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CFSEI
COLD-FORMED STEEL ENGINEERS INSTITUTE

TECHNICAL NOTE

On Cold-Formed Steel Construction

Cold-Formed Steel Engineers Institute ● Falls Church, VA ● www.cfsei.org ● 800-79-STEEL

COLD-FORMED STEEL FLOOR JOIST DESIGN

This Tech Note Updates and Replaces Tech Note J100-11

Summary: Cold-formed steel (CFS) joists have become very popular where non-combustible material and long unsupported spans are required in design. The purpose of this Tech Note is to provide a review and summary of the AISI S240, *North American Standard for Cold-Formed Steel Structural Framing* and S100, *North American Specification for the Design of Cold-Formed Steel Structural Members* design requirements for cold-formed steel floor joists.

BEHAVIOR OF C-SECTIONS

Cold-formed steel joist members are typically C-shaped cross sections. The C-shape is singly symmetric with the shear center eccentric from the centroid as shown in Figure 1. If the C-section is not braced and is not loaded through the shear center, it will twist (Figure 1). If the C-section is discretely braced the C-shape member may also undergo global, i.e., lateral-torsional, buckling between the brace locations when subject to major axis bending.

In addition to global buckling, the local buckling mode may influence the behavior of the compression elements of the cross section, i.e., web, compression flange, and edge stiffener. Distortional buckling also must be considered, and it occurs when the compression flange and the lip rotate about the flange web junction with the web providing some elastic restraint to rotation. A rigid floor sheathing, such as plywood, may also provide some restraint against distortional buckling.

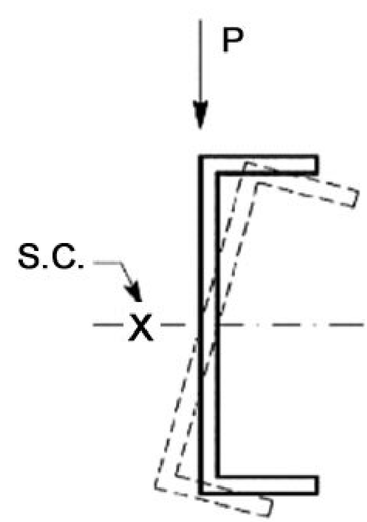

Figure 1: C-Section Behavior.

A floor joist is a structural element within a floor assembly. The assembly consists of the cold-formed steel C-section, sheathing attached to the top compression flange, and discrete braces attached to the tension flange. Thus, within the floor assembly the behavior of the C-section is restrained, and the following potential strength and serviceability limit states may occur:

- Initiation of yielding for major axis bending.
- Distortional buckling.
- Web crippling.
- Shear.
- Combinations of bending and shear and bending and web crippling (continuous spans).
- Vertical deflection of the joist.
- Floor vibration.

An excellent resource for design of CFS floor systems is AISI D110, *Cold-Formed Steel Framing Design Guide.*

BUILDING CODE SPECIFIED DESIGN REQUIREMENTS

Cold-formed steel floor systems are designed in accordance with the AISI S240, *North American Standard for Cold-Formed Steel Structural Framing* or solely in accordance with the requirements of the AISI S100, *North American Specification for the Design of Cold-Formed Steel Structural Members*.

AISI S240 permits design based on either discretely braced design or on based on continuously braced design. However, the typical floor joist is continuously braced by sheathing attached to the compression flange. The design provisions of AISI S240 for a continuously braced design are summarized as follows:

Bending (Section B2.2.1)

For flexure alone, the yield moment, as determined in accordance with Chapter F of AISI S100 applies. Both yielding and distortional buckling are to be considered.

To achieve the yield moment, continuous bracing must be provided in accordance with Section B2.6 of AISI S240 which stipulates that the sheathing shall consist of a minimum of 3/8 inch wood structural sheathing that complies with DOC PS 1, DOC PS 2, or steel deck with a minimum profile depth of 9/16” and a minimum thickness of 0.0269”. The sheathing or deck shall be attached with minimum No. 8 screws at a maximum 12 inches on center.

