research report

CFS Bracing Design Using Combinations of Discrete and Sheathing Bracing

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PREFACE

This report summarizes efforts related to establishing the behavior and design of cold-formed steel wall assemblies potentially braced by discrete steel bracing and wall sheathing.

The report and associated spreadsheets for the project are posted by the researcher at:
http://jhir.library.jhu.edu/handle/1774.2/62986

The related test report is posted by the researcher at:
http://jhir.library.jhu.edu/handle/1774.2/62115

CFS Bracing Design Using Combinations of Discrete and Sheathing Bracing

Final Report

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August 2020

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Executive Summary

The objective of this report is to summarize efforts related to establishing the behavior and design of cold-formed steel wall assemblies potentially braced by discrete steel bracing and wall sheathing.

Cold-formed steel wall assemblies are typically designed with discrete steel braces; however, the predicted accumulation of brace forces in these systems can lead to demands at odds with past successful practice. At the same time, testing on sheathing braced wall studs demonstrate the effectiveness of sheathing bracing, but questions persist about their effectiveness in extreme conditions. It is hypothesized that a combined bracing system could provide adequate strength from the steel system under extreme (environmental) conditions and benefit from the effectiveness of sheathing bracing in service and other conditions.

A focused series of experiments on wall stud assemblies in compression with different combinations of discrete bracing and sheathing bracing were completed. The testing indicated that sheathing bracing dominates the braced stud response and that brace forces in discrete braces do not accumulate when sheathing is present.

A series of spreadsheets were developed to provide engineers with a clear and efficient means to predict the strength of studs with both discrete bracing and sheathing bracing. The proposed strength calculations agree with the limit states observed in past and current testing; however, unlike in previous work where predicted strengths were conservative, in the testing conducted in this project the predicted strength is from 7 to 19% unconservative depending on the details of the tested specimen.

Enabling combined bracing in cold-formed steel design requires modifications to AISI S100 and AISI S240 and a series of ballots that would be necessary for adoption of the new methods are detailed and priorities for adoption given.

It is recommended that additional testing and design aids be developed.

1 Introduction

Cold-formed steel (CFS) gravity, load bearing, walls consist of vertical lipped channel studs capped with horizontal plain channel track – typically fastened together by self-drilling screws. The open cross-section lipped channel studs have relatively weak torsional stiffness and are oriented such that minor axis bending is in the plane of the wall. Without bracing of the studs, the wall capacity would be severely limited.

The most common form of wall bracing are small channels, known as cold-rolled channel (CRC) bridging, that are installed through holes (punchouts/knockouts) in the stud web. These bridging channels provide minor-axis flexural bracing and depending on their stiffness and installation details can also restrict torsion of the stud. Of course, an isolated bridging channel must be resolved to a stiff member so that the bracing forces can be carried out of the wall. However, predictions of the accumulated brace force and stiffness requirements for an entire wall can be significant and result in design requirements that are not aligned with long-standing practice.

From a practical standpoint most CFS walls will have finish applied to both sides of the wall, this finish typically includes sheathing which is directly applied to the stud flanges. Gypsum board sheathing attached with screws is the most common form of finish. Once installed the gypsum board can also serve to brace the studs – particularly if installed on both sides such sheathing can be an effective restraint against both minor-axis and torsional deformations of the stud. A comprehensive series of research on the role of sheathing in bracing cold-formed steel walls, summarized in Schafer (2013) and supported by the efforts in Vieira (2011), Vieira and Schafer (2013), Peterman (2012), and Peterman and Schafer (2014) unequivocally demonstrated that sheathing bracing could effectively stabilize cold-formed steel stud walls, and developed a supporting design method. However, since many finish systems are non-structural concerns persist as to whether such systems will be available during construction or during an overload or other critical loading condition (e.g., fire).

In practice, both steel discrete bridging and wall sheathing exist in a cold-formed steel stud wall. It is desired to know how these two systems work when under load and acting as bracing. What is the impact of not fully resolving (anchoring) the bridging? What is the impact of the construction sequence on the relative bracing forces between the bridging and the sheathing? When both bridging and sheathing are present, which system actually carries the bracing demands? A focused series of tests was developed to explore these questions.

The design method developed in Schafer (2013) is relatively involved. Specifically (a) the stiffness supplied by the sheathing to the stud as bracing must be calculated; (b) this stiffness must be included when solving for the global buckling load which is now coupled in terms of major axis flexure, minor axis flexure, and torsion; (c) traditional column design with these buckling loads must be completed, and finally (d) the sheathing-to-stud connections must be checked for adequacy. It is desired to aid engineers with performing and understanding these steps and so the method was implemented in a series of spreadsheets and extended to cover discrete bracing.

This document is the final report for a project funded by the American Iron and Steel Institute and the Steel Framing Industry Association to address "CFS Bracing Design Using Combinations of Discrete and Sheathing Bracing".

2 Testing

Compression testing was conducted on an 8 ft × 8 ft CFS frame with 362S162-68 [50 ksi] studs spaced 2 ft apart and attached at top and bottom to two 8-ft long 362T125-68 [50 ksi] tracks. The studs had standard obround punchouts with dimensions of 1 1/2 in. x 4 in. When specified 150U150-54 CRC bridging was supplied through the punchout at the mid-height of the stud. The bridging was attached to the studs with a 1 ½ in. x 1 ½ in. 54 mil angle connected with #10 steel-to-steel fasteners. When specified the CRC bridging was anchored to a fixed support at one end. When specified ½ in. lightweight sheetrock (installed vertically) with #6 @ 12 in. o.c. screw fasteners were added to one or both sides of the wall. The steel for a typical wall is provided in Figure 1.

The test results are detailed in a separate report: Qian and Schafer (2020) and summarized in a paper: Schafer et al. (2020). Please see these materials for details and key findings from the testing. Most importantly the testing indicated definitively that bridging forces only accumulate for translation, not for torsion, and this accumulation only occurs when sheathing is not present. When sheathing is present the sheathing, not the bridging, dominates the bracing response.
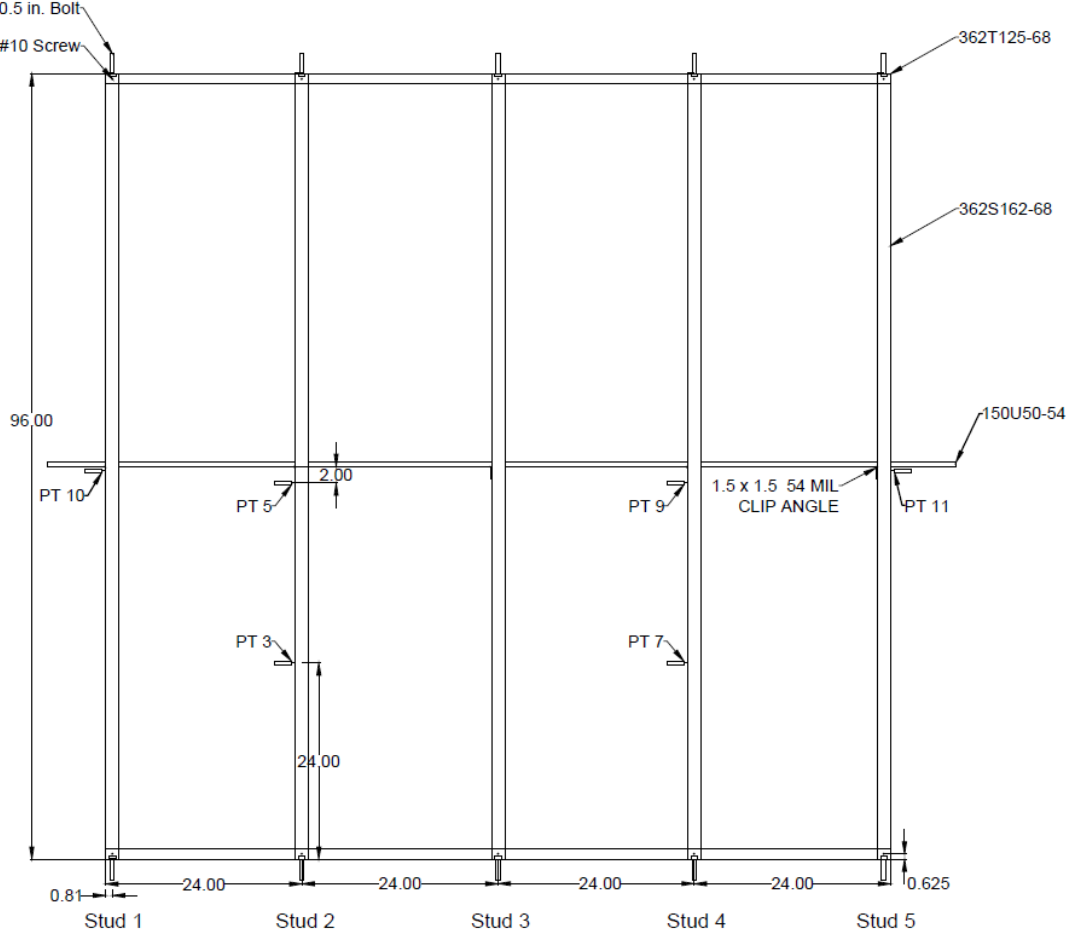

