Cold-Formed Steel

An Introduction for Building Structural Engineers

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- Teaching
  - Structural Steel Design
  - Advanced Steel Structures
  - Capstone Design
  - Building Loads and Computer Analysis & Design
  - Cold-Formed Steel Design
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Outline

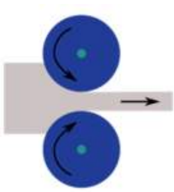
- What is Cold-Formed Steel (CFS)?
- Characteristics of CFS
- CFS in structures
- CFS design
  - Specifications and Standards
  - Limit states
- Useful resources

Cold-Formed Steel

- What is Cold-Formed Steel?
  Steel Sections cold-formed from steel sheet, strip, plate, or flat bar in roll-forming machines or by press brake or bending brake operations.
  - Relatively thin sections of steel plates or sheets
  - Formed into the desired shape while "cold" (room temperature)
- Definition – AISI S100
  "Shapes manufactured by press-braking blanks sheared from sheets, cut lengths of coils or plates, or by roll forming cold- or hot-rolled coils or sheets; both forming operations being performed at ambient room temperature, that is, without manifest addition of heat such as would be required for hot forming."

Cold-Forming

- Steel thin sheets and coils




Cold-Formed To Shapes


Press Brake


Roll Forming


Stamping


Bending Brake

Why use Cold-Formed Steel?

- Efficiency
  - High Strength-to-Weight ratio
- Durability
  - Mold, termites, dry-rot free
  - Corrosion resistant – galvanized
  - Non-combustible
  - Dimensionally stable
- Sustainability
  - 100% recyclable
- Economy
  - Low material cost
  - Prefabrication and panelization

Uses of Cold-Formed Steel

- Common Uses – Non-building
  - Automobiles (cars & trucks), railway cars, etc.
  - Equipment – many industries
  - Furniture
  - Appliances
  - Storage racks
  - Grain bins, silos, etc.

Uses of Cold-Formed Steel

- Building – Non-structural
  - HVAC
  - Doors, windows
  - Partition walls – non-loading carrying
- Building – Structural
  - Decking for floors and roofs
  - Roofing, siding
  - Shear wall sheathing
  - Structural framing
    - Wall studs, braces
    - Floor joists, beams & headers, roof rafters & trusses

CFS Floors and Roofs

Pictures credit: Doug Fox, iSPAN Systems LP

CFS Floors & Roofs

Pictures credit: Don Allen, Super Stud Building Products, Inc.

CFS Walls

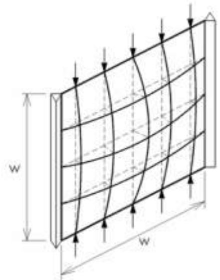
Pictures credit: Don Allen, Super Stud Building Products, Inc.

CFS in Structures


CFS Key Characteristics

- Shapes are cold-formed from flat sheets or plates.
- Thin material (mostly less than 1/8-inch).
- Original mechanical properties of steel are changed in certain areas of shapes, due to cold forming.
- Standardized & customized shapes are available.
- Local buckling is dominant and ubiquitous.
- Post-(local)buckling strength.

Post-Buckling Strength



CFS vs. Steel (Hot-rolled)

- Material thickness (b/t ratio) – Local buckling
- Residual stresses vs. cold-forming strength increase
- Failure modes
  - Hot-rolled steel members
    - Yielding or Global buckling
    - Local buckling is not common.
  - CFS members
    - Yielding or Global buckling mixed with local buckling
    - Local buckling is dominant.
    - Distortional Buckling – unique mode for CFS

Cold-Forming Strength Increase

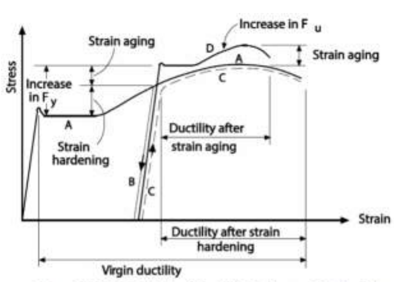
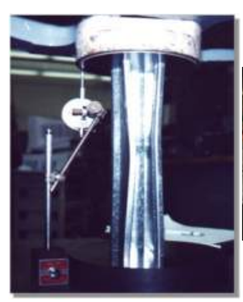
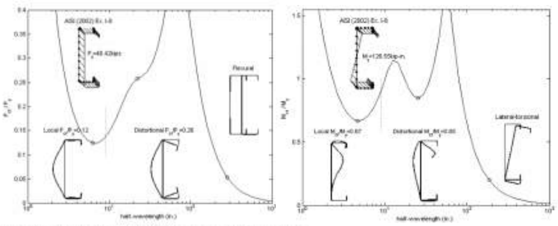