In addition to sheathing or deck attached to the compression flange, Section B2.6 of AISI S240 requires that for joist spans that exceed 8 feet, the tension flange shall be laterally braced at a maximum spacing of 8 feet (Figures 2 and 3). AISI S240 Section 4.5 stipulates that each brace is to be designed for the following force for uniformly loaded joists:

$P_L = 1.5\ (m/d)\ F$ (B4.5-1, AISI S240)

F = uniform joist load x brace spacing
m = distance from shear center to mid-plane of web
d =depth of C-shape section

For concentrated load applications, see AISI S240 Section B4.5.

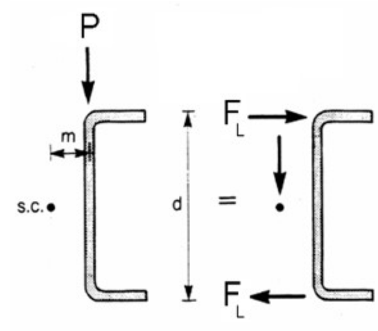

Figure 2: Required Brace Force.

Shear (Section B2.2.2)

Shear alone shall be evaluated in accordance with AISI S100 Chapter G. Chapter G contains provisions for both the un-punched and punched web.

Web Crippling (Section B2.2.3)

Unless a web stiffener is used, web crippling alone shall be evaluated by using AISI S240 Section B1.6 and AISI S100 Chapter G. S100 contains design provisions for both the un-punched and punched web.

Bending and Shear (Section B2.2.4)

AISI S100 Chapter H is to be used to evaluate the combination of bending and shear.

Bending and Web Crippling (Section B2.2.5)

Unless a web stiffener is used, AISI S100 Chapter H is to be used to evaluate the combination of bending and web crippling.

Distortional Buckling (Section B2.2.1)

AISI S240 enables design based on discretely braced design or based on continuously braced design. AISI S100 Chapter F is to be used to assess the flexural performance of a beam. CFSEI Tech Note G101, *Design Aids and Examples for Distortional Buckling* provides design aids as well as examples to assist with the evaluation of distortional buckling.

Bearing Stiffeners (Section B2.5)

For bearing stiffeners other than clip angles, the design shall be in accordance with Chapter F of AISI S100. For clip angle bearing stiffeners the design is to be in accordance with Section B2.5.1 of AISI S240. Design guidance and examples for clip angle bearing stiffeners are given in CFSEI Tech Note F100.

Serviceability

AISI S240 is silent regarding design for serviceability of floor joists. However, AISI S100 Chapter L provides guidance regarding the design for serviceability. Serviceability limits should be chosen based on the intended function of the structure and should be evaluated using realistic loads and load combinations.

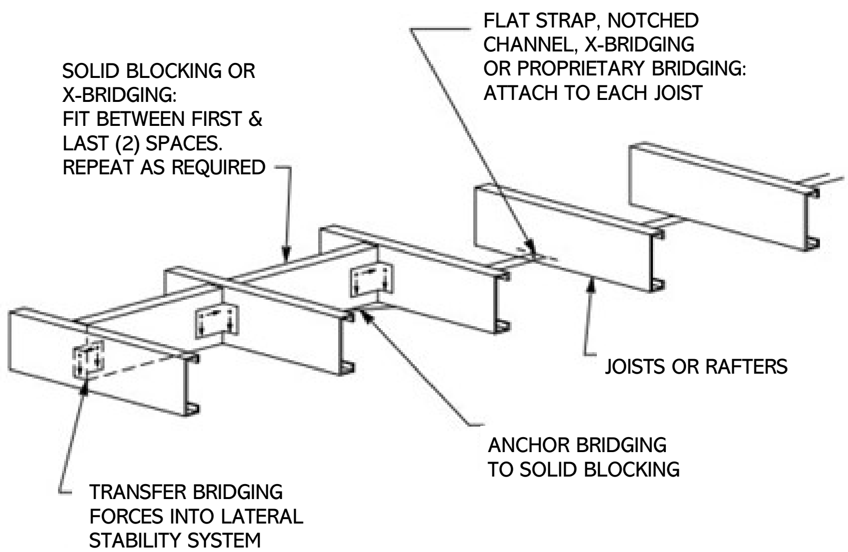

Figure 3: Tension Flange Bracing.

For floor vibrations AISI S240 is silent. A common industry guideline is to limit the live load deflection to L/480. The tacit assumption is that this more stringent static load deflection limit provides for an acceptable floor vibration performance. This is an oversimplified vibration assessment and may not be applicable to all floor systems. If a concrete floor slab is being used the AISC *Design Guide* No. 11 may be used.