Figure 1. Elevation of Typical CFS Frame, Nomenclature, and Sensors

3 Elastic Buckling Calculations/Spreadsheets

The elastic buckling load is necessary for design. The elastic buckling calculations for a stud under compression, braced by discrete bridging, strapping, and/or sheathing and buckling in either local, distortional, and/or global buckling are provided through a series of spreadsheets. The provided spreadsheets are:

- 01_Pcre_analytical_v10.xlsm
- 02_Pcrd_analytical_v2.xlsx
- 03_Pcrl_Pcrd_database_v2.xlsx

Note, these same elastic buckling values can be determined using general purpose finite strip elastic buckling tools such as CUFSM, THIN-WALL, etc. or general purpose plate/shell finite element tools such as ABAQUS, ANSYS, etc. The spreadsheets provide solutions without recourse to analysis tools and could be directly incorporated into in-house design solutions.

A video has been provided for basic use of the spreadsheets (Video_spreadsheet_explainer.mp4). Here we describe the function of each spreadsheet and address the basic source material. Complete source references and full details are provided within the spreadsheets themselves.

3.1 Local ($P_{cr\ell}$) and Distortional (P_{crd}) Buckling (03_Pcrl_Pcrd_database_v2.xlsx)

Local and distortional buckling for pinned warping free boundary conditions was calculated for every structural section in the SFIA product technical catalog (SFIA 2018) using CUFSM and provided as a database. In addition, the approximate finite strip method for members with holes recommended in AISI S100-16 Appendix 2 was adopted and provided for all Steel Framing Industry Association (SFIA) sections with standard punchouts. This database provides the necessary local and distortional buckling loads for bare steel stud sections with and without punchouts.

3.2 Distortional Buckling (P_{crd}) with Sheathing Restraint (k_ϕ) (02_Pcrd_analytical_v2.xlsx)

AISI S100-16 Section 2.3.1.3 and 2.3.2.3 are implemented in this spreadsheet to provide the distortional buckling strength considering rotational restraint provided by sheathing.

3.3 Global Buckling (P_{cre}) (01_Pcre_analytical_v10.xlsm)

Global buckling for a stud considering the beneficial restraint provided from bridging, discretely fastened sheathing, or strap are provided for all stud sections in this spreadsheet. This spreadsheet provides a number of ancillary calculations in addition to the final elastic buckling calculation that aid designers.

Gross and net section properties for any SFIA stud are automatically populated based on a database of properties provided in separate sheets within the spreadsheet.

For sheathing, based on the sheathing type, stud spacing, and fastener type and spacing the discrete restraint provided at the attachment points to the studs is calculated per Vieira and Schafer (2013) for shear restraint (k_x) per Vieira and Schafer (2013) for out-of-plane restraint (k_y), and per an adaptation of AISI S240 Appendix 1 for (k_ϕ). See Schafer (2013) report for further details on

sheathing bracing including illustrative examples for k_x, k_y and k_ϕ that can be compared with the spreadsheet output.

For bridging, only through the punchout CRC bridging attached by screw fastened clip angles is explicitly considered. For other cases there is an option to manually enter the provided bracing stiffness. The bracing stiffness is drawn from the work of Sputo and Green (Green et al. 2006) as detailed in their student Urala's (2004) M.S. thesis. The bridging channel, connection (clip angle, fasteners, stud web), and kicker/strongback are considered as springs in series to determine the discrete stiffnesses (k_x) supplied to the stud. The connection stiffness, which is generally the weakest stiffness in the series, is based directly on the work of Urala (2004), but with interpolation allowed. For k_x the available data covers studs from 33 to 97 mil and webs from 3.62 to 8 in. deep. Separate tests on the rotational restraint of the connection are also available from Urala (2004) and these provide k_ϕ for screw fastened clip angles and CRC bridging attached to studs from 68 to 97 mil and webs from 3.62 to 6 in. deep. The final bridging stiffness values are automatically populated into the spreadsheet.

The spreadsheet also includes the condition of strap bracing, where screw fastened strap are attached to the stud flanges. For strapping, screwed to the flange of the studs, the in-plane bracing stiffness (k_x) is calculated using the same spring in series approach as for bridging, but with the connector stiffness based on AISI S310-16 Section D5.2.

The spreadsheet then solves the global buckling problem.

Specifics of the buckling solution follow. The solution is adapted from Vieira and Schafer (2013) and Li (2011). The elastic buckling calculation is an eigenvalue problem:

$$(K_e - \lambda K_g)\phi = 0$$

where the eigenvalue λ is the buckling load (P_{cre}) and the eigenvector ϕ is the buckling shape and where K_e is the elastic stiffness of the stud against xx and yy-axis bending (EI_{xx}, EI_{yy}) and torsion (GJ, EC_w) including additional stiffness supplied by j different bracing springs k_{xj}, k_{yj} and $k_{\phi j}$ located at h_{xsj}, h_{ysj} in the section and z_{sj} along the length and may be expressed as:

$$K_e = \begin{bmatrix} EI_{yy}I_4 + \sum_{j=1}^{n_s} k_{xj}I_{1j}^D & EI_{xy}I_4 & -\sum_{j=1}^{n_s} k_{xj}h_{ysj}I_{1j}^D \\ & EI_{xx}I_4 + \sum_{j=1}^{n_s} k_{yj}I_{1j}^D & \sum_{j=1}^{n_s} k_{yj}h_{xsj}I_{1j}^D \\ Sym- & & GJI_5 + EC_wI_4 + \sum_{j=0}^{n_s} I_{1j}^D\left[k_{xj}h_{ysj}^2 + k_{yj}h_{xsj}^2 + k_{\emptyset j}\right] \end{bmatrix}$$

where I_1 and I_4 are a function of the longitudinal shape function Z, which when a sine series is employed becomes:

$Z_{[m]} = \sin\left(\frac{m\pi z}{L}\right)$, $I_1 = \int_0^L Z_{[m]}Z_{[n]}dz = \frac{L}{2}$, $I_{1j}^D = Z_{[m]}(z_{sj})Z_{[n]}(z_{sj}) = \sin^2\left(\frac{m\pi z_{sj}}{L}\right)$, and $I_4 = \int_0^L Z_{[m]}''Z_{[n]}''dz = \frac{m^4\pi^4}{2L^3}$

and K_g is the load dependent geometric stiffness that degrades the elastic stiffness under axial load with x_o and y_o the distance from the shear center to the centroid in the cross-section plane:

$$K_g = \begin{bmatrix} I_5 & I_5 & -z_o I_5 \\ & I_5 & x_o I_5 \\ sym- & & r_o^2 I_5 \end{bmatrix}$$

and the additional terms are

$r_o^2 = x_o^2 + y_o^2 + (I_{xx} + I_{yy})/A$, and $I_5 = \int_0^L Z'_{[m]} Z'_{[n]} dz = \frac{m^2\pi^2}{2L}$

