# Designing Cold-Formed Steel Framed Lateral Force-Resisting Systems

By Jeff Ellis, P.E., S.E.

Provisions for the design of cold-formed steel (CFS) framed lateral force-resisting systems were first introduced in the 1997 edition of the *Uniform Building Code* (UBC). Since that time the provisions have been refined and expanded, and currently address CFS framed diaphragms with wood panel sheathing, shear walls, and diagonal strap braced walls. This article discusses the history of the code provisions, some of the design considerations unique to CFS framed lateral force-resisting systems, and resources available to aid designers.

*CFS framed structure. Courtesy of Don Allen of DSi Engineering.*

## History of Code Provisions

The original code provisions for CFS framed lateral force-resisting systems appeared in Chapter 22 of the 1997 UBC and covered fully sheathed shear walls with overturning restraint at each end (Type I shear walls) as shown in *Figure 1*, and diagonal strap braced walls used to resist wind and seismic forces. However, the shear wall applications were limited to those sheathed with wood structural panels and gypsum board attached to 33 mil (20 ga) and 43 mil (18 ga) framing, with an aspect ratio of 2:1 or less. The 2000 *International Building Code* (IBC) added steel sheet sheathed shear walls and permitted shear wall assemblies with an aspect ratio up to 4:1. Also, nominal assembly strengths were tabulated, which were multiplied by a resistance factor, ϕ, or divided by a safety factor, Ω, to determine the LRFD or ASD shear strength, respectively. In the 2003 IBC, Type I (segmented) and Type II (perforated) shear wall types were introduced.

In 2004, the American Iron and Steel Institute (AISI) published the *Lateral Design Standard and Commentary* (AISI-Lateral) with tabulated diaphragm strengths and shear wall and diaphragm deflection equations. This standard was referenced in the 2006 IBC. In 2007, AISI published a new edition of the *Lateral Design Standard*, AISI S213-07, which was adopted by the 2009 IBC. AISI S213-07 contained more robust provisions for diagonal strap braced walls, provisions for seismic forces contributed by masonry and concrete, as well as Canadian provisions for CFS framed shear walls. The most recent *Lateral Design Standard*, AISI S213-07-S1-09, is adopted by the 2012 IBC. This document adds another steel sheet shear wall assembly and limits the aspect ratio of a diagonal strap braced wall (*Figure 2*) to 2:1 unless an analysis is performed taking into account joint flexibility and end moments in the vertical boundary members (end studs).

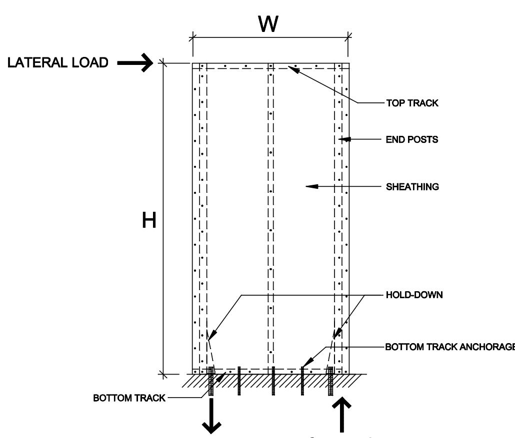


*Figure 1: Typical CFS framed shear wall.*

## Boundary Member and Hold-down Design

One of the most discussed code provisions for CFS framed shear walls and walls with diagonal strap bracing designed using a seismic response modification coefficient, R, greater than 3 is the requirement to design the vertical boundary members (end studs) and the overturning restraint for the minimum of the amplified seismic force or the load the system can deliver. This requirement to design for increased seismic forces is found in AISI S213 Section C5.1.2.2 (shear walls) and C5.2.2.2 (walls with diagonal strap bracing) and is intended to help protect elements in the wall from premature failure and allow energy to dissipate in the sheathing to framing connections or diagonal strap bracing.

The amplified seismic force is defined as the load determined using the code seismic load combinations that include the overstrength factor, $\Omega_o$. It should be noted that ASCE 7 Table 12.2-1 footnote g permits 0.5 to be subtracted from the overstrength factor when the diaphragm is considered flexible. ASCE 7-10 permits untopped steel deck or wood structural panel diaphragms to be idealized as flexible for one- and two-family dwellings, when the simplified design procedure

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*Figure 2: Diagonal strap braced wall with 4:1 aspect ratio. Courtesy of AISI & McGill University.*

is used, and for light-frame structures where there is no topping on the diaphragm or where the non-structural topping is less than or equal to 1½-inch thick and each line of seismic force-resisting elements complies with the seismic story drift limitation.

