$5.00

TECHNICAL NOTE

On Cold-Formed Steel Construction

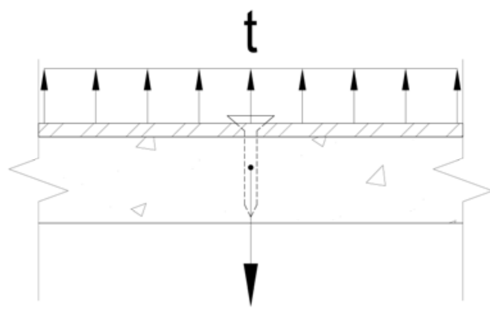
Cold-Formed Steel Engineers Institute ● Washington, DC ● www.cfsei.org ● 800-79-STEEL

GENERAL CONSIDERATIONS FOR COLD-FORMED STEEL CONNECTIONS

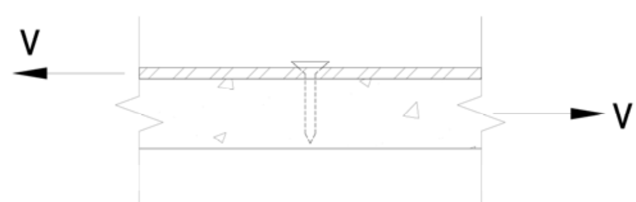
Summary: Cold-formed steel (CFS) connections present unique design challenges to consider due to the thickness of the steel. Connections with thin steel materials behave differently than connections with thicker hot-rolled steel materials and are prone to unique limit states. This Technical Note is an introduction to typical CFS connection design issues as defined by common limit states.

INTRODUCTION

Cold-formed steel (CFS) connections present unique design challenges to consider due to the thickness of the steel. Connections with thin steel materials behave differently than connections with thicker hot-rolled steel materials and are prone to unique limit states. This Technical Note is an introduction to typical CFS connection design issues as defined by common limit states. Additional information and equations are provided in AISI S100-16, *North American Specification for the Design of Cold-Formed Steel Structural Members, 2016 Edition, S*ection J, "Connections and Joints."



Applied Tension
Figure 1



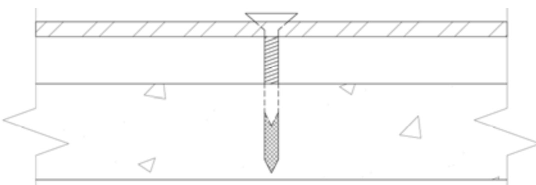
Applied Shear
Figure 2

BEHAVIOR OF COMMON COLD-FORMED STEEL CONNECTION LIMIT STATES

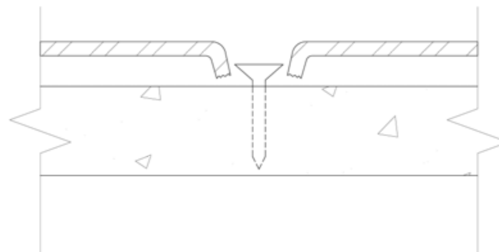
Figures 1 and 2 show typical CFS connections using a dowel type fastener, i.e., screw or power-actuated fastener (PAF). The top sheet is the material in contact with the fastener head, and the bottom material is not in contact with the fastener head. In Figure 1, the applied tension load is attempting to pull the top sheet and the bottom material apart. In Figure 2, the applied load results in a shear force in the two connected sheets. Each connection could potentially fail in several different ways (referred to as limit states), and each limit state must be analyzed to determine which will occur first, and therefore control the capacity of the connection.

PULL-OUT

Consider a screw or PAF connection as shown in Figure 1. As tension is applied, the connected materials are held in place by the fastener—the head of the fastener keeps the top sheet in place, and the shaft of the fastener keeps the bottom material in place. Pull-out strength refers to the amount of tension the connection can resist before the fastener is “pulled out” of the bottom material, as shown in Figure 3. To illustrate this limit state with an extreme example, imagine the connection behavior if the bottom material were extruded polystyrene. In this situation, it would not take much applied tension before the fastener pulled out of the extruded polystyrene, and pull-out would control the capacity of the connection. (Note: pull-out is not a limit state for a bolted connection, as it is fastened under the bottom material by a nut.)