A lipped channel (C-shape) cross-section at longitudinal location z with a single set (j) of discrete springs attached to Face 1 of the section is depicted in Figure 2 the summation of these springs consistent with K_e, and the solution for various m longitudinal terms is provided in the spreadsheet.
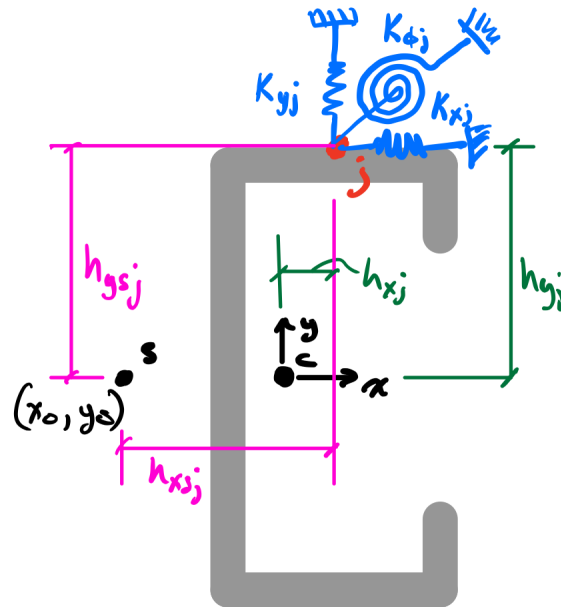
Figure 2. Cross-section with a set of discrete springs from bracing

The video provided for basic use of the spreadsheets (Video_spreadsheet_explainer.mp4) covers additional practical details in the use of the spreadsheet and, for example, how to use the spreadsheet to develop the global buckling solution for an unbraced stud, a stud braced only with through the punchout CRC bridging, a stud braced with CRC bridging and gypsum board on one side, and finally a stud with CRC bridging and gypsum board on both sides.

4 Strength Prediction and Comparison to Testing

A spreadsheet is provided for the strength prediction:

- 04_Pn_DSM_v2.xlsx

This spreadsheet implements AISI S100-16 Chapter E for compression members without modification. The strength is a function of the gross and net squash load (P_y and P_{ynet}) and the local, distortional, and global buckling loads ($P_{cr\ell}, P_{crd}$ and P_{cre}). The buckling loads reflect the cross-section, including holes, and the presence of bridging, strapping, and sheathing and their calculation using the spreadsheets is detailed in the video which accompanies this report (Video_spreadsheet_explainer.mp4).

For the walls tested and reported in Qian and Schafer (2020) Table 1 provides the yielding loads, elastic buckling loads and characteristics, predicted strength, and observed strength. For the global elastic buckling mode the shape is summarized in terms of the components of its in-plane buckling deformation (**u** – minor axis flexure, **v** - major axis flexure, ϕ - torsion/twist, and **m** – mode number). The global buckling load and mode changes dramatically as the bracing is introduced. The predicted strength and limit states are in good qualitative agreement with the testing, but strength agreement is not as good as previously conducted wall tests with sheathing alone (Vieira and Schafer 2013) and additional discussion is warranted.

Table 1 Predicted and observed compressive strength for CFS-framed wall tested (Qian and Schafer 2020) with combinations of discrete CRC bracing and gypsum sheathing

Condition	Yielding		Buckling			Φ				Pred.**		Observed	
	P_y	P_{ynet}	P_{cre}	u	v	ϕ	m	P_{crd}	P_{crl}	P_n	LS	$P_{test}/5$	LS
	(kips)	(kips)	(kips)					(kips)	(kips)	(kips)		(kips)	
Unbraced	26.2	20.8	5.7	**1.0**	0.0	0.0	1	31.9	31.5	5.0	G1		
CRC bridging	26.2	20.8	18.1	0.0	-0.3	**1.0**	2	31.9	31.5	14.3	G2	13.3	FTB2
CRC* + 1 Side Gyp	26.2	20.8	22.5	0.4	-0.2	**0.9**	2	31.9	31.5	16.1	G2	13.5	TB2
CRC + 2 Side Gyp	26.2	20.8	32.6	0.0	**1.0**	-0.2	1	37.4	31.5	18.4 D (hole) 18.7 G1		15.1	LB@Hole (TB/FB)

*note, the CRC is not anchored in this test – the gypsum sheathing must resolve the bridging force
**nominal predictions based on t = 0.0713 in. F_y = 50 ksi, measured stud t = 0.0691 in. F_y = 52 ksi

For the "CRC bridging" case of Table 1 (also known as the "all steel" case) the bridging successfully restrains minor-axis flexure (u) and the stud fails in a global (G) limit state of 2nd mode flexural-torsional (v-ϕ or FTB) buckling. AISI S100-16 Chapter E with the appropriate global buckling load accurately predicts the limit state and the observed strength is 93% (13.3 kips/14.3 kips) of the predicted strength. The section is "fully effective" in local buckling – i.e. no local-global interaction is predicted, and none is observed. The agreement for the all steel case is deemed acceptable – though broader study may be warranted.

For the case with (unresolved) CRC bridging, and gypsum sheathing on 1 side of the wall, the test fails predominately in restrained-axis 2nd mode torsional buckling (TB2). The predicted limit state

is also 2nd mode global buckling, dominated by torsion. However, in this case the test strength is only 84% of the predicted strength. The single stud test strength for the CRC bridging with one-side of gypsum (13.5 kips) is nearly the same as the CRC bridging alone (13.3 kips) perhaps leading on to think the gypsum board has little effect; however, the test with the gypsum had a different failure mode, sustained greater deformation, and had a much more benign post-peak response than the test with CRC bridging alone. The case with OSB sheathing only on one side in Vieira and Schafer (2013) did not have CRC bridging, but did have good agreement with this same basic method. A definitive explanation for the discrepancy between the predicted and tested strength has not been developed at this time.

For the case with CRC bracing and gypsum sheathing on both sides of the wall, the tested strengths per stud across the three tests in this category were 14.4, 14.5, and 16.3 kips vs. a predicted strength of 18.4 kips. Resulting in a test-to-predicted of 82% on average, ranging from 78% to 88%. For comparison Vieira and Schafer (2013) tested similar walls with gypsum sheathing on both sides and the mean per stud strength was 19.3 kips, while isolated and sheathed studs had a mean stud strength of 21.4 kips – both exceeding the test results presented here. Key differences in the earlier testing included: studs did not have holes, normal weight gypsum attached at 6 in. o.c. was employed, CRC bridging was not present. Test-to-predicted ratios in Vieira and Schafer (2013) under these conditions were in good agreement.

5   Draft Ballots

5.1   Previous sheathing braced design ballots

Before discussing new ballots, it is necessary to review the progress of adoption for the ballots proposed for revisions to sheathing braced design in the Schafer (2013) final report, Table 2. These ballots are needed by engineers, in some form, to enable a stiffness-based solution to elastic buckling with combined bracing.

