

# Connections in Cold-Formed Steel Framing – Designing with AISI 2007

## Specification and Application Overview

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The *North American Specification for the Design of Cold-Formed Steel Structural Members* (S100-2007, or 2007 AISI) is a standard referenced in the 2009 *International Building Code*. Chapter E of 2007 AISI contains provisions for the design of connections to cold-formed steel structural members. Where the design requirements among the three North-American countries differ, the Specification references country-specific provisions provided in the Appendices. Starting with 2007 AISI, Appendix A contains the provisions specific to both the United States & Mexico, including those pertaining to the connection design.

### Scope of 2007 AISI Connection Provisions

The 2007 AISI covers three types of connections: welded (Sec. E2), bolted (Sec. E3) and screw (Sec. E4). While the Specification sets its general applicability thickness upper limit in Chapter A at 1.00 inches, the applicability of Chapter E in the design of welded and bolted connections is limited to connections in which the thickness of the thinnest connected part does not exceed  $\frac{3}{16}$  inch. For larger thicknesses, the applicable provisions of the *AISC Specification for Steel Buildings* (AISC 360-05) Chapter J will apply instead. An additional thickness based application limitation exists in Section E2.2, whereby the arc spot (puddle) welds cannot be used in connections where the thinner of the connected parts exceeds 0.15 inches in thickness. Also, additional geometric and strength property limitations for screw and welded connections, respectively, are given in Section E4, mostly stemming from the extents of the variables used in the testing program to generate the specification equations. While 2007 AISI sets no thickness limits with respect to connected parts in screw connections, the authors recommend that screws not be used in connections where the thickness of the thinnest connected part (i.e., the part in contact with the screw head or washer) exceeds  $\frac{1}{8}$  inch. This recommendation is based on practical installation considerations, typical applications, and the fastener reliability. In all the connection types described above,

the thickness of the thicker connected part is not limited, and is not subject to the 2007 AISI Chapter A general upper thickness limit of 1 inch. However, for screw connections, the thickness of the thicker part will generally be limited by practical limitations and the screw tapping characteristics to about  $\frac{1}{2}$  inch.

Ductility is an important aspect of cold-formed steel connection strength, reliability and performance. To limit the adverse effect of low ductility, Section A2.3 limits the nominal yield and tensile strengths of certain steels in both member and connection design.

It is important to note that when welds and screws are utilized in diaphragm applications, the provisions of Chapter E do not apply. Instead, the screws or welds become a part of a diaphragm assembly, whose strength is determined by either tests or calculations in accordance with 2007 AISI Section D5. The associated test procedures are given by AISI TS-7-02. In such applications, strengths of individual fasteners or welds cannot be calculated using the provisions of Chapter E, and a single factor of safety, or the resistance factor, depending on the design method used, is imposed on the overall system strength. Fastening requirements for the cold-formed steel are generally stipulated with the catalogued tested values reduced by the appropriate factor of safety and expressed as “width of single deck sheet/ no. of uniformly spaced fasteners per sheet width.” Generally, for diaphragms featuring screws, a higher resistance factor, and a lower factor of safety is stipulated then for those with welds.

### Connection Design Elements & Considerations

With respect to welded structures, the 2007 AISI provides the provisions to calculate the tensile, compressive, and shear strengths for applicable limit states of groove welds in butt joints (E2.1), arc spot welds (E2.2), arc seam welds (E2.3), fillet welds (E2.4), flare groove welds (E2.5), and spot welds (E2.7). The welded section net fracture check incorporating the effect of shear lag is to be checked for all other than joined flat sheets (E2.7).



Similar to AISC 360-05, the strength of bolted connections in 2007 AISI is calculated considering strength based on edge distance and spacing (E3.1), fracture of net section considering shear lag (E3.2), bearing with or without consideration of bolt hole deformation (E3.3), and shear and tensile strength of bolts including the combined loading (E3.4). Unlike in AISC 360-05, only bearing type bolted connections are covered by 2007 AISI.

