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CFSEI
COLD-FORMED STEEL ENGINEERS INSTITUTE

TECHNICAL NOTE
On Cold-Formed Steel Construction

1201 15th Street, NW, Suite 320 Washington, DC 20005 (202) 785-2022

Design of Diagonal Strap Bracing Lateral Force Resisting Systems for the 2006 IBC

Summary: This Technical Note is intended to discuss some of the design requirements, detailing and practical limitations of diagonal strap bracing design. Diagonal flat strap bracing is a commonly used type of lateral force resisting system in residential and low rise commercial cold-formed steel applications.

INTRODUCTION

Structures require a resisting system to transfer lateral loads imposed on them. Typically these loads are from wind or seismic forces. A commonly used type of lateral force resisting system in residential and low rise commercial cold-formed steel applications is diagonal flat strap bracing. When designing this type of force resisting system there are a number of design and serviceability considerations that should be investigated. These include loads, strap size, fastener quantity, connection detailing, and construction practices.

GENERAL BRACING REQUIREMENTS

The *International Building Code* (IBC) and the *Uniform Building Code* (UBC) contain limited information on requirements for designing diagonal strap bracing lateral force resisting systems. The designer is required to design diagonal straps and their connections in accordance with the design standard referenced in the model code. The 2006 IBC references the *North American Specification for the Design of Cold-formed Steel Structural Members* (AISI NAS-01), including *2004 Supplement* (AISI NASPEC-SUP04) and the 1997 UBC references the AISI *Specification for Design of Cold-Formed Steel Structural Members, 1986 (with December 1989 Addendum)*. In the AISI *Standard for Cold-Formed Steel Framing - Lateral Design* (Lateral-04) the design of diagonal strap bracing is to be done in accordance to the provisions of NAS-01.

TYPES OF DIAGONAL STRAP BRACING

Diagonal strap bracing can be detailed in a variety of different styles. Commonly diagonal strap bracing is used on the outside flange of perimeter load bearing studs (Figure 1). Another option is to use double sided diagonal strap bracing where there are straps on both the inside and outside flange of the studs. With either of these styles the strap may either be a wide strap connecting directly to the stud and track (Figure 2), or a narrower strap where a gusset plate is used to make the connection between the strap and the stud and track (Figure 3).

Wide straps that connect directly to the stud and track may be preferred over straps with gusset plates for a couple of reasons. First the gusset plates and associated fasteners add thickness to the wall which may be difficult to conceal with siding or exterior finish. Second, wider straps connecting directly to the stud and track will ultimately require fewer fasteners which will reduce installation time.