Table 2 Status and resolution of sheathing braced design ballots from Schafer (2013)

Sheathing Braced (SB) Design Draft Ballots from Schafer (2013)	Current status (June 2020)	Proposed Resolution
SB Ballot 1: Lateral Restraint Provided by Fastener-Sheathing System (k_x)	Never adopted	Provide in commentary to new AISI S100 Appendix 3 on stiffness
SB Ballot 2: Testing for Local Lateral Restraint of Sheathed Members ($k_{x\ell}$)	Never adopted	Ballot as new AISI Test Standard (TS)
SB Ballot 3: Vertical Restraint Provided by Fastener-Sheathing System (k_y)	Never adopted	Provide in commentary to new AISI S100 Appendix 3 on stiffness
SB Ballot 4: Rotational Restraint Provided by Fastener-Sheathing System (k_ϕ)	Adopted in AISI S240 Appendix 1, not available in AISI S100	Provide in commentary to new AISI S100 Appendix 3 on stiffness (remove from AISI S240 Appendix 1)
SB Ballot 5: New Test Standard, Similar to AISI S901, for Rotational Restraint (k_ϕ)	Adopted as AISI S918-17	No action required
SB Ballot 6: Commentary Addition to Appendix 1 Direct Strength Method for Elastic Stability of Sheathed Walls with emphasis on using the Finite Strip Method	Never adopted	Provide as commentary to AISI S100 Appendix 2 elastic buckling analysis
SB Ballot 7: Clean up Distortional buckling notation in AISI-S100 C3.1.4 and C4.2	Adopted in AISI S918-17 and next edition of AISI S100 (Ballot CS17-437).	No action required
SB Ballot 8: Add new section to C4.1 for Flexural-Torsional Buckling with Sheathing	Never adopted	Ballot for AISI S100, but in Appendix 2 or I4
SB Ballot 9: Add new section to C3.1.2.3 for Lateral-Torsional Buckling with Sheathing	Never adopted	Ballot for AISI S100, but in Appendix 2 or I4

SB Ballot 10: Clean up Sheathing-Braced Design Charging Language in S100	Never Adopted	Abandon
SB Ballot 11: Fastener (Bearing and Pull-through) Demands [Required Loads]	Never Adopted	Add to <u>commentary</u> in new AISI S100 Appendix 3 on stiffness, or to AISI S240, or to Design Guide
SB Ballot 12: Fastener (Bearing and Pull-through) Capacity [Available Loads]	Never Adopted	<u>Ballot</u> for AISI S100 J4 Screw Connections
SB Ballot 13: Strength Table (Mock Up) for COFS or Design Manual	Never Implemented	Add to AISI D100

In short, the proposed AISI S100 Appendix 3 for stiffness of connections needs to be completed and enabled so engineers have access to the stiffness values needed in the bracing elastic buckling calculations.

From the perspective of AISI S240, design of steel studs follows either all steel design or sheathing braced design. Enabling combined bracing could involve (a) creating a new third category: combined bracing, or (b) modification of sheathing braced design. The option explored here is the modification of sheathing braced design, i.e. option (b).

Beyond the ballots of Table 2 the following ballots are proposed.

5.2 Draft Ballot CB1: Enable Combined Bracing in AISI S100

A simple means to enable strength calculations for combined bracing conditions would be to mirror the AISI S100-16 provisions in I6.1 for Metal Roof and Wall Systems to I4 Cold-Formed Steel Light-Frame Construction. AISI S240 could provide simplifications, while AISI S100 provides the basic methodology. This is not absolutely necessary, but since the method parallels I6 and also places the I4.1 all steel stud design method in context it is recommended. Draft provisions of the enabling language in AISI S100:

I4 Cold-Formed Steel Light-Frame Construction

The design and installation of *structural members* utilized in cold-formed steel repetitive framing applications shall be in accordance with AISI S240 and, as applicable, the seismic requirements of AISI S400.

I4.1 All-Steel Design of Wall Stud Assemblies

Wall stud assemblies using an all-steel design shall be designed neglecting the structural contribution of the attached sheathings and shall comply with the requirements of Chapters D through H

I4.2 Sheathing Braced Design of Wall Stud Assemblies

Wall stud assemblies using sheathing braced design are permitted to consider discrete bracing and the bracing and composite action[1] provided by attached sheathing and shall comply with the requirements of Chapters D through H.

I4.2.1 Compression Member Design

The *nominal axial strength* [*resistance*], P_n, shall be the minimum of P_{ne}, $P_{n\ell}$, and P_{nd} as calculated in accordance with Chapter E. It shall be permitted that F_{cre} in E2 and/or P_{crd} in E4 include the effect of bridging, strapping, and/or sheathing. For members meeting the geometric and material limits of Section B4, the *safety* and *resistance factors* shall be as follows: Ω_c = 1.80 (*ASD*) ϕ_c = 0.85 (*LRFD*) = 0.80 (*LSD*). For all other members, the *safety* and *resistance factors* in Section A1.2(c) shall apply. The *available strength* [*factored resistance*] shall be determined in accordance with the applicable method in Section B3.2.1, B3.2.2 or B3.2.3.

I4.2.2 Flexural Member Design

The *nominal flexural strength* [*resistance*], M_n, shall be the minimum of M_{ne}, $M_{n\ell}$, and M_{nd} as calculated in accordance with Chapter F. It shall be permitted that F_{cre} in F2 and/or M_{crd} in F4 include the effect of bridging, strapping, and/or sheathing. For members meeting the geometric and material limits of Section B4, the *safety* and *resistance factors* shall be as follows: Ω_b = 1.67 (*ASD*) ϕ_b = 0.90 (*LRFD*) = 0.85 (*LSD*).

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[1] Note, some members of the project monitoring task group were unsure if "composite action" should be included in the future ballot and thus this will be a matter for future discussion.

For all other members, the *safety* and *resistance factors* in Section A1.2(c) shall apply. The *available strength* [*factored resistance*] shall be determined in accordance with the applicable method in Section B3.2.1, B3.2.2 or B3.2.3.

5.3 Draft Ballot CB2: Re-scope Sheathing Bracing in AISI S240 B1.2

The next obvious place to provide modification is to expand the design method options for Wall Studs in AISI S240. Draft provisions of the enabling language in AISI S240 are based on modifications to MS19-13A which updated AISI S240-15 to reference AISI S100-16 and is assumed to be a modestly better starting place for changes. First the scoping in AISI S240 B1.2 could be clarified for sheathing bracing.

B1.2.2 Wall Studs

B1.2.2.1 Wall *studs* shall be designed either on the basis of all steel design, or on the basis of sheathing braced design, in accordance with the following:

(a) All Steel Design. Wall *stud* assemblies using all steel design shall be designed neglecting the structural *bracing* and composite-action contribution of the attached sheathings.

(b) Sheathing Braced Design. Wall *stud* assemblies using sheathing braced design are permitted to consider discrete *bracing* and the *bracing* and composite-action[2] provided by attached sheathing. ~~shall have sheathing attached to both *flanges* of the wall *stud* or sheathing attached to the one *flange* and discrete bracing to the other *flange*.~~ The *stud* shall be connected to the bottom and top *track* or other horizontal member(s) of the wall to provide lateral and torsional support to the wall *stud* in the plane of the wall. ~~Wall *studs* with sheathing attached to both sides that is not identical shall be designed based on the assumption that the weaker of the two sheathings is attached to both sides.~~

B1.2.2.2 When sheathing braced design is used, the *construction documents* shall identify ~~the~~any sheathing considered to supply *bracing* or composite-action as a structural element.

B1.2.2.3 For *curtain wall studs* […no change to this section, redacted for space]

B1.2.2.4 In the United States and Mexico, when sheathing braced design is used, the wall *studs* shall also be evaluated, considering only such sheathing that is in-place during construction and able to withstand conditions[3] expected during the life of the assembly without substantial loss in stiffness, ~~without the sheathing *bracing*~~ for the following *load* combination[4]

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[2] See footnote 1 regarding composite action.

[3] This provision was a topic of much discussion amongst the project monitoring task group. Implemented in this draft is a generic condition – concerns for the commentary would include primary concerns related to fire-fighting: sprinklers, fire hoses, etc., and secondary environmental concerns such as long term exposure to very high or very low humidity, more development with task groups in AISI COFS will be needed. Some in the PMTG also were interested in contemplating sheathing performance requirements to be allowed to use these proposed provisions.