The strength of screw connections is determined using the provisions of Section E4. Applicable limit states in shear are tilting and bearing (E4.3.1), shear strength limited by end distance (E4.3.2), and the shear in screws (E4.3.3). In tension, the strength of connection is determined considering pull-out (E4.4.1), pull-over (E4.4.2), and the tension in screws (E4.4.3). It should be noted that the limit states of tension and screw shear are defined as 80% of the nominal shear and tensile strength, respectively, obtained from the manufacturer, or by independent testing in accordance with 2007 AISI Chapter F and test procedures outlined in AISI TS-4-02. Therefore, the design strengths of screw connections in tension and shear cannot be determined by computations alone. The specification allows for a factor of safety of 3.0, and a resistance factor of 0.50 to be used for all limit states, if the strengths are calculated using the provision of Section E4.3. Alternatively, strengths for each of the tensile and shear limit states listed above can for any given screw connection be determined entirely through testing. While this approach can be applied to any connection, it is mandatory in those that fall outside the geometric and other limitations of Section E4.3. The required test procedures are given by AISI TS-4-02/-5-02, and the appropriate factors of safety and resistance are determined per Chapter F. Separate factors may be computed for each limit state, or the highest factor of safety, or the lowest

resistance factor, calculated from either limit state could be used for simplicity.

Rupture limit states are covered by Sec. E5. They include shear rupture of coped section (E5.1), tension rupture (E5.2), and block shear rupture (E5.3). Although not specifically indicated by the Specification, the block shear provisions apply to all three types of connection covered by the specification. The tension rupture only concerns welded and bolted connections.

Section E6 of 2007 AISI covers connection strength in bearing, tension, and shear of cold-formed elements to other materials. While no explicit design requirements are provided, the designer is required to insure the proper embedment and attachment to other materials in accordance to their product data and code approvals and to consider all possible limit states and loading resulting from the attachment of cold formed steel element. The Specification does not cover the power actuated fasteners or proprietary connection assemblies. Where AISI S100 limitations are exceeded, or when connections not covered by the Specification are used, the design strength values are established by testing.

The Specification provides explicit criteria, identical to that given by AISC 360-05, for consideration of combined shear and tension in bolts (E3.4). Starting with 2004 Supplement to 2001 AISI, the Section (E4.5) provides new criteria to consider combined shear and pull-over in screws. No other combined loading criteria are currently available in the specification. As with any other connection design, the designer must consider all loading conditions acting on a connection assembly, and properly assign forces to individual connection elements, such as screws, welds, bolts, etc. For individual connection elements, such as screws or welds

in combined shear and tension, for which the Specification provides no other criteria, the authors recommend the following linear interaction:

$$\left(\frac{T_a}{T_p}\right) + \left(\frac{V_a}{V_p}\right) \leq 1.0$$

In the interaction, T denotes tension, V denotes shear, subscript (a) indicates applied force (service for ASD, factored for shear), and (p) indicates provided resistance (allowable for ASD, factored for LRFD). While the proposed equation is almost certainly very conservative for all applications considered herein, as it neglects the actual envelope of resisting stresses in individual elements, it provides a fast, safe and intuitive way for considering the combined tension and shear where the Specification provides no other guide.

### Typical Applications

Most typical applications of the connections covered by 2007 AISI are found in the metal building industry, cold-formed steel stud construction, cladding attachments in buildings, attachments of mechanical and non-building elements, and industrial storage rack industry.

In cold-formed steel stud construction and cladding attachments in buildings, screws can be used in virtually every type of the steel-to-steel connection. Relatively low design loads and high level of redundancy make screw connections appropriate for lateral bracing, bridging, member-to-member, and top track connections alike. Bolts are generally used for anchorage and bolting to higher-thickness elements with higher load demand. Although possible, welded connections are rarely used

unless unusual connection configurations and load conditions are encountered.

In the metal building industry, screw connections are appropriate for the attachment of lightly loaded members in framed openings. The authors do not recommend using screws in connecting stability bracing, gravity load connections, or applications involving lateral force resisting systems other than vertical and horizontal diaphragms, given comparatively lower reliability of screw connections, and low redundancy associated with these applications. Screws are also not recommended in applications involving high ductility demands or fatigue and load reversals, such as crane support systems. While bolted and welded connections are appropriate for most applications involving cold-formed steel member connections in metal buildings, the former are generally limited to field applications, and the latter to shop joints. The reason for this lies primarily in construction efficiency given the logistic and cost issues associated with field presence of welding equipment and personnel qualified to execute welds per AWS D1.3.