Figure C-A3.3.2-2 Effect of Strain Hardening and Strain Aging on Stress-Strain Characteristics

Distortional Buckling




Signature Curve

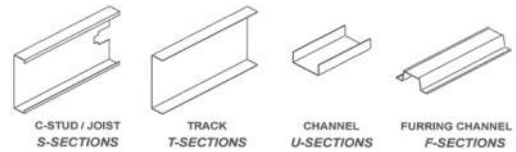


(a) 9CS2.5x059 of AISI *Cold-Formed Steel Design Manual* (2002), Example I-8

Common CFS Shapes

- Joist/Stud and Track Section Nomenclature
  - Member depth in 1/100 in. (S – outer; T – inner)
  - Type of section – S or T
  - Flange width in 1/100 inch
  - Minimum base metal thickness in mils (1/1000 in.)

600S162-43



CFS Thickness

Minimum Thickness (mil)	Design Thickness (inch)	Reference Gauge
18	0.0188	25
27	0.0283	22
30	0.0312	20 Drywall
33	0.0346	20 Structural
43	0.0451	18
54	0.0566	16
68	0.0713	14
97	0.1017	12
118	0.1242	10

CFS Structural Systems

- As secondary framing
  - Façade framing
  - Local framing
- As building main framing
  - Floor and roof framing
    - Gravity load resisting systems
    - Lateral load resisting systems – as diaphragm
  - Wall framing
    - Gravity load resisting systems – bearing walls
    - Lateral load resisting systems – shear walls

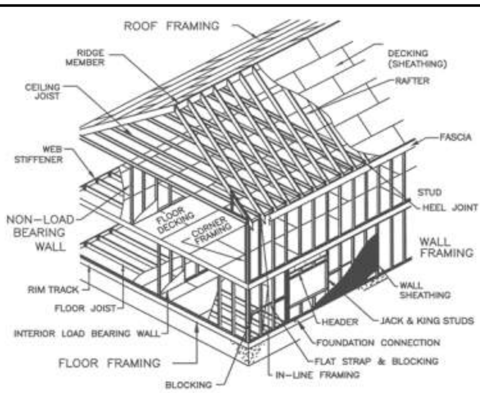
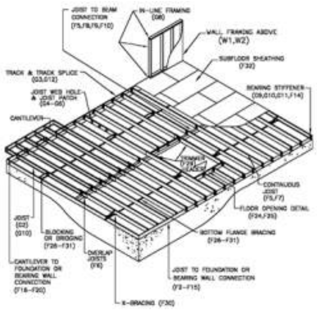


Figure 1.4
Schematic of Typical Steel Framed Building

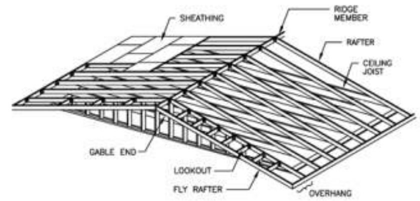
CFS Floor & Roof Systems

- Floor Joists
- Ceiling Joists
- Roof Purlins and Rafters
- Roof trusses
- Flexural members

CFS Floors



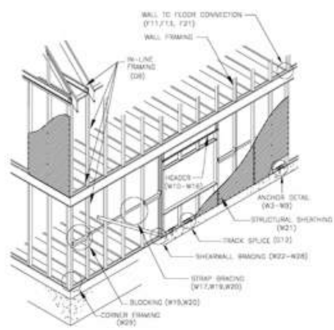
CFS Roofs



CFS Wall Systems

- CFS wall studs similar to traditional wood construction
- Façade wall studs – non-load-bearing
  - Flexural members
- Bearing wall studs – bearing
  - Axial compression members
  - Beam-columns (exterior walls)
- Shear wall studs
  - Work with sheathing (wood or CFS)
  - Often also serve as bearing walls