[4] Final version of the ballot may point to ASCE 7 construction load combinations.

1.2D + (0.5L or 0.2S) + 0.2W   (*Eq*. B1.2.2-1)

where D = Dead *load,* L = Live *load,* S = Snow *load, and* W= Wind *load*

B1.2.2.5 In Canada, the provisions for sheathing braced design shall be in accordance with a theory, tests, or *rational engineering analysis* and shall comply with Chapters E and F of AISI S100 [CSA S136], as applicable.

5.4   Draft Ballot CB3: Cleanup All Steel Design in AISI S240 B3.2 / B3.4
AISI S240 Section B3.2 and B3.4 on Wall Stud Design should be modified to align with bracing provisions in AISI S100. This issue is separated out as it is not distinctly part of combined bracing; however, a benefit of combined bracing is in properly addressing the resolution of accumulated bracing forces.

B3.2 Wall Stud Design

Wall *studs* shall be designed in accordance with the requirements of this section.

B3.2.1 Compression

Wall studs shall be designed for compression either on the basis of all steel design, or on the basis of sheathing braced design with both ends of the stud connected to restrain rotation about the longitudinal stud axis and horizontal displacement perpendicular to the stud axis, in accordance with the following:

(a) All Steel Design. For all steel design of wall *studs* in compression, Chapter E of AISI S100 [CSA S136] shall define the *available* axial *strength* [*factored resistance*]. The effective length, KL, shall be determined by *rational engineering analysis* or testing, or in the absence of such analysis or tests, K_x, K_y and K_t shall be taken as unity. The unbraced length with respect to the major axis, L_x, shall be taken as the distance between end supports of the member, while unbraced lengths L_y and L_t shall be taken as the distance between braces. For distortional buckling i~~If~~ the discrete *bracing* fully restricts rotation of both *flanges* about the *web*/*flange* juncture, the distance between braces shall be used as L_m ~~in determining the distortional buckling force~~ in accordance with Sections 2.3.1.3 and 2.3.2.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. If the discrete *bracing* spaced at distance L_b has rotational stiffness k^*_ϕ against rotation of both *flanges* about the *web*/*flange* juncture then k^*_ϕ/L_b shall be used as k_ϕ in accordance with Sections 2.3.1.3 and 2.3.2.3 (as applicable) of AISI S100 [CSA S136] Appendix 2.

B3.2.2 Bending

Wall *studs* shall be designed for bending either on the basis of all steel design or on the basis of sheathing braced design, in accordance with the following:

(a) All Steel Design. For all steel design, Chapter F of AISI S100 [CSA S136] shall define the *available* flexural *strength* [*factored resistance*]. For distortional buckling if the discrete

bracing fully restricts rotation of the compression *flange* about the *web/flange* juncture, the distance between braces shall be used as L_m in accordance with Sections 2.3.2.3 and 2.3.4.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. If the discrete *bracing* spaced at distance L_b has rotational stiffness k^*_φ against rotation of the compression *flange* about the *web/flange* juncture then k^*_φ/L_b shall be used as k_φ in accordance with Sections 2.3.2.3 and 2.3.4.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. (Draft Ballot CB3)

B3.4 Bracing

B3.4.1 Intermediate Brace Design

B3.4.1.1 For bending members, each intermediate brace shall be designed in accordance with Section C2.2.1 of AISI S100 [CSA S136].

B3.4.1.2 For axial loaded members, each intermediate brace shall be designed in accordance with Section C2.3 of AISI S100 [CSA S136]; however, it shall be permitted for each intermediate brace to be designed for 2% of the design compression force in the member.

B3.4.1.3 For combined bending and axial *loads*, each intermediate brace shall be designed for the combined brace force from bending determined in accordance with Section C2.2.1 of AISI S100 [CSA S136] and from compression determined in accordance with Section C2.3 of AISI [CSA S136] or 2% of the design compression force in the member.

B3.4.1.4 In all steel design accumulation of brace forces shall be considered[5].

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[5] Note, some on the project monitoring task group argued for more prescriptive consideration preferring language such as "and addressed in the design details" as opposed to the more generic "considered" in this clause.

5.5 Draft Ballot CB4: Enable Combined Bracing in AISI S240 B3.2 / B3.4

AISI S240 Section B3.2 and B3.4 on Wall Stud Design should be enabled to allow the new combined bracing provisions through expansion of sheathing braced design provisions.

B3.2 Wall Stud Design

Wall *studs* shall be designed in accordance with the requirements of this section.

B3.2.1 Compression

Wall studs shall be designed for compression either on the basis of all steel design, or on the basis of sheathing braced design with both ends of the stud connected to restrain rotation about the longitudinal stud axis and horizontal displacement perpendicular to the stud axis, in accordance with the following:

(a) All Steel Design. For all steel design of wall *studs* in compression, Chapter E of AISI S100 [CSA S136] shall define the *available* axial *strength* [*factored resistance*]. The effective length, KL, shall be determined by *rational engineering analysis* or testing, or in the absence of such analysis or tests, K_x, K_y and K_t shall be taken as unity. The unbraced length with respect to the major axis, L_x, shall be taken as the distance between end supports of the member, while unbraced lengths L_y and L_t shall be taken as the distance between braces. For distortional buckling i~~I~~f the discrete *bracing* fully restricts rotation of both *flanges* about the *web/flange* juncture, the distance between braces shall be used as L_m ~~in determining the distortional buckling force~~ in accordance with Sections 2.3.1.3 and 2.3.2.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. If the discrete *bracing* spaced at distance L_b has rotational stiffness k^*_φ against rotation of both *flanges* about the *web/flange* juncture then k^*_φ/L_b shall be used as k_φ in accordance with Sections 2.3.1.3 and 2.3.2.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. (Draft Ballot CB3)

(b) Sheathing Braced Design. For sheathing braced design of wall *studs* in compression, the *available* axial *strength* [*factored resistance*] shall be determined in accordance with Chapter E of AISI S100 [CSA S136] following either (i) the simplified method or (ii) the analysis method.

(i) simplified method: The stud shall have sheathing attached to both *flanges* of the wall *stud*. The unbraced length with respect to the major axis, L_x, shall be taken as the distance between end supports of the member. The unbraced length with respect to the minor axis, L_y, and the unbraced length for torsion, L_t, shall be taken as twice the distance between sheathing connectors, but not less than 12 in. [305 mm]. The buckling coefficients K_x, K_y, and K_t shall be taken as unity.

In determining the distortional buckling strength, the rotational stiffness, k_φ, provided by the sheathing to the *wall stud* shall be determined in accordance with Appendix 1.

To prevent failure of the sheathing-to-wall *stud connection*, where identical gypsum sheathing is attached to both sides of the wall *stud* with screws spaced at a

maximum of 12 inches (305 mm) on center, the maximum axial *nominal load* [*specified load*] in the wall *stud* shall be limited to the values given in Table B3.2-1.

Table B3.2-1
Maximum Axial Nominal Load [Specified Load]
Limited by Gypsum Sheathing-to-Wall Stud Connection Capacity

Gypsum Sheathing	Screw Size	Maximum Nominal [Specified] Stud Axial Load
1/2 inch (12.7 mm)	No. 6	5.8 kips (25.8 kN)
1/2 inch (12.7 mm)	No. 8	6.7 kips (29.8 kN)
5/8 inch (15.9 mm)	No. 6	6.8 kips (30.2 kN)
5/8 inch (15.9 mm)	No. 8	7.8 kips (34.7 kN)

(i) analysis method: The effective length, KL, shall be determined by *rational engineering analysis* or testing, or in the absence of such analysis or tests, K_x, K_y and K_t shall be taken as unity. The unbraced lengths L_x, L_y and L_t shall be taken as the distance between end supports of the member. The stiffness supplied by discrete *bracing* and sheathing *bracing* as defined in AISI S100 [CSA S136] Appendix 3 shall be included when determining the global buckling stress, F_{cre}, per Appendix 2 of AISI S100 [CSAS136].