DESIGN OF FLOOR JOISTS

Floor joist design typically involves the determination of the maximum permissible joist span for a specified loading condition and spacing. Manufacturer's load tables and AISI S230, *Standard for Cold-Formed Steel Framing – Prescriptive Method for One- and Two-Family Dwellings* tabulates the maximum permissible span. Figures 4, 5 and 6 illustrate typical floor joist installations.

The following discussion summarizes the evaluation of the maximum permissible span for the various limit states.

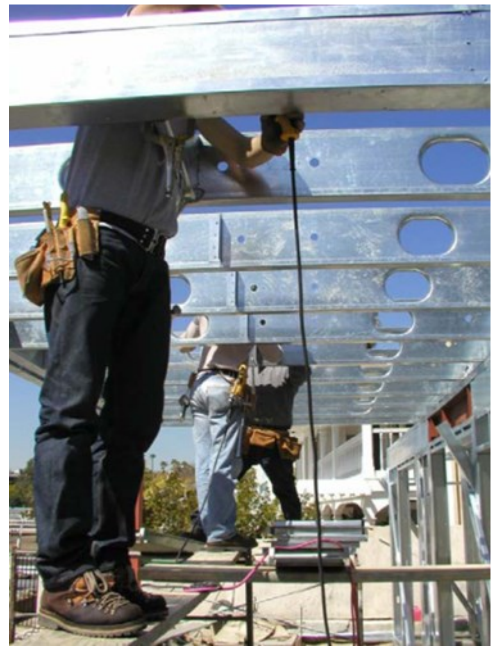

Figure 4: Solid segments of stud used as blocking and bridging: during and (below) after installation.

Bending

The maximum joist span is a function of the span, simple or continuous, and the cross section bending strength. For a simple span joist with uniform load.

For load and resistance factor design (LRFD):

$$\phi M_n = wL^2/8 \qquad L = \sqrt{8\phi M_n / w}$$

For allowable strength design (ASD):

$$M_n/\Omega = wL^2/8 \qquad L = \sqrt{8M_n / \Omega w}$$

Figure 4: After installation.

Shear

Figure 5: Flat strapping for tension flange bracing. Solid blocking is used at each end of strap, as well as 10′ on center along length of strap. Although top flanges may be braced with sheathing, this installation uses top strap as well.

For a simple span joist with uniform load.

For LRFD:

$\varphi V_n = wL/2$ $\quad$ $L = 2\varphi V_n/w$

For ASD:

$V_n/\Omega = wL/2$ $\quad$ $L = 2V_n/\Omega w$

Web Crippling

The equations below are for a simple span joist uniformly loaded without web stiffeners. If web stiffeners are used, this design check is not required.

For LRFD:

$\varphi R_n = wL/2$ $\quad$ $L = 2\varphi R_n/w$

For ASD:

$R_n/\Omega = wL/2$ $\quad$ $L = 2R_n/\Omega w$

Deflection

Defection is evaluated at service load therefore ASD and LRFD design checks are the same. For a simple span joist uniformly loaded,

$\Delta = 5wL^4/(384EI_x)$

Although L/360 is permitted by code, the deflection limit is typically L/480 for live load and L/240 for total load. If expressed as L/δ the above equation is

$1/\delta = 5wL^3/(384EI_x)$

$L = \sqrt[3]{(384)ELx)/(5w\delta)}$

Figure 6: Detail of solid blocking – from installation shown in Figure 5.

DESIGN EXAMPLE

1000S162-54, F_y = 33 ksi joists are simple span members spaced 24" on center. The joist does not have web holes. The floor live load is 40 pounds per square foot (psf) and dead load is 10 psf. The compression flange of the joist is continuously braced by sheathing that complies with Section B2.6 of AISI S240.

Determine the maximum joist span and the tension flange brace requirement, P_L.