Industrial storage rack structures feature primarily field-bolted, shop welded connections, while screws can be used for the attachment of steel deck and stud walls. Screws can also be used where cold-formed members are used to frame non-building supports and containment for items such as light mechanical equipment. However, screws should not be used in applications where fatigue, vibration and connection ductility are of concern.

### When to Use AISC 360 and when AISI S100

In general, AISI S100 should be used in all cases where the thickness of the thinnest connected element does not exceed  $\frac{3}{16}$  inch. The AISC 360 Chapter J does not have an explicit application limit in terms of minimum thickness. However, the design of welded connections is therein implicitly limited at the minimum of  $\frac{1}{8}$  inch by virtue of the AWS D1.1 scope. For smaller thicknesses, the welded joints are governed by AWS D1.3. While various connection design checks are configured nearly identically in the two specifications (i.e., combined shear and tension on bolts, block shear, etc.), it is important to recognize that they are not interchangeable, as most often the safety and resistance factors are different. Furthermore, ductility provisions of AISI S100 Section A2.3 require that the nominal strength properties be reduced for many steel types, directly affecting the design parameters and the computed design strength.

In all instances, screw connections should be designed using AISI S100. In determining which specification governs in the design of

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welded and bolted connections, the designer can apply two criteria. First is to consider what specification was used to design the connected members. For instance, if an 18-Ga. thick cold-formed steel stud is web-bolted to the flange of a hot-rolled W10X22 column, stud specific design elements (i.e., bolt bearing, block shear, and net section checks) would be performed per AISI S100, while the column-specific design checks would be considered using AISC 360; the strength of bolts would be evaluated using AISI S100 (the governing of the two specifications). The second criteria relates to member thickness. For instance, if a ¼-in. thick cold-formed member is bolted to a W10X22 column, than all the design elements would be considered per AISC 360 as the AISI S100 applicability range would be exceeded.

## Interface with 2009 IBC

Depending on a specific design situation, the designer is cautioned that the AISI S100 is not the only document governing the design elements, and that the prescriptive and other requirements and limitations of 2009 IBC Chapter 22 can further tighten the limitations of AISI S100, or introduce additional requirements. While AISI S100 covers elemental connection design elements, various IBC-referenced standards prescribe additional application-specific requirements.

The 2009 IBC referenced cold-formed steel standards that impose additional requirements with respect to connection design include AISI S200-07 (General Provisions), AISI S210-07 (Floor & Roof System Design), AISI S211-07 (Wall Stud Design), AISI S213-07 Lateral Design, AISI S214-07 (Truss Design) and AISI 230-07 (Prescriptive Method for One- and Two- Family Dwellings). For instance, AISI S214 prescribes a reduction factor for the shear strength of the coped sections calculated per AISI S100, S230 prescribes the use of No. 8 and No. 10 screw connections, although under some conditions other fasteners are allowed, and AISI S211 permits for the web-crippling strength of the stud at stud-to-track connections to be increased due to presence of track by providing an alternative strength model to the AISI S100 in certain cases.

## Future Specification Editions

The current target is to publish the next edition of AISI S100 in 2011 or 2012. Findings of recent and current research efforts, as well as committee activities, are likely to result in several important changes and additions as they relate to the connection design. The AISI 2011 is expected to feature the new criteria for considering the combined shear and pull-out in screw connections and combined shear tension in screws, complementing the current

criteria for combined shear and pull-over. Research is currently under way to generate strength prediction models for shear and tension strength of power actuated fastener connections. Once incorporated into the Specification, this strength prediction model would parallel that currently available in Section E4 for screw connections, and would eliminate the need for catalogue-based strength values derived through ICC testing protocols. Where possible, the specification will also make further steps in harmonizing the design requirements with those of AISC 360, as well as in eliminating overlap between the two specifications. ■

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