In determining the distortional buckling strength, the rotational stiffness, k_φ, provided by the sheathing or deck to the *wall stud* shall be determined in accordance with Appendix 1 and additional rotational restraint provided by discrete bracing is permitted to be considered in determining the elastic distortional buckling force in accordance with Sections 2.3.1.3 and 2.3.2.3 (as applicable) of AISI S100 [CSA S136] Appendix 2.

To prevent failure of the sheathing-to-wall *stud connection*, the bearing and pull-through strength of the connection shall be greater than 4% of the design compression force in the member divided by the number of fasteners along the length of the member.

B3.2.2 Bending

Wall *studs* shall be designed for bending either on the basis of all steel design or on the basis of sheathing braced design, in accordance with the following:

(a) All Steel Design. For all steel design, Chapter F of AISI S100 [CSA S136] shall define the *available* flexural *strength* [*factored resistance*]. For distortional buckling if the discrete *bracing* fully restricts rotation of the compression *flange* about the *web/flange* juncture, the distance between braces shall be used as L_m in accordance with Sections 2.3.2.3 and 2.3.4.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. If the discrete *bracing* spaced at distance L_b has rotational stiffness k^*_φ against rotation of the compression *flange* about the *web/flange* juncture then k^*_φ/L_b shall be used as k_φ in accordance with Sections 2.3.2.3 and 2.3.4.3 (as applicable) of AISI S100 [CSA S136] Appendix 2. (Draft Ballot CB3)

available flexural *strength* [*factored resistance*].

(b) Sheathing Braced Design. For sheathing braced design of wall studs in bending the *available* flexural *strength* [*factored resistance*] shall be determined in accordance with Chapter F of AISI S100 [CSA S136] following either (i) the simplified method or (ii) the analysis method.

(i) simplified method:, and for sheathing attached at 12 in. on center or less, global buckling need not be considered and local buckling strength shall be determined in accordance with Section F3 of AISI S100 [CSA S136] assuming full rotational restraint provided by the sheathing, the *available* flexural *strength* [*factored resistance*] shall be the strength determined in accordance with Section F3 with $F_n = F_y$ or $M_{ne} = M_y$ and the strength determined in accordance with Section F4 of AISI S100 [CSA S136].

In determining the distortional buckling strength, the rotational stiffness, k_φ, provided by the sheathing to the compression *flange* of the *wall stud* shall be determined in accordance with Appendix 1

(ii) analysis method: The stiffness supplied by discrete *bracing* and sheathing *bracing* as defined in AISI S100 [CSA S136] Appendix 3 shall be included when determining the global buckling stress, F_{cre}, per Appendix 2 of AISI S100 [CSAS136]. It is permitted to consider inelastic reserve per Section F2.4.

In determining the distortional buckling strength, the rotational stiffness, k_φ, provided by the sheathing or deck to the *wall stud* shall be determined in accordance with Appendix 1 and additional rotational restraint provided by discrete bracing is permitted to be considered in determining the elastic distortional buckling moment in accordance with Sections 2.3.2.3 and 2.3.4.3 (as applicable) of AISI S100 [CSA S136] Appendix 2.

To prevent failure of the sheathing-to-wall *stud connection* the bearing strength of the connection shall be greater than the torsional demand tributary to the fastener divided by the ½ the web width and the pull-through strength of the connection shall be greater than the torsional demand tributary to the fastener divided by ½ the flange width. The torsional demand tributary to the fastener is $w_r d_f e$ where w_r is the distributed line load transverse to the stud, d_f is the length tributary to the fastener (i.e., the fastener spacing) and e is the distance from the shear center of the stud to the line of load application.

B3.4 Bracing

B3.4.1 Intermediate Brace Design

B3.4.1.1 For bending members, each intermediate brace shall be designed in accordance with Section C2.2.1 of AISI S100 [CSA S136].

B3.4.1.2 For axial loaded members, each intermediate brace shall be designed in accordance with Section C2.3 of AISI S100 [CSA S136]; however, it shall be permitted for each intermediate brace to be designed for 2% of the design compression force in the member.

B3.4.1.3 For combined bending and axial *loads*, each intermediate brace shall be designed for the combined brace force from bending determined in accordance with Section C2.2.1 of AISI S100 [CSA S136] and from compression determined in accordance with Section C2.3 of AISI [CSA S136] or 2% of the design compression force in the member.

B3.4.1.4 In all steel design accumulation of brace forces shall be considered.

B3.4.1.5 In sheathing braced design accumulation of brace forces need not be considered, except when evaluating per the load combination of B1.2.2.4 in the condition when bracing from sheathing is not permitted. When intermediate discrete braces and sheathing bracing are both resisting buckling of the wall stud the relative stiffness may be used to determine the demands on the intermediate braces when evaluating per the criteria of B3.4.1.1, B3.4.1.2, or B3.4.1.3.

6   Recommendations

The ballots provided in the previous section give a clear picture of what would be required to implement combined bracing wall stud design in AISI S240 and AISI S100. However, the test-to-predicted ratios consistently less than 1.0 for the small testing sample suggest some caution before adoption. Conservative adjustment of the resistance and safety factors may be possible.

Additional testing should be conducted. The testing should consider 6 in. and potentially 8 in. deep studs that have greater reductions due to local buckling than the 362S162-68 [50ksi] tested here, and potentially those studs where distortional bucking (narrow flanges cause this) is predicted to control the capacity. Examination of studs with higher gravity loads (i.e. larger compressive capacity), and as a result higher connection forces, is also recommended.

Criteria for defining when sheathing can be considered in design is needed. In Ballot CB2 proposed herein the following language is developed "sheathing that is in-place during construction and able to withstand sprinklers or other environmental conditions expected during the life of the assembly without substantial loss in stiffness." This is useful but substantial loss in stiffness is not quantified. In the past the stiffness of gypsum board sheathing to steel shear connections under different humidity conditions has been examined and is known to be significant. With the elastic buckling tools now in place it is possible to perform a parametric study to demonstrate the sensitivity of the predicted stud strength to degradation in sheathing stiffness – if targets for allowed strength degradation are established then it would be possible to quantify what is a "substantial loss in stiffness" and provide engineers with usable guidance. This study is recommended.

The proposed analysis method was fully implemented in spreadsheets for SFIA shapes. If expert opinion could agree on wall stud assembly parameters: stud height and spacing; bridging size, connection, and termination; strapping size and connection (if present); sheathing type and stud-to-sheathing details, then design strength tables could be readily generated. Such tables could be generated and aligned with AISI S100 alone, or enabled with specific details from AISI S240.

Of previous (SB1-SB13 in Table 2) and proposed ballots (CB1-CB5) the following ballot recommendations are made.

High Priority (do now)

- Develop and complete AISI S100 Appendix 3 to provide engineers a clear means to establish stiffness of connections and other elements that are critical in defining the behavior of CFS systems. This addresses previous SB Ballots 1,3,4, and 11 and enables the CB ballots.

- Process CB Ballot 1 to broadly enable combined bracing of wall studs in AISI S100.

- Advance SB Ballot 12 which provides needed connection capacity calculations for sheathing.

Medium Priority (initiate soon)

- Advance CB Ballot 3 to clean up all steel design and align with AISI S100.

- Add additional elastic buckling solutions to AISI S100 Appendix 2 and commentary, addressing SB ballots 6, 8 and 9.

Low Priority (initiate when additional work/discussion completed)

- Enable S240 specific combined bracing design with ballots CB2 and 4.

