DESIGN CONSIDERATIONS FOR FLEXURAL AND LATERAL-TORSIONAL BRACING

SUMMARY: Load bearing cold-formed/light gauge steel (CFS/LGS) framed walls are typically designed for a combination of axial and lateral out-of-plane (flexural) loading. Under this loading condition, common C-section studs may be susceptible to local, torsional, flexural, torsional-flexural, lateral-torsional or distortional buckling. The response performance of the stud depends on a number of parameters most notably how it is supported along its length (including its ends), the relative magnitudes of the applied loads and the distribution of these loads. This technical note discusses the behavior of the typical wall stud and provides some practical considerations for design of torsional-flexural and lateral-torsional bracing. Recommendations and considerations suggested in this technical note are done in accordance with acceptable practices and existing design documents.

Introduction:

The response of any structural member depends on, but is not limited to, the loads applied to or induced in the member, the member support conditions (along the length of the member), the cross-section configuration and the members material properties. In cold-formed/light gauge steel design, two of the most often realized loading conditions for framing members involve a combination of axial and bending (flexural) loads, or bending only. Current design guidelines for members under these loading conditions require, initially, separate analysis for each type of loading (axial and bending) separately. If overall buckling of the member is inhibited, failure of the section will be governed by the local and possibly distortional buckling behavior of the cross-sectional elements. Assuming, neither local or distortional buckling occurs, Figure 1 illustrates the theoretical overall behavior of the common C-sections under concentric axial compression and under bending. The more likely response of the

loaded C-section will involve a coupling of the local, distortional and overall buckling modes. Thus, it can be appreciated that the resulting response of the C-section member becomes relatively complex. This complex behavior is usually treated using some form of an interaction equation.

Overall failure modes for CFS/LGS C-section members in axial compression or bending

Figure 1
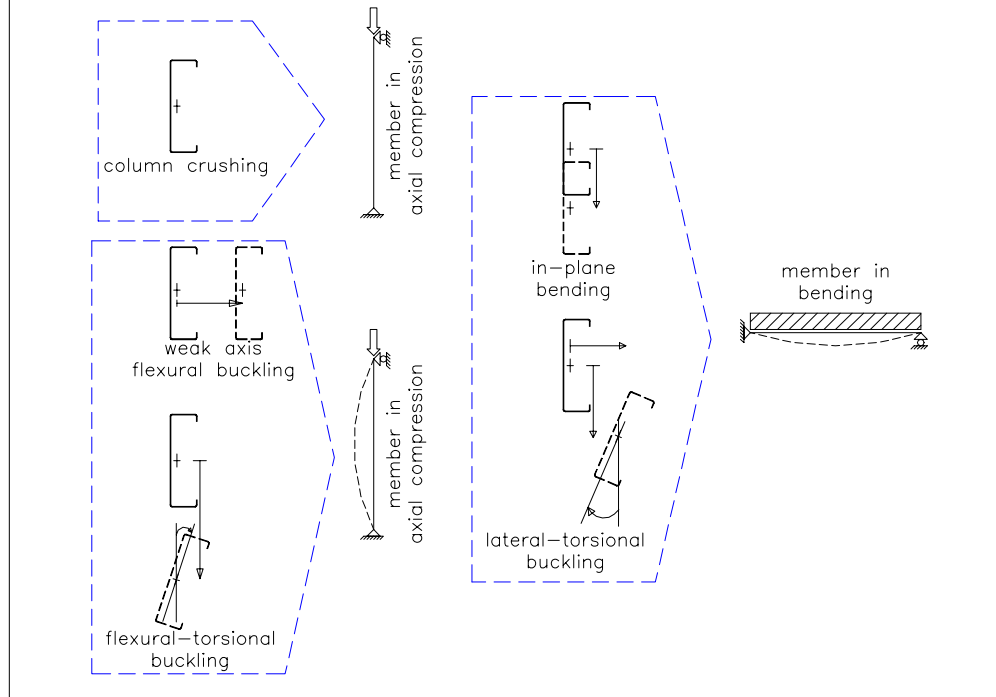
The 1996 AISI Specification for the Design of Cold-Formed Steel Structural Members, Section D4 (and associated Sections C3, C4 and C5), provides a basis for evaluating the strength of wall studs subjected to axial and bending, and combined axial and bending loads. The design equations in Section D4 for estimating the stud capacity are based on the assumption that sheathing is attached to both flanges of the stud. Section D4, however, also states that the effect of sheathing attached to the wall stud may be neglected in the calculation of the stud capacity. This allowance implies that the stud capacity may be computed on the basis of the requirements in Section C, with due consideration for the use of mechanical bracing.