CFS Walls



Design of CFS Structures

- American Iron & Steel Institute (AISI) Codes & Standards
  - Same codes and standards in Canada & Mexico
  - Three main documents for CFS structural design
  - AISI S100 – *North American Specification for the Design of Cold-Formed Steel Structural Members* – Main Design Code, equivalent to AISC 360
  - AISI S240 – *North American Standard for Cold-Formed Steel Structural Framing* – Prescribed requirements for different components, design largely refer to S100
  - AISI S400 – *North American Standard for Seismic Design of Cold-Formed Steel Structural Systems* – Seismic provisions, equivalent to AISC 341

S100-16 – Specification

- Main design code for CFS
- 2016 version was reorganized to align with AISC Specification
- Two parallel methods in dealing with local buckling of CFS members
  - Effective Width Method (EWM)
  - Direct Strength Method (DSM)

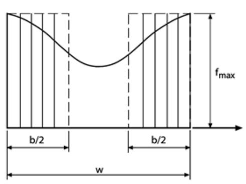
ANSI/AISI S100-16 – Specification

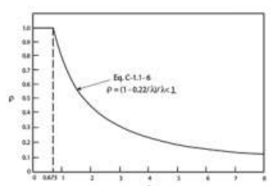
A. General Provisions
B. Design Requirements
C. Design for Stability
D. Members in Tension
E. Members in Compression
F. Members in Flexure
G. Members in Shear and Web Crippling
H. Members under Combined Forces

ANSI/AISI S100-16 – Specification

I. Assemblies and Systems
J. Connections and Joints
K. Strength for Special Cases
L. Design for Serviceability
M. Design for Fatigue
Appendix 1: Effective Width of Elements
Appendix 2: Elastic Buckling Analysis of Members
Appendix A: Provisions Applicable to the US & Mexico
Appendix B: Provisions Applicable to Canada

Effective Width Method





$$\lambda = \sqrt{\frac{f_{max}}{F_{cr}}}$$

Direct Strength Method

- Alternative method to EWM in local buckling
- Only method in distortional buckling
- Based on the idea that nominal strength is a function of slenderness
- An extension of EWM
- Use $\sqrt{\frac{P_y}{P_{cr}}}$ as slenderness index
- Equations were calibrated with experimental data

Direct Strength Method

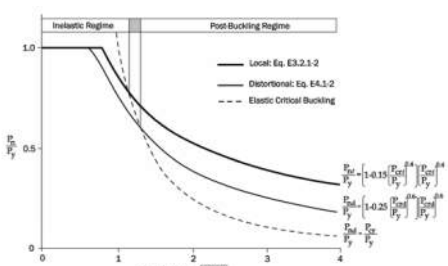


Figure C-E1-1 Local and Distortional Direct Strength Curves for a Braced Column ($P_{ne} = P_y$)

S240 – Standard for CFS Framing

- Six Chapters and Two Appendices
- Chapter B is about design
- B2 – Floor and Ceiling Framing
- B3 – Wall Framing
- B4 – Roof Framing
- B5 – Lateral Force-Resisting Systems
- Largely refers to AISI S100 for member and connection design

S400 – Standard for Seismic Design

- Use CFS as seismic force resisting system (SFRS)
- ASCE 7 Table 12.2-1:
  - CFS SFRS: A16, A18, B23, C12, H
  - S400 applies to all except H
- Eight Chapters and One Appendix
- Chapter C – Analysis
- Chapter E – Seismic Force-Resisting Systems
- Chapter F – Diaphragms

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CFS Compression Members

- Bearing wall studs – S100 Ch. E, S240 B3
- Bracing: Sheathing vs. all steel design
- Limit states
  - Yielding and Global Buckling (Flexural, Torsional, Flexural-Torsional) (S100 E2)
  - Local Buckling Interacting With Yielding and Global Buckling (S100 E3)
  - Distortional Buckling (S100 E4)

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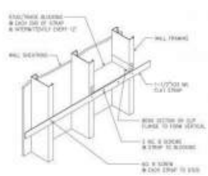
Bracing of Wall Studs