7   Conclusions

Cold-formed steel walls rely on both discrete bracing and sheathing bracing of the wall studs in real assemblies to achieve successful performance under gravity loads. When sheathing is not yet in place, e.g. during construction using on-site stick building methods, or when sheathing is compromised, e.g. due to sprinklers or prolonged high levels of humidity that degrade some sheathing materials, steel discrete bracing is critical; however, in all other situations the relative stiffness of sheathing bracing is such that the sheathing is the primary means of bracing the stud. Design methods which consider only discrete bracing indicate large accumulation of forces in the provided braces; however, if sheathing is also present this accumulation does not readily occur. Combined discrete and sheathing bracing is an important benefit of typical cold-formed steel wall assemblies, but these benefits are not currently enabled in design through AISI S240 or AISI S100.

Compression tests of a typical wall assembly demonstrate that when sheathing is present the bridging need not be resolved at the wall ends. Gypsum sheathing on both sides of the wall leads to higher strength and a more favorable failure mode and post-peak response than fully resolved discrete bridging. Further, with respect to ultimate response, it is shown that the sheathing can be applied after service dead load without changing the bracing condition. Finally, we also show that one-sided sheathing can provide bracing at least as effective as a fully anchored discrete bridging; however, to achieve the most desirable limit state, strength, and post-peak response two-sided sheathing is favored.

A complete suite of spreadsheets was prepared for aiding the engineer in calculating the elastic local, distortional, and global buckling load of a wall stud considering both discrete bracing and sheathing bracing. The spreadsheets were utilized to predict the strength of the tested walls and it was found that the predictions of the walls tested in this effort with combined bracing are currently unconservative. This contrasts with previously tested walls with only sheathing bracing that were predicted conservatively. This result suggests at least a modest amount of additional work is needed. Recommendations are provided for this additional work. A complete suite of ballots was provided that would enable combined bracing to be utilized by engineers employing future editions of AISI S240 and AISI S100 in their designs.

References

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AISI S240 (2015). "North American Standard for Cold-Formed Steel Structural Framing." American Iron and Steel Institute, *AISI-S240-15,* Washington, DC.

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Appendix: Written Example of Predicted Strength

Complete examples are given in the accompanying spreadsheets and video explainer. A brief written example is provided here for additional reference.

Details: Similar to the wall tested in this project, consider an 8 ft × 8 ft CFS wall with 362S162-68 [50 ksi] studs spaced 2 ft apart and attached at top and bottom to two 8-ft long 362T125-68 [50 ksi] tracks. The studs have standard obround punchouts with dimensions of 1 1/2 in. x 4 in. 150U150-54 CRC bridging is utilized through the punchout at the mid-height of the stud. The CRC bridging is attached to the studs with a 1 ½ in. x 1 ½ in. 54 mil angle connected with #10 steel-to-steel fasteners. The CRC bridging is anchored to a fixed support at one end. Also ½ in. lightweight sheetrock (installed vertically) with #6 @ 12 in. o.c. screw fasteners is attached to one side of the wall.
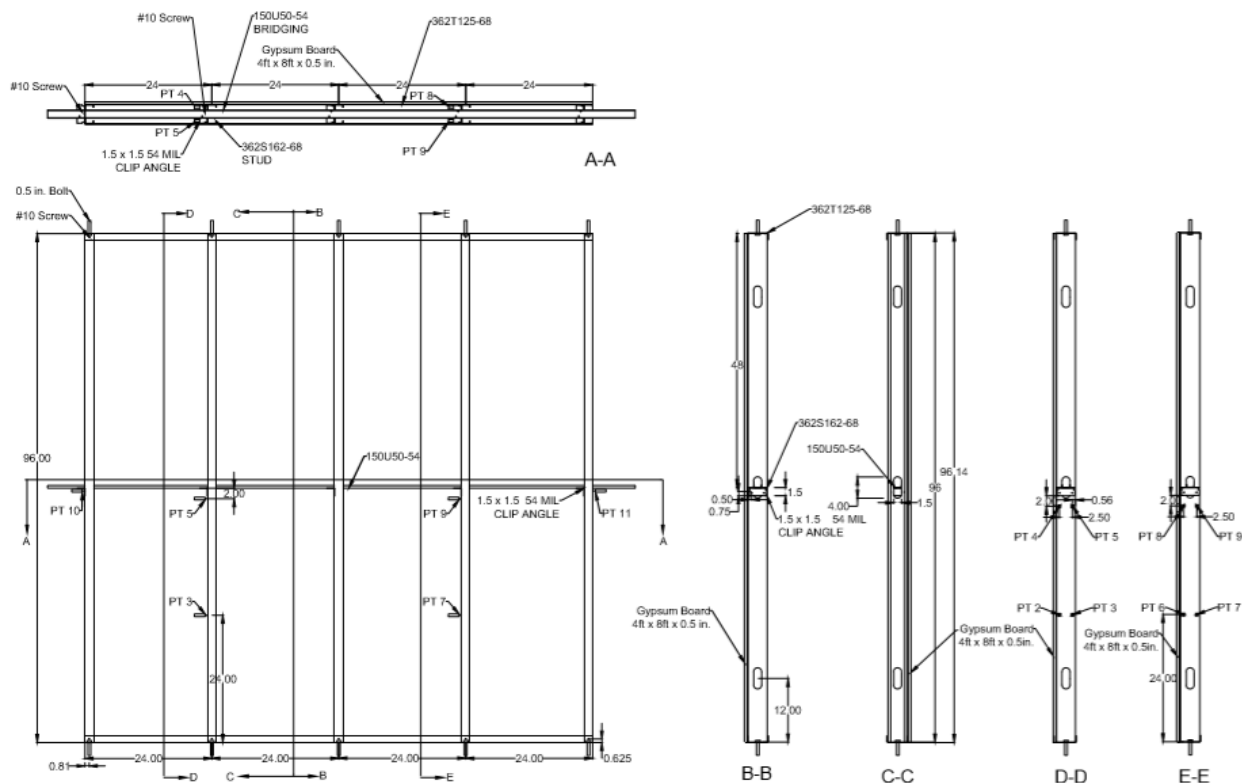
Objective: What is the nominal strength of a typical stud in this wall?

Solution:

Find the squash load and net squash load of the stud:

$$P_y = A_g F_y = 0.524in^2 \times 50ksi = 26.2 \ kips$$

> A_g can be found from the SFIA Technical Catalog or AISI D100 and is also automatically calculated in spreadsheet 01_Pcre_analytical_v10 once the stud section is selected based on SFIA tables.

$$P_{ynet} = A_{net}F_y = 0.4166in^2 \times 50ksi = 20.8 \ kips$$

A_{net} is not conveniently available in the SFIA Technical Catalog or AISI D100, but it is automatically calculated in spreadsheet 01_Pcre_analytical_v10 once the stud section is selected based on the standard punchout defined in the SFIA Technical Catalog.

Note, P_{ynet} is a practical upperbound. If this is a design problem this is the maximum capacity this stud will be able to withstand under fully braced and fully effective conditions. If this capacity is insufficient a new section should be selected before continuing with more involved calculations.

Global Buckling:

Elastic Critical Global Buckling, P_{cre}

The CRC bridging and gypsum board attached to one side of the stud have a strong influence on the global buckling strength. The spreadsheet "01_Pcre_analytical_v10" provides the calculation details. However the major steps are as follows: (1) find the spring stiffness for the CRC bridging system, (2) find the spring stiffness for the gypsum sheathing, (3) find the elastic critical global buckling load using these spring stiffness values.

(1) Stiffness of CRC bridging system

In-plane lateral stiffness

$$\beta = \left(\beta_{connection}^{-1} + \beta_{bridging}^{-1} + \beta_{strongback}^{-1}\right)^{-1}$$

$\beta_{connection} = 7.02\ kip/in.$ is the stiffness of the clip and fastener to the stud, this has been tested, and is referenced in the "01_Pcre_analytical_v10" spreadsheet. Interpolation of the tested data which is sensitive (primarily) to the stud thickness is utilized.