Pull-Out
Figure 3



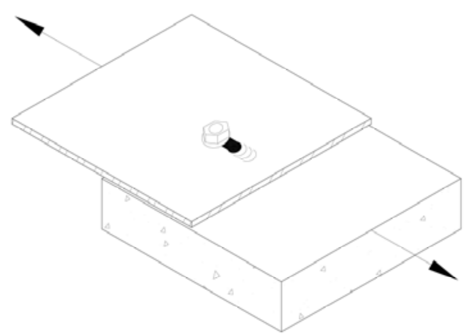
Pull-Over
Figure 4

PULL-OVER

In cases where the screw or PAF connection in the base material is strong and the pull-out capacity is high, pull-over may be the controlling limit state. Again, consider the connection shown in Figure 1. Pull-over refers to the amount of tension that can be applied before the top sheet “pulls over” the fastener head, as shown in Figure 4. To illustrate this limit state with an extreme example, imagine the connection behavior if the top sheet were aluminum foil. In this situation, it would not take much applied tension before the aluminum foil pulled over the head of the fastener and pull-over would control the capacity of the connection.

BEARING

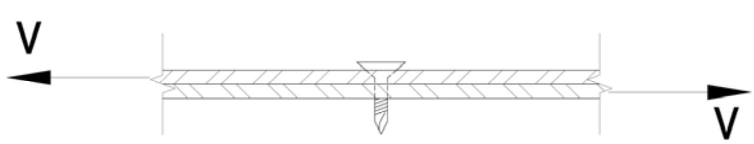
Consider a bolt, screw or PAF connection as shown in Figure 2. As shear force is applied, the connected materials are held in place by the shank of the fastener. As the magnitude of the applied shear load increases, eventually one or both materials could deform/buckle and/or tear around the fastener shank. This limit state is referred to as bearing. Figure 5 illustrates the top sheet failure in bearing.



Bearing
Figure 5

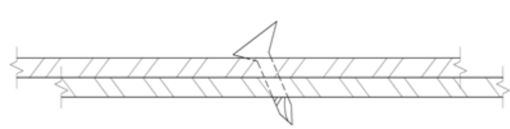
TILTING AND TEARING

Consider a screw or PAF connection of two thin steel sheets as shown in Figure 6. The fastener shank is originally oriented vertically (perpendicular to the applied load), similar to Figures 1 and 2. However, if enough shear force is applied, the fastener could potentially tilt before the steel fails, deforming the connection and changing the direction of the fastener in relation to the applied force, as shown in Figure 7. This limit state is referred to as tilting and tearing.



Applied Shear

Figure 6



Tilting
Figure 7

RUPTURE

Rupture is the failure of a member cross-section along its points of connection. One way to describe this type of failure is to compare it to a perforated sheet of paper. When several holes that are arranged in a relatively closely spaced pattern or line are made across a member section, the section may fail along that pattern or line when load is applied. AISI S100-16 provides additional information and equations for different types of rupture—net section rupture (Section J5.3.4), shear rupture (Section J6.1), tension rupture (Section J6.2), and block shear rupture (Section J6.3). Figure 8 from the AISI S100-16 *Commentary* illustrates an example of the potential failure paths of a stiffened channel connection due to rupture. The *Commentary* includes additional illustrations and information. Additional illustrations and information are included in the AISI S100 Commentary.

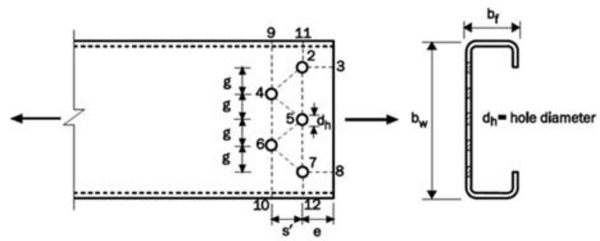


Figure C-J6-4 Potential Failure Paths of Stiffened Channel (Tension or Block Shear Rupture)

Figure C-J6-4 – Potential Failure Paths of Stiffened Channel
(Tension or Block Shear Rupture)
Figure 8

SPECIFIC CONNECTION TYPES AND ASSOCIATED LIMIT STATES

SCREWS

Courtesy of Simpson Strong-Tie Company, Inc.