The nominal capacities of a member will depend on the unbraced length of that member and the distribution of load (axial, shear and moment) in that unbraced length. The unbraced length is usually taken as the member length between brace points, per Section D3 of the AISI Specification. The "effective" unbraced length depends on the degree of rotational and lateral restraint (simple, partial or full) provided by the brace point support.

The common bracing schemes currently used in residential and commercial construction are illustrated in Figure 2. As shown in this figure,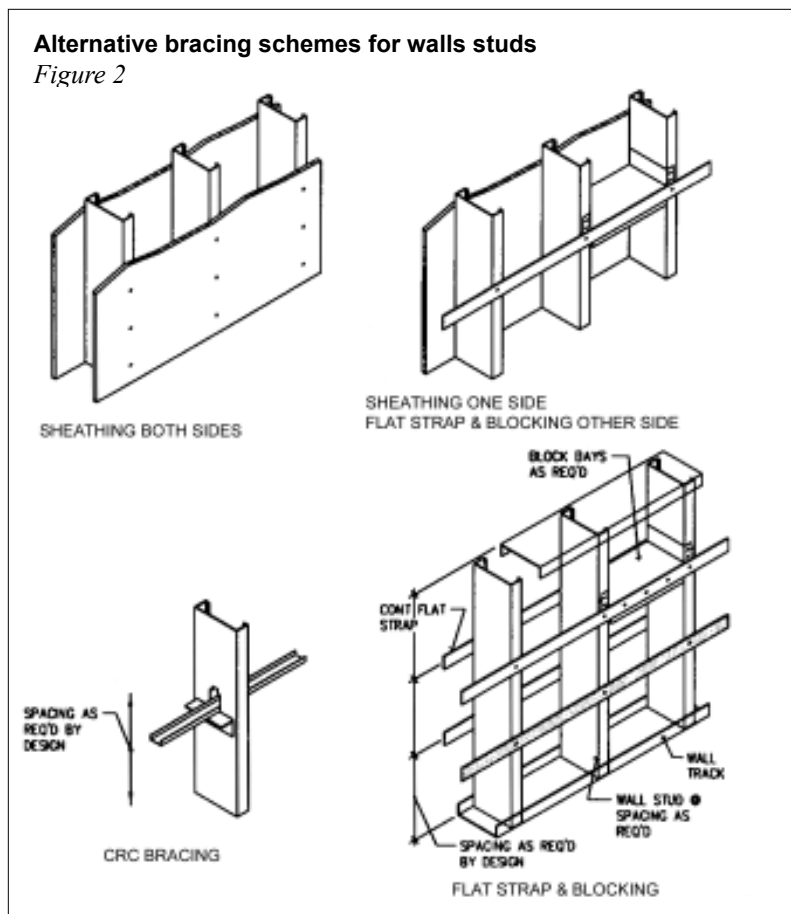 mechanical bracing may be located at discrete points (strap and blocking or bridging) or it can be more uniformly distributed as is the case with sheathing attached to the framing members with fasteners. When sheathing is used as bracing wall members it is important that due consideration be given to the designed function of that wall. Specifically, if the load-bearing wall also serves as a shear wall, the sheathing should not be relied upon to provide bracing for members under axial load. This recommendation is based on the presumption that at the design lateral load attached sheathing will be damaged in achieving the desired lateral response. In its damaged state, the amount of bracing resistance at the fastener connections would be compromised which in turn can compromise the integrity of the gravity load resisting system. For members in bending (out-of-the-plane of a wall, for example) and axial load only, sheathing alone may be satisfactory as bracing for both bending and axial load. Given this design philosophy, the design process then involves two steps: (1) choice of a bracing system and (2) determination of the strength and stiffness demands for bracing.

Lateral Bracing Design Requirements: Once the system that will be used for bracing is chosen (example: see Figure 2 details), the next step is to determine the required strength and stiffness of that system. For flexure of studs, where the studs are attached to the top and bottom tracks (plates) with fasteners, the stud may be treated as laterally and torsionally supported at these points of attachment. Where conventional sheathing (plywood, oriented strand board, or gypsum wallboard/sheathing) is attached to the wall stud (on both flanges), it is generally assumed that the sheathing provides lateral support for flexure via the fasteners. If sheathing is attached to only one flange of the stud, the stud is considered flexurally unbraced except at its ends (stud-track connection). In this case, lateral-torsional support/bracing, if needed, may be developed per the requirements of Section D3.2.2 of the AISI Specification.