The nominal shear strength for CFS framed shear wall assemblies are tabulated in AISI S213. However, as AISI S213 Commentary C5.1 states, the tabulated values are based on a test protocol and the backbone curve which underestimates the nominal strength of the shear wall by up to 30%. This greater strength should be considered in design when determining the maximum the system can deliver.

The nominal strength of the vertical boundary studs and overturning restraint (hold-down) is required to be greater than the amplified seismic load or the maximum load that the system can deliver. The nominal tension strength for the overturning restraint device (hold-down) is listed in the manufacturer's literature. If the nominal hold-down tension strength is not available, designers may divide the LRFD tension strength by the resistance factor, $\phi$, provided by the manufacturer, or multiply the ASD tension load by 1.2 for use with the ASD seismic load combinations with the overstrength factor as permitted by ASCE 7-10 Section 12.4.3.3.

## Aspect Ratio

CFS framed shear walls, walls with diagonal strap bracing, and horizontal diaphragms have aspect ratio restrictions to limit excessive deflection of the assembly. For walls, the aspect ratio is defined as the height divided by the width (h/w), and for diaphragms it is defined as the length divided by the width (l/w). For horizontal diaphragms, the maximum aspect ratio is 4:1 for blocked diaphragms and 3:1 for unblocked diaphragms (*Figure 3, page 14*). The aspect ratio is limited to a maximum of 2:1 for wood sheathed, steel sheet sheathed, and gypsum board sheathed CFS framed shear walls as well as for walls with diagonal strap bracing. The ratio for wood panel or steel sheet sheathed

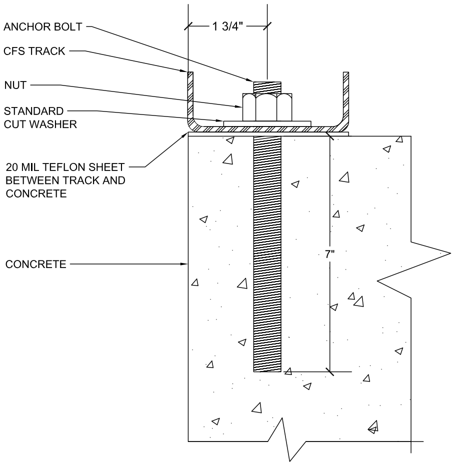


*Figure 4: Shear transfer near edge of concrete test specimen.*

CFS framed shear walls can be increased up to 4:1 for assemblies identified in AISI S213, as long as the shear strength is multiplied by a load reduction factor equal to 2w/h.

AISI S213 also permits the aspect ratio to be increased for walls with diagonal strap bracing resisting wind or seismic forces, as long as "a rational analysis is performed which includes joint flexibility and end moments in the design of the chord studs." For walls with high aspect ratios, the chord studs develop bending moments in addition to axial forces. These bending moments can be conservatively predicted in a standard 2D frame model of the diagonal strap braced wall. If the chord studs are designed with these bending moments included, strap braced walls at high aspect ratios may still perform adequately. Fiberboard sheathed CFS framed shear walls are limited to a maximum aspect ratio of 1:1. It is also worth noting that fiberboard sheathed shear walls may be used in Seismic Design Category (SDC) A through C, and gypsum board sheathed shear walls may be used in SDC A through D.

## Shear Transfer near Edge of Concrete

The 2009 IBC requires bolts embedded in concrete be designed in accordance with ACI 318-08 Appendix D where strength design or load combinations including earthquake loads are used. Although Appendix D only provides strength design procedures for use with LRFD, it's somewhat common for engineers to divide calculated values by 1.4 to obtain allowable anchor strengths for use with seismic design. Such a calculation results in allowable loads for the embedded bolt that are significantly lower than the allowable bearing of the bolt in the CFS track. For example, the allowable shear strength in bearing for a ⅝-inch diameter anchor bolt in a 54 mil CFS track is 1860 lbs, while the allowable shear strength parallel to the edge of concrete for the embedded bolt is 364 lbs (based on SDC C through F with L-bolt embedded 7 inches and located 1¾ inch from the edge of cracked concrete with $f'_c$=2500 psi.)

To address this issue, AISI supported a research project that showed the bolt to track connection (*Figure 4*) provides the necessary ductility for shear wall shear anchorage, and substantiated a code exception (2012 IBC Section 1905.1.9) allowing the near edge shear anchorage design strength to be determined based on the bearing strength of the bolt in the track in accordance with AISI S100 Section E3.3.1. The exception applies to CFS track between 33 mil and 68 mil in thickness anchored with shear anchor bolts ⅝ inch or less in diameter, that are embedded a minimum of 7 inches and are located a minimum of 1¾ inch from the edge of concrete, and a minimum of 15 diameters from the end of the foundation.