$\beta_{briding} = EA/L = 39.95\ kip/in.$ is the stiffness of the CRC bridging. Here we have chosen the stud farthest from the supported end (strongback end) and $L =96$ in., A of the CRC is automatically taken from SFIA tables based on the designation in the "01_Pcre_analytical_v10" spreadsheet.

$\beta_{strongback}$ termed β_{brace} in the spreadsheet is the stiffness of the support for the CRC bridging. In practice this might be the bending stiffness of a strong back, axial stiffness of a kicker, etc. Here we assume termination to a fixed support and use an artificially high value of 1000 kip/in. to eliminate this flexibility.

$\beta = 5.94\ kip/in.$ also known as k_x in the calculations, and is applied at mid height.

Torsional stiffness

$$\beta_T = 14.8\ kip - in./rad$$

This is the torsional stiffness the clip fastened CRC bridging provides to a stud – this is based on tests, and is referenced in the "01_Pcre_analytical_v10" spreadsheet. Interpolation of the tested data which is sensitive (primarily) to the stud depth and thickness is utilized. β_T is also known as k_ϕ in the calculations.

(2) Stiffness of Fastened Gypsum Sheathing

In-plane lateral stiffness

$$k_x = (k_{xl}^{-1} + k_{xd}^{-1})^{-1}$$

$k_{xl} = 2.779\ kip/in.$ is the in-plane stiffness of stud-fastener-gypsum connection and can be based on formulas developed in the sheathing bracing project or on testing. The formula from Schafer (2013) is implemented here:

$$k_{xl} = \frac{3\pi E d^4 t^3}{4t_b^2(9\pi d^4 + 16 t_b t)}$$

where E is Young's modulus of the steel, t is the thickness of the flange of the stud, d is the diameter of the fastener, and t_b is the thickness of the gypsum board, see spreadsheet for intermediate calculations.

$k_{xd} = 12.337\ kip/in.$ is the in-plane stiffness of the gypsum sheathing, the formula from Schafer (2013) is implemented here:

$$k_{xd} = \frac{\pi^2 G_b t_b d_f^4 w_{tf}}{L^2}$$

where d_f is the distance between fasteners, w_{tf} is the width of the sheathing tributary to the fastener, G_b is the shear modulus of the gypsum which can come from testing or bounds provided from the Gypsum Association (lowerbound used here), t_b is the thickness of the gypsum sheathing board, and L is the sheathing height, see spreadsheet for full implementation.

$k_x = 2.268\ kip/in.$

Torsional Stiffness

$$k_\phi = 0.989\ kip - in./rad$$

The torsional stiffness is the same calculation used in distortional buckling and already explained in AISI S240-15 Appendix 1. Contributions from both the local connection stiffness and the gypsum are both considered in series. Here the local stiffness, not the foundation stiffness (i.e. per unit length), is employed.

Out-of-plane stiffness

$$k_y = 0.005\ kip/in.$$

The out-of-plane stiffness is a means to account for the gypsum sheathing contribution in major-axis bending of the studs. Schafer (2013) defines this as follows:

$$k_y = \frac{(EI)_w \pi^4 d_f}{L^4}$$

where d_f is the distance between fasteners, L is the sheathing height, and $(EI)_w$ is the additional bending rigidity contributed by the sheathing. If composite action is ignored it is just the EI of the sheathing alone, e.g., from GA-235-10 for gypsum sheathing. If composite action is included then the contribution is back-calculated from tested stiffness – Schafer (2013) provides details. Here composite action is

ignored and tabulated values from the Gypsum Association are employed – and effectively the amount is small enough it could be ignored.

Summary of Springs
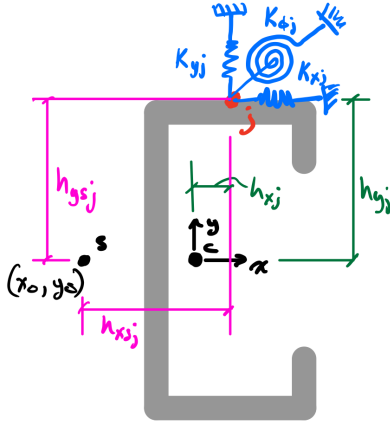
at mid-height from the CRC bridging system the stud has spring $k_{xi} = \beta$ and spring $k_{\phi i} = \beta_T$ located mid-web

every 12 in. o.c. up the height developed from the screw fastened gypsum board the stud has springs k_x, k_y, and k_ϕ located mid-flange of one flange.

(3) Elastic critical global buckling load

The specific formula for the elastic critical global buckling load are given in this report and implemented in 01_Pcre_analytical_v10.

Note, the member itself has holes, so the spreadsheet 01_Pcre_analytical_v10 implements the reduced average global properties (I, C_w, etc.) recommended by AISI S100 to account for this effect. These properties are calculated for all SFIA sections and provided in the spreadsheet – these properties are not provided in the SFIA Technical Catalog.

The solution is:

$$P_{cre} = 22.49 \; kips = 0.86P_y$$

Note, the spreadsheet also provides the buckling mode in details which indicates the mode includes torsion as well as major- and minor-axis flexure (this is primarily due to having gypsum on one side only) and the lowest mode is the 2nd mode (this is primarily due to the large restraint provided by the CRC bridging at mid-height of the stud).

Global Buckling Strength, P_{ne}

With the elastic buckling load and the squash load known the global buckling strength may be readily found using AISI S100 Chapter E. Specifically AISI S100 Section E2, Eq. E2-2 ad E2-3 provides the solution and the formula are implemented in the spreadsheet 04_Pn_DSM_v2:

$$P_{ne} = 16.1 \; kips$$

This is the global strength of the stud independent of local and distortional buckling. Since this value is less than P_{ynet} this is now the new upperbound strength. Calculations continue if this capacity is adequate, otherwise a new section must be sought.

Local buckling strength, $P_{n\ell}$

The local buckling strength includes interaction with global buckling. Per AISI S100 Section E3 this strength may be calculated by EWM or DSM – either is acceptable. For this example DSM is followed. The first step in the DSM approach is to provide the elastic critical local buckling load, this is provided for all SFIA sections in the spreadsheet 03_Pcrl_Pcrd_database_v2.

$P_{cr\ell-nohole} = 31.5\ kips$

$P_{cr\ell-hole} = 48.4\ kips$

In this member local buckling away from the hole is at a lower elastic buckling load than in the net section. So the elastic critical local buckling load is therefore

$P_{cr\ell} = 31.5\ kips$

With the elastic critical buckling load, $P_{cr\ell}$, and the global buckling strength P_{ne}, the local buckling strength can be determined per AISI S100 Eq. E3.2.1-1 and -2 resulting in

$P_{n\ell} = 16.1\ kips$

This value is lower than P_{ynet} so this is the predicted local strength of the section as detailed in the spreadsheet 04_Pn_DSM_v2.

Distortional buckling strength, P_{nd}

The distortional buckling strength is calculated independently. The first step in the DSM approach is to provide the elastic critical local buckling load, this is provided for all SFIA sections in the spreadsheet 03_Pcrl_Pcrd_database_v2.

$P_{crd-nohole} = 38.4\ kips$

$P_{crd-hole} = 31.9\ kips$

In this member the hole reduces the elastic distortional buckling load. So the elastic critical distortional buckling load is therefore:

$P_{crd} = 31.9\ kips,$

with the elastic critical buckling load, P_{crd}, and the squash load, P_y, and net squash load, P_{ynet}, the distortional strength P_{nd} can be determined per AISI S100 Section E4:

$P_{nd} = 17.99\ kips$

Predicted nominal strength

$P_n = min(P_{ne}, P_{n\ell}, P_{nd}) = 16.1\ kips$

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