Using Section D3.2.2 of the AISI Specification, the brace lateral force demand at each flange, P_{brace}, may be determined as:

$$P_{brace} = 1.5 \frac{m}{d} w \left(\frac{a_l}{2} + \frac{a_r}{2} \right) \quad \text{Eq. 1}$$

where w is the uniform load on the stud (plf) a_l is the distance between braces to the left of the brace under consideration, a_r is the distance between braces to the right of the brace under consideration, d is the depth of the stud and m is the distance from the shear center of the studs to the mid-plane of the web. The

Alternative bracing schemes for walls studs
Figure 2

SHEATHING BOTH SIDES

SHEATHING ONE SIDE
FLAT STRAP & BLOCKING OTHER SIDE

CRC BRACING

BLOCK BAYS AS REQ'D

CONT FLAT STRAP

SPACING AS REQ'D BY DESIGN

WALL TRACK

WALL STUD @ SPACING AS REQ'D

SPACING AS REQ'D BY DESIGN

FLAT STRAP & BLOCKING

distance m may be computed as:

$$m = \frac{w_f dt}{4I_x} \left[w_f d + 2D \left(d - \frac{4D^2}{3d} \right) \right] \qquad \text{Eq. 2}$$

where w_f is the horizontal projection of the flange from the inside face of the web, t is the stud thickness, I_x is the moment of inertia of the gross section about the x-axis ($\perp$ to the web) and D is the overall depth of the lip. In addition to providing the required brace strength, a minimum brace stiffness must be imposed to limit the secondary stress in the stud due to deformation of the brace. Assuming a maximum overstrees of 15% is permitted and that this overstress is related to a 0.026 radian rotation of the section (Yu, 1991), the axial stiffness of the brace, k_{brace}, may be computed as:

$$k_{brace} = \frac{2P_{brace}}{0.026d} \qquad \text{Eq. 3}$$

Thus, equations 1 and 3 above provide a straightforward method of determining the brace requirements for mechanically braced studs in flexure.

Similar expressions are now needed for members in axial compression. Apart from studs sheathed both sides (Section D4.1), the AISI Specification provides no guidance on the bracing requirements for the wall studs in compression. However, following the recommendations in the "Guide to Stability Design Criteria for Metal Structures" (Galambos 1998), the brace demand at each flange (P_{brace} and k_{brace}) for discrete bracing systems may be taken as:

$$P_{brace} = 0.004 \left(4 - \frac{2}{n} \right) \frac{P}{2} \qquad \text{Eq. 4}$$

and

$$k_{brace} = \left(4 - \frac{2}{n} \right) \frac{2}{L} \left(\frac{P}{2} \right) \qquad \text{Eq. 5}$$

where P is the axial load in the stud, L is the unbraced length (assuming equaly unbraced lengths), and n is the number of braces (not including the member end braces). Note that as n goes to infinity, $2/n$ goes to zero. Thus, the maximum value of the $(4 - 2/n)$ term is 4.0. This value may be conservatively used to estimate the brace requirements (strength and stiffness).

The above equations are written in general terms and need to be modified for ASD and LRFD design (i.e. use appropriate safety and resistance factors). In addition, these equations apply to a single stud. In the actual bearing wall conditions multiple studs will be connected and loaded. As a result, the brace force will theoretically be cumulative and the required stiffness will be the larger of the stiffness defined above. As a practical matter however, because an entire wall acts as a system there will be some built-in redundancy. Therefore, it can be expected the theoretical cumulative brace force would be reduced. The amount of this reduction depends on a number of factors: tributary wall length for the brace, ratio of required stud strength to stud capacity, and the whether or not the wall also acts as a shear wall.

DESIGN EXAMPLE

The following example illustrates the design of lateral bracing for a 14-ft. long, 8 ft.-1 in. tall wall with studs at 2 ft. on center. The studs are SSMA designated 350S162-43 sections with a specified minimum yield strength of 33 ksi. Lateral bracing will be provided at the stud mid-height and it is required to develop the axial compressive strength of the studs when an out-of-plane factored lateral load of 15 psf is acting. Sheathing is attached to one side of the wall and is assumed to provide no lateral resistance under flexural loading. The lateral brace configuration will comprise a 33 mil (20 gauge, or 0.0346 in.) flat strap attached to 33 mil solid

Figure 3

track-section blocking, as illustrated in Figure 2. The solid blocking is assumed to provide the basic mechanism for anchoring the strap load. The entire end bay which includes the block, studs, upper and lower tracks (and their attachments), and attached sheathing or coverings, collectively take the shear in the blocking to diaphragm or foundation levels above and below the wall. Other engineered systems may be used to anchor the strap.