For strength limit states, the required strength:

For LRFD: R_u = 1.2 D + 1.6 L = (1.2 x 10 psf + 1.6 x 40 psf) x 2′ = 152 plf

For ASD: R = D + L = (10 psf + 40 psf) x 2′ = 100 plf

For serviceability limit state, the total design load is D + L = 100 plf

Bending

φM_n = 51.14.98 in.-kips = 4,261 ft-lb (Yield Limit State)
= 46.72 in.-kips = 3,893 ft-lb (Distortional Buckling Limit State)

L = $\sqrt{8\phi Mn/w}$ = $\sqrt{8x3{,}893\ /152}$ = 14.31 = 14′- 4″

ASD:

$M_n\Omega$ = 34.03 in-kips = 2,836 ft-lb (Yielding Limit State)
= 31.09 in-kips = 2,591 ft-lb (Distortional Buckling Limit State)

L = $\sqrt{8\ Mn\ /w}$ = $\sqrt{8\ x\ 2{,}591\ /100}$ = 14.40 = 14′- 5″

Shear

For a simple span joist,

For LRFD:

φV_n = 2.52 kips = 2,520 lbs
L = $2\varphi V_n/w$ = 2 x 2,520 / 152 = 33.15 = 33′ - 2″

FOR ASD:

V_n/Ω = 1.66 kips = 1,660 lbs
L = $2V_n/\Omega w$ = 2 x 1,660 / 100 = 33.20 = 33′ - 2″

Web Crippling

Floor joists are typically required to have bearing stiffeners therefore web crippling need not be evaluated.

Deflection

Deflection is evaluated at service load therefore ASD and LRFD design checks are the same. The service total load is 100 lb/ft = 8.33 lb/in., service live load = 80 lb/ft = 6.67 lb/in, and I_{xe} = 9.5788 in.^{4} at $0.6F_y$.

The deflection limit is L/480 (δ = 480) for live load and L/240 (δ = 240) for total load.

$L = \sqrt[3]{(384)ELx)\ /(5w\sigma)}$

For live load, $L = \sqrt[3]{(384\ x\ 29{,}500{,}000\ x\ 9.5788)\ /(5\ x\ 6.67\ x\ 480)}$

= 189.25″ = 15′ – 9″

For total load, $L = \sqrt[3]{(384\ x\ 29{,}500{,}000\ x\ 9.5788)\ /(5\ x\ 8.33\ x\ 240)}$

= 221.42″ = 18′-5″

Conclusion

The maximum joist span is the minimum span calculated for the above limit states. In this case the maximum span is governed by bending.

Tension Flange Brace

In accordance with AISI S240, the brace spacing shall not exceed 8 ft. Therefore, the tributary load to a brace, F = w a, where a is the brace spacing.

LRFD:

F = 152 lb/ft x 8′ = 1,216 lbs.

m = 0.5029″ and d = 10″

P_L = 1.5 (m/d) F = 1.5 x (0.5029 / 10) x 1,216 = 92 lbs

The required cross section area of a tension strap for tensile yielding is computed to be,

$A_s = P_L / 0.90 F_y$ = .092 kips / 0.90 x 33 ksi = 0.0031 in.^{2}

ASD:

F = 100 lb/ft x 8′ = 800 lbs.

m = 0.5029″ and d = 10″

P_L = 1.5 (m/d) F = 1.5 x (0.5029 / 10) x 800 = 60 lbs

The cross section for a tension strap is computed to be,

$A_s = 1.67 P_L / F_y$ = 1.67 x 0.06 kips / 33 ksi = 0.0030 in^2

REFERENCES

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3. AISI S100-16 (2020), *North American Specification for the Design of Cold-Formed Steel Structural Members*, 2016 Edition (Reaffirmed 2020) with Supplement 2 2020 Edition, American Iron and Steel Institute, Washington, D.C.

4. AISI S240-20, *North American Standard for Cold-Formed Steel Structural Framing*, American Iron and Steel Institute, Washington, D.C.

5. AISI S230-19, *North American Standard for Cold-Formed Steel Framing - Prescriptive Method for One- and Two-Family Dwellings*, American Iron and Steel Institute, Washington, D.C.

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8. DOC PS 1-09, *Voluntary Product Standard for Structural Plywood,* 2009 edition, U.S. Department of Commerce, National Institute of Standards and Technology (NIST), Washington, D.C.

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Primary Author of Tech Note:
Nader Elhajj, P.E., FrameCAD Solutions

Technical Reviewers:
Roger LaBoube, Ph.D., P.E., Cold-Formed Steel Engineers Institute.
Brandon Wahl, 360 Engineering Group