## Fasteners

There are several methods to attach sheathing to CFS framing including self-drilling or self-piercing tapping screws, power-driven driven smooth and knurled pins, and adhesive. While the code does not specifically recognize power-driven driven pins to attach sheathing to CFS framing, several products are recognized in product evaluation reports – based on testing – that may be referenced to determine if the application warrants their use. The code also does not specifically recognize adhesive to attach sheathing

*Figure 3: Blocked wood sheathed CFS framed diaphragm. Courtesy of Don Allen of DSi Engineering.*

*Figure 5: Winged tip and non-winged tip #8 and #10 self-drilling tapping screws.*

to CFS framing. Furthermore, AISI S213 Commentary Section C2 states that there is only limited testing regarding this assembly method and the data demonstrates that installations will not perform the same as an assembly with the sheathing attached to the framing with screw fasteners, and the system may have limited ductility.

The typical method to attach sheathing to CFS framing is with steel tapping screws. When an R factor of 3 or more is used for the seismic force-resisting system, Table C2.1-3 must be used to determine the nominal shear strength of shear walls, and the noted limitations on screw size and framing thickness must be followed. For example, a wood sheathed CFS framed shear wall with #8 screws may not use framing thicker than 54 mil. S213 Commentary Section C2.1 states that S213 "prescribes a maximum stud thickness in order to preclude a change in failure mode of the screw fasteners." In addition, minimum screw head diameters are prescribed in S213 Section C2.2.2 for wood sheathing attachment to the framing members (0.285 inch and 0.333 inch for a #8 and #10 screw, respectively).

Screws with a winged tip and with a non-winged tip have been used to attach wood sheathing to CFS framing. Recent full-scale testing at the Simpson Strong-Tie Tyrell Gilb Research Laboratory compared the performance of shear walls constructed with these two screw types (*Figure 5*). Test walls consisted of 4 x 8 foot CFS framed assemblies with 7⁄16-inch thick wood structural panels with #8 screws spread at 6 inches on center spacing at panel edges and 33 mil framing on one assembly and #10 screws spread at 2 inches on center and 54 mil framing on the other (*Figure 6*). Results showed that, while the peak loads were within 5 to 10% of one another, the assemblies with the winged tip screws were less stiff compared to the non-winged tipped screws and this resulted in an approximate 20% design strength reduction. This may be due to the wings creating a larger hole in the wood panel sheathing, which in turn creates a less stiff assembly.

Some limited testing has been conducted on wood sheathed, CFS framed shear walls to investigate the effect of overdriven fasteners, and is referenced in AISI S213 Commentary Section C2.1. The wood sheathing was ⅜-inch plywood and 50% of the fasteners were overdriven by at least ⅛-inch. The results showed significantly reduced strength, stiffness and ductility for the overdriven fastener assembly, so care should be taken so as not to overdrive the sheathing fasteners.

## Design Resources and Tools

There are many useful tools to help facilitate and expedite the design process. These include design guides, new product systems and connections, as well as computer software and research reports. Many of these are available from the AISI and CFSEI websites. Additional resources include the Cold-Formed Steel Engineers Institute's (CFSEI) *Cold-Formed Steel Framed Wood Panel or Steel Sheet Sheathed Shear Wall Assemblies Design Guide*, several CFSEI technical notes, the AISI *General Provisions* standard (AISI S200), the AISI *Wall Stud Standard* (AISI S211), the AISI *Manual* (AISI D100-08), and the AISI CFS *Framing Design Guide* (AISI D110-07). Currently, there is AISI supported CFS framed lateral force-resisting system research at McGill University and the University of North Texas, as well as an NEES project entitled "Enabling Performance-Based Seismic Design of Multi-Story CFS Structures." For more information on the NEES project, visit **www.ce.jhu.edu/cfsnees**.

*Figure 6: Non-winged self-tapping screw test assembly failure.*

## Conclusion

Cold-formed steel framed lateral force-resisting systems are relatively new to the construction industry. The code provisions for these systems have been revised and enhanced over the last 15 years for clarification, and new provisions have been added to increase the number of potential solutions for a given project. CFS systems have some unique design considerations, but more tools and design aids are becoming available and additional research is underway. Expect to see additional changes and improvements that will enhance the requirements and methods for successful cold-formed steel framed lateral system design.▪