Determine the design loads and brace requirements:
  Maximum stud factored moment:

$$M_{Max} = \frac{wl^2}{8} \text{(where } w = 30 \text{ plf and } l = 8.083 \text{ ft.)}$$

$$= 245 \text{ lb. - ft.}$$

Using a commercially available software package, the axial compressive strength of the 350S162-43 stud with mid-height bracing was computed as = 3320 lb. when the out-of-plane load is acting.

Applying the equations above for the brace force and the stiffness, and noting that the brace force for axial compression and bending are cumulative but stiffness is not, the required brace force per stud is:
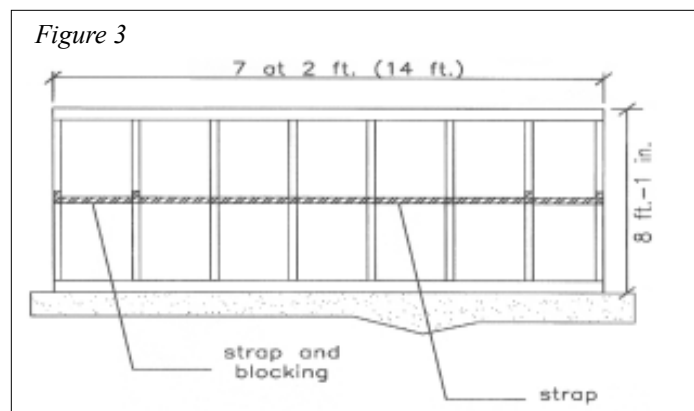
$$P_{brace\,(total)} = P_{brace\,(bending)} + P_{brace\,(axial\,compression)}$$

$$P_{brace} = 41 + 13 \; lb.$$

(See appendix for sample calculation)

Thus,

$$P_{brace\,(total)} = 54 \; lb.$$

and the required brace stiffness is:

$$k_{brace} = \max \left[k_{brace\,(bending),} \; k_{brace\,(axial\,compression)} \right]$$

$$k_{brace} = \max \left[902, 137 \right] \; lb. \,/\, in.$$

(See appendix for sample calculation)

$$k_{brace} = 902 \; lb. \,/\, in$$

In this example, the shear strength of the solid block (in the end bays) can be directly computed. Alternatively, the designer can determine the size of solid blocking required on the basis of a practical choice for spacing of the blocking. The strap and spacing of the blocking must be such that the cumulative force transferred to the blocking does not exceed the blocking capacity.

The shear strength of the 33 mil track blocking was computed as 1585 lb. (see appendix for sample calculation). Thus, if the total required brace force per stud is 54 lbs., the solid block can support 1585/54 = 23 studs. Therefore, the blocking can be placed a maximum of 46 ft. on center. Since the wall in this example is 14 ft. long, solid blocking will be

required in the two end bays only (i.e. 12 ft on center). Under this condition, the maximum force, P_{strap}, to be developed in the flat strap will be:

$$P_{strap} = 4 * 54 \; lb$$
$$P_{strap} = 216 \; lb$$

The tensile brace strength may be computed as $P_{strength} = 0.95 \, A_n F_y$, per the AISI Specification where A_n is the net cross-sectional area of the strap. Assuming No. 10 screws (nominal diameter = 0.183 in.) are used for the framing connections, the following table gives the strap strength and stiffness for three practical 33 mil (33 ksi) strap widths (*Table 1*): The strap tensile stiffness in the above table was computed from the expression:

$$k_{strap} = \frac{A_g E}{L} \qquad\qquad Eq.\ 6$$

Table 1 Strap Dimensions	Strap Nominal Strength ($P_{strength}$) lb.	Strap Stiffness (k_{strap}) lb / in.
1" x 0.0346"	885	10632
1-1/2" x 0.0346"	1429	15948
2 x 0.0346"	1971	21265

where A_g is the gross cross-sectional area of the strap and L is the length of the strap in tension. In this example, the strap supports 4 studs, therefore the strap length L in equation 6 will be 8 ft. (96 in.). Thus, on the basis of these calculations, 33 mil solid blocking on the end bay with a 1-in. 33 mil (33 ksi) strap will be sufficient to develop the prescribed stud loads.