Self-drilling and/or self-tapping screws are the most common fastener types used for CFS connections. Self-drilling means that pre-drilling a hole to install the fastener is not required because the screw tip cuts into the material. Self-tapping means that the screw taps its own threads. Screws have different drill tip styles that are designed for the type and thickness of materials they are intended to connect. For example, there are screws specifically designed for metal-to-metal, metal-to-wood, and wood-to-wood connections. It is important to specify the appropriate type of screw and drill tip required, as they are not intended to be used interchangeably for different materials or different steel thicknesses. Screws come in a wide variety of diameters, lengths, thread dimensions, and head styles depending on the materials they are intended to connect, and how much load they will need to resist. For CFS screw connections, pull-out and pull-over, tilting and tearing, as well as bearing capacities must be checked. AISI S100 Section J4 provides additional information and equations for screw connections to CFS. Screw manufacturers typically also provide allowable values for their proprietary screws that incorporate these limit states. Additionally, the AISI's *Cold-Formed Steel Framing Design Guide*, D110-16 provides design examples. CFSEI Tech Notes F101-12, *Screws for Cold-Formed Steel-To-Wood and Wood-To-Cold-Formed Steel Attachments*; F701-12, *Evaluation of Screw Strength*; and F102-11, *Screw Fastener Selection for Cold-Formed Steel Frame Construction* can be referenced for additional information.

PAFs

Courtesy of Simpson Strong-Tie Company, Inc.

Power-actuated fasteners, or PAF, are also sometimes referred to as "pins" or "shot pins".

Different types of PAFs include:

- Powder-actuated fasteners (installation tools use powder cartridges for driving energy)
- Gas-actuated fasteners (installation tools use compressed gas canisters for driving energy)
- Pneumatically driven fasteners (compressed air is used for driving energy)
- Mechanical/battery-driven fasteners.

PAFs can be used to connect CFS to hot-rolled steel or concrete base materials. In these types of connections, the PAF manufacturer typically provides allowable shear and tension values for the PAF connection to the base material. However, the tension and shear capacities of the PAF in contact with the CFS top sheet must also be evaluated to determine the pull-over and bearing capacity of the CFS. If these values are not provided by the manufacturer, then the designer must analyze them independently. AISI S100 Section J5 provides additional information and equations for PAF connections. CFSEI Tech Notes 562, *Powder- Actuated Fasteners in Cold-Formed Steel Construction* and F300-09, *Pneumatically Driven Pins for Wood-Based Panel Attachment* are additional resources.

BOLTS

Bolts may be used to connect CFS to CFS, hot-rolled steel or concrete base materials. In these types of connections, the bolt to base material connection capacity must be evaluated to ensure that the bolt and the base material are adequate for the applied loads. Additionally, the bolt-to-CFS connection must be evaluated to ensure that the CFS material is adequate for the applied loads. CFS limit states to consider include bearing around the bolt shank and pull-over from the bolt head/nut/washer. AISI S100 Section J3 provides additional information and equations for bolted connections to CFS, but it does not provide an equation for pull-over specifically for bolts. Refer to applicable product code approvals, product specifications or other literature, or alternately check pull-over using the equations provided for screws if other information is not available.

WELDS

Welding to cold-formed steel is different than welding to hot-rolled steel and presents unique challenges due to the thickness range of CFS material. One challenge is that a welder who is not familiar with welding CFS can accidentally burn holes in the thinner CFS sheets. An American Welding Society (AWS) D1.3 qualified welder should perform CFS welded connections, as AWS D1.3 addresses welds with thinner steels (3/16" or less). Different types of welds are designed differently, but in general, both sheets of steel that are being welded together must be checked for load in both the transverse and the longitudinal directions (transverse describes when load is normal to the weld length, and longitudinal describes when load is parallel to the weld length). Additionally, the capacity of the weld itself must be checked. AISI S100 Section J2 provides additional information and equations for specific types of welded CFS connections. CFSEI Tech Note F140-16, *Welding Cold-Formed Steel* can also be referenced.

Courtesy of ADTEK Engineers, Inc.

