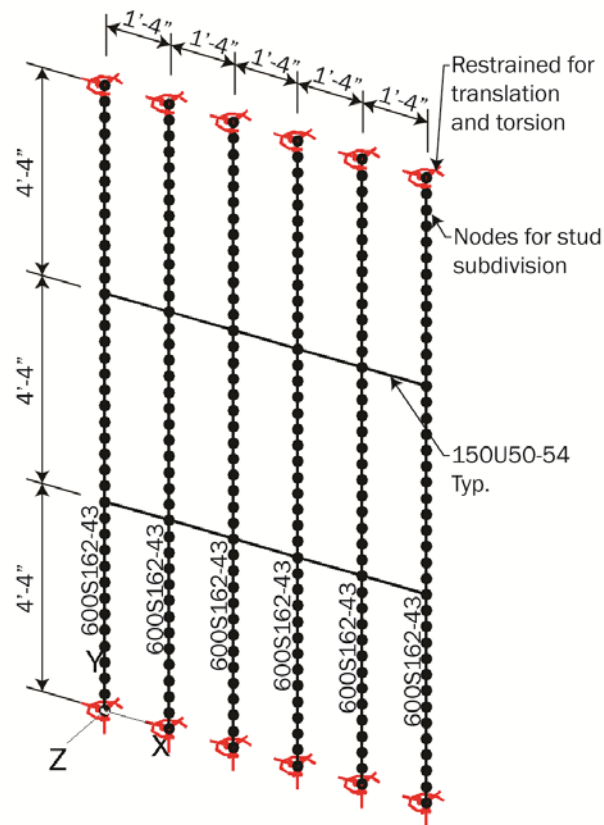


Figure 2: MASTAN2 Analysis Model

Deflected Shape: Elastic Critical Load, Mode # 1, Applied Load Ratio = 6.3335

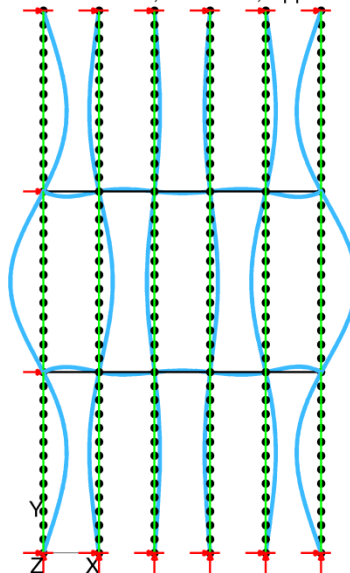


Figure 3: Lateral-Torsional Buckling - Elastic Buckling Analysis