References

1. AISI, 1996. Specification for the Design of Cold-Formed Steel Structural Members. American Iron and Steel Institute, Washington, DC, October.
2. SSMA, 2000. Product Technical Information: ICBO ER-4943P. Steel Stud Manufacturers Association, Chicago, IL April.
3. Yu, W-W, 1991. Cold-Formed Steel Design: 2nd edition. John Wiley and Sons, Inc.
4. Galambos, T. V., 1998. Guide to Stability Design Criteria for Metal Structures: 5th edition. John Wiley and Sons, Inc.

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APPENDIX

(Sample Calculations)

Computation of Brace Force and Stiffness

Bracing Requirements for Flexure (AISI Specification, Section D3.2.2):

Input --

Applied uniform load (plf): $w := 30$
Dist. between braces to the left of this brace (in.): $a_l := 48.5$
Dist. between braces to the right of this brace (in.): $a_r := 48.5$
Stud web depth --out-to-out (in.): $d := 3.5$
Horizontal proj. of stud flange from web inside face (in.): $w_f := 1.625 - .0451 - .0712$
Stud thickness (in.): $t := 0.0451$
Stud gross moment of intertia (in.^{4}): $Ix := 0.6546$
Overall--out-to-out--depth of stud lip (in.): $D := 0.5$

Computed Values --

Dist. from stud shear center to web mid-plane (in.): $m := \dfrac{w_f * d * t}{4 * I_x} * \left[(w_f) * d + 2 * D * \left(d - \dfrac{4 * D^2}{3 * d} \right) \right]$

$$P_{brace\_bending} := 1.5 * \frac{m}{d} * \frac{w}{12} * \left(\frac{a_l}{2} + \frac{a_r}{2} \right)$$

$$k_{brace\_bending} := \frac{2 * P_{brace\_bending}}{0.026 * d}$$

$P_{brace\_bending} = 41.048$ lb.

$k_{brace\_bending} = 902.164$ lb./in.

Bracing Requirements for Axial Load (Stability Design Guide, Section 12.5):

Input --

Applied factored axial load (lb.): $P = 3320$
Stud unbraced length (in): $L := 48.5$
Number of braces (installed mechanical braces): $n := 1$

Computed Values --

$$P_{a\_brace} := 0.004 * \left(4 - \frac{2}{n} \right) * \frac{P}{2}$$

$$k_{a\_brace} := \left(4 - \frac{2}{n} \right) * \frac{2}{L} \left(\frac{P}{2} \right)$$

$P_{a\_brace} = 13.28$ lb.

$k_{a\_brace} = 136.907$ lb./in.

Capacity of Shear Blocking

Design Data:

$F_y := 33$ ksi $b_{flange} := 1.625$ $r := 0.0764$ in. (inside corner radius)

$t := 0.0346$ in. (33 mil / 20 gauge) $d_{stud} := 3.500$ in.

$s := 24.0$ $E := 29500$ ksi

Determine the Shear Buckling Factor:

$a := s - b_{flange}$ $a = 22.375$ in.

$h := d_{stud} - 2 * r - 2 * t$ $h = 3.278$ in.

$$k_v := if\left[\frac{a}{h} > 1.0, \left[5.34 + \frac{4.00}{\left(\frac{a}{h}\right)^2}\right], \left[4.00 + \frac{5.34}{\left(\frac{a}{h}\right)^2}\right]\right]$$ $k_v = 5.426$

Compute the Shear Strength of the Block Based in the AISI Equations and the Following Assumptions:

$web\_slenderness := \dfrac{h}{t}$ $web\_slenderness = 94.74$

$S_1 := \sqrt{\dfrac{E * k_v}{F_y}}$ $S_1 = 69.645$

$S_2 := 1.1415 * S_1$ $S_2 = 98.547$

$V_{1n} := 0.577 * F_y * h * t$ $V_{2n} := 0.9 * 0.64 * t^2 * \sqrt{k_v * F_y * E}$ $V_{3n} := 0.9 * 0.905 * E * K_v * \dfrac{t^3}{h}$

$V_{1n} = 2.16$ kips $V_{2n} = 1.585$ kips $V_{3n} = 1.647$ kips

$\phi V_n := if(web\_slenderness < S_1, V_{1n}, if(web\_slenderness > S_2, V_{3n}, V_{2n}))$

THE CAPACITY OF THE SOLID BLOCK IS: $\phi V_n = 1.585$ **kips**