Picture credit: https://www.buildsteel.org

Picture credit: Don Allen, Super Stud Building Products

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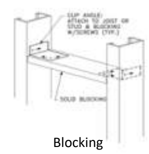
Bracing of Wall Studs



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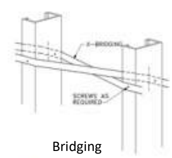

Bridging

Proprietary Systems

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CFS Flexural Members

- Floor joists, ceiling joists and roof rafters
- Non-load bearing exterior wall studs
- Discretely braced design vs. continuously braced design
- Limit states (Flexure)
  - Yielding and Global (Lateral-Torsional) Buckling (S100 F2)
  - Local Buckling Interacting With Yielding and Global Buckling (S100 F3)
  - Distortional Buckling (S100 F4)

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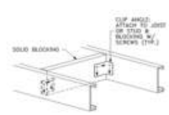
Bracing of Joists



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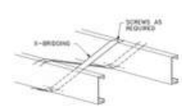
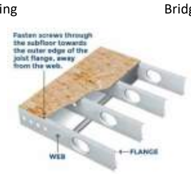


Bridging



Continuously braced

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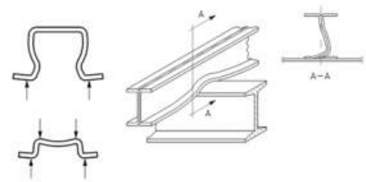
Shear Strength

- Similar to plate girders, even more slender
- Limit States
  - Shear yielding
  - Shear local buckling
- Shear strength of members w/o web openings (S100 G2)
- Effects of web openings (S100 G3)
- Transverse web stiffeners (S100 G4)

Web Crippling

- A local buckling phenomenon under local high intensity of compressive stresses due to applied loads or reactions
- S100 G5 and G6



Web Crippling

- Several factors play important role in web crippling strength
- For loading conditions

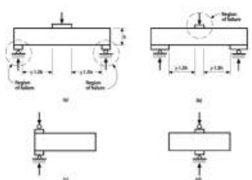


Figure C-G5-2 Loading Conditions for Web Crippling Tests:
(a) EOF Loading, (b) IOF Loading, (c) ETF Loading, (d) ITF Loading

Bearing Stiffeners

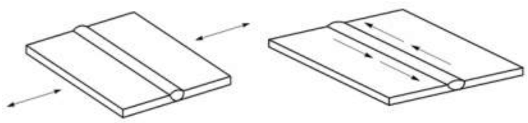
Connections – S100 Chapter J

- Welds
  - AWS D1.3, C1.1 or C1.3 for resistance welds
- Bolts
  - Typically non-high strength, small diameter
  - ASTM A307 most common
- Screws
  - No pre-drilling, fast installation
  - Probably most common connection in CFS
- Power-Actuated Fasteners (PAFs)
  - Proprietary products

Welds – Section J2

- Groove welds in butt joint
- Arc spot welds
- Arc seam welds
- Top arc seam sidelap welds
- Fillet welds
- Flare groove welds
- Resistance welds

Groove Welds

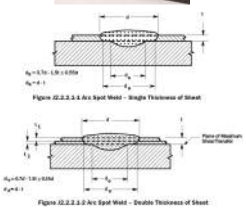


In Tension
Limit state to check:
- Base material (sheets) yielding

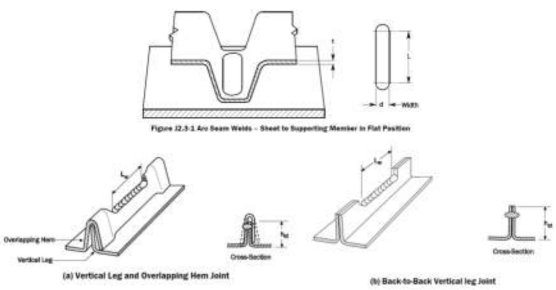
In Shear
Limit states to check:
- Weld metal rupture
- Base material (sheets) yielding

Arc Spot (Puddle) Welds

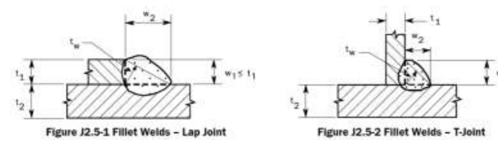
- Very common attaching deck to steel
- Shear
  - Weld shear strength
  - Sheet tearing
- Tension
  - Weld tensile strength
  - Sheet tearing
- Combined Shear and Tension