ANGLE CLIP LIMIT STATES

Angle clips or "L clips" are a common type of CFS connection. Depending on the direction of the applied load(s), clip capacities should be checked for tension, shear, plate bending, and/or moment due to eccentricity. Fasteners on each clip leg (anchored leg and cantilevered leg) should also be checked for limit states explained above, including eccentric loads on fasteners if required. CFS clip connections in tension are unique in that they tend to display "prying" or "unfolding"/plate-bending behaviors. In "unfolding"/ plate bending, the clip is not strong enough under the applied load to keep its "L" profile shape and yields in bending.

Courtesy of Simpson Strong-Tie Company, Inc.

In "prying", the clip keeps its "L" profile shape, and the eccentricity between the applied load on the cantilevered leg and the resisting fasteners on the anchored leg creates a moment that increases tension on the resisting fasteners (similar to the behavior of a crowbar or prybar when used to pry things apart). Additionally, the "prying" connection behavior produces a nonuniform load on the fasteners in the anchored leg, resulting in a reduced pull-over capacity (i.e., the tension load on the anchored fasteners is only resisted by half of each fastener head). Refer to AISI S100 for tension, shear, and moment equations for CFS. For additional information and equations specific to clip angle design, refer to AISI Research Reports RP15-2, *Load Bearing Clip Angle Design* and RP18-4, *Load Bearing Clip Angle Design - Phase II*. Additionally, reference "Suggested Design of Cold-Formed Steel Clip Angles for Tension" from the Spring 2002 LGSEA (Light Gauge Steel Engineers Association) Newsletter.

ADDITIONAL CONNECTION LIMIT STATE CONSIDERATIONS

MINIMUM SPACING EDGE AND END DISTANCES

The limit state equations for dowel type fasteners such as screws, PAFs, and bolts are dependent on adhering to the minimum spacing, edge and end distance requirements for the fasteners. These requirements are minimum limits for how close fasteners can be installed next to each other, and how close fasteners can be installed to the edge or end of a material. It is important to note that minimum edge and end distance requirements for the same fastener may be different depending on the direction of the applied load. Refer to AISI S100 for additional information and for minimum spacing, edge and end distance requirements for CFS connections.

CHECKING LIMIT STATES IN COMBINATION

When connections experience load in different directions concurrently (for example, tension combined with shear), then the connection must be checked for the loads in combination. Imagine a typical clip connection. Both the maximum tension capacity and maximum shear capacity based on the applicable limit states can be determined. If only tension load is applied to the clip connection, then the full tension capacity of the connection could be achieved. Similarly, if only shear load is applied, then the full shear capacity of the connection could be achieved. However, if tension and shear are applied concurrently, then neither the full tension nor the full shear capacity will be achieved, as the fasteners will have to do "double duty" and resist load in two directions at the same time instead of resisting load in only one direction. AISI S100 provides guidance for some types of connections in combined shear and tension. If a proprietary product is used, then the manufacturer's technical report and/or specifications may also provide design guidance for the product in combined loading. In general, the equations provided to address loads in combination will be some variation of the following:

[Actual Load 1 / Allowable Load 1] + [Actual Load 2 / Allowable Load 2] $\leq$ 1.0

FOR OTHER MATERIALS LIMIT STATES

The limit states addressed in this Tech Note are specific to the failure of connected CFS members. The limit states of all other materials and members of the connection, including fasteners and hardware, must also be analyzed per the appropriate codes, standards and specifications including, but not limited to, the following:

- Proprietary manufacturer specifications and allowable load data
- Design of hot-rolled steel and bolts per ANSI/AISC 360
- Connections to concrete per ACI 318
- Connections to masonry per TMS 402/602
- Connections to wood per National Design Specification for Wood Construction (NDS).

Primary author of original Tech Note:
Julie Lowrey, P.E., Insurance Institute for Business and Home Safety

Technical Review:
Roger LaBoube, Ph.D., P.E., Wei-Wen Yu Center for Cold-Formed Steel Structures
Robert Madsen, P.E., Devco Engineering, Inc.
Andrew Newland, P.E., ADTEK Engineers, Inc.
Brandon Wahl, P.E., 360 Engineering Group
Robert Wills, P.E., American Iron And Steel Institute