CFS Welds

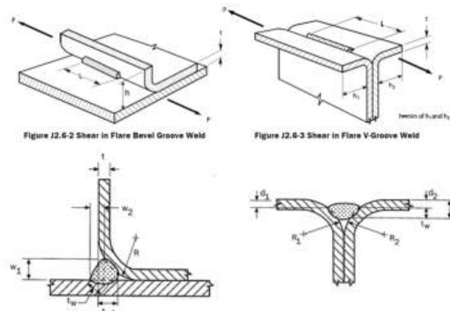


Fillet Welds



- Weld profile no longer a 45° right triangle
- Sheet tearing is the only limit state to check

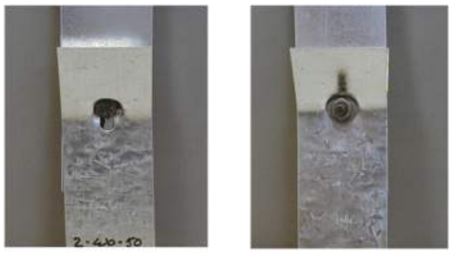
Flare Groove Welds



Bolts – Section J3

- Bolt hole sizes
  - Similar to AISC, d + 1/32" for d < ½"
- Minimum spacing – 3d
- Minimum edge and end distances – 1.5d, d
- Limit states
  - Bearing – governing for most cases
  - Shear and tension in bolts

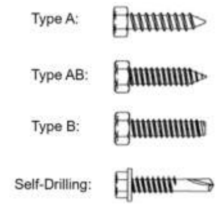
Bolts



Without Washers　With Washers

Screws – Section J4

- Most versatile connections for CFS
- Fast and easy installation
- Thread-forming or thread-cutting, with or without self-drilling point.



Screws – Limit States

- <u>Shear</u>
  - Longitudinal shear of sheet (edge tearing)
  - Bearing failure of the sheet
  - Tilting of screw and tearing of sheet
  - Shear failure of screw
- <u>Tension</u>
  - Tension pull out of screw
  - Tension pull over of sheet
  - Tension failure of screw
- <u>Combined shear and tension</u>

Power-Actuated Fasteners – J5

- A variety of proprietary products available
- Need special tools to install
- J5 has a fairly narrow range, does not exclude manufacturers or independent lab test data

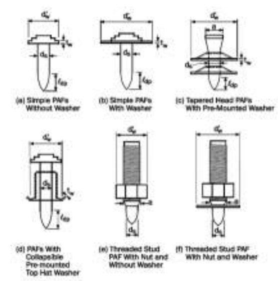


Figure J5-1 Geometric Variables in Power-Actuated Fasteners (PAFs)

PAFs – Limit States

- Shear strength of PAFs
- Bearing and tilting strength
- Pull-out strength in shear in steel
- Net section rupture strength
- Shear strength limited by edge distance
- Pull-out strength in shear in concrete

Useful Resources

- AISI Specifications and Standards
- AISI Manuals and Design Guides
- Textbook by W.-W. Yu, R. LaBoube, & H. Chen
  - ISBN: 978-1-119-48741-8
  - Fifth Edition published by Wiley
- CUFSM – Cross-Section Elastic Buckling Ben Schafer et al. at Johns Hopkins
- Commercial software

Useful Websites

- American Iron and Steel Institute
  http://www.steel.org/
- Cold-Formed Steel Engineers Institute
  http://www.cfsei.org/
- Wei-Wen Yu Center for Cold-formed Steel Structures
  http://ccfssonline.org/
- CUFSM – Cross-Section Elastic Buckling Analysis
  https://www.ce.jhu.edu/cufsm/
- Steel Framing Alliance
  https://www.steelframingalliance.com/
- Steel Framing Industry Association Resource Center
  https://www.cfsteel.org/resource-center
- Steel Deck Institute
  http://www.sdi.org/

CFS-NEES: Seismic Performance of CFS Buildings
https://www.ce.jhu.edu/cfsnees/?_ga=2.15829237.232972839.1641828773-150783958.1641828773

Thank you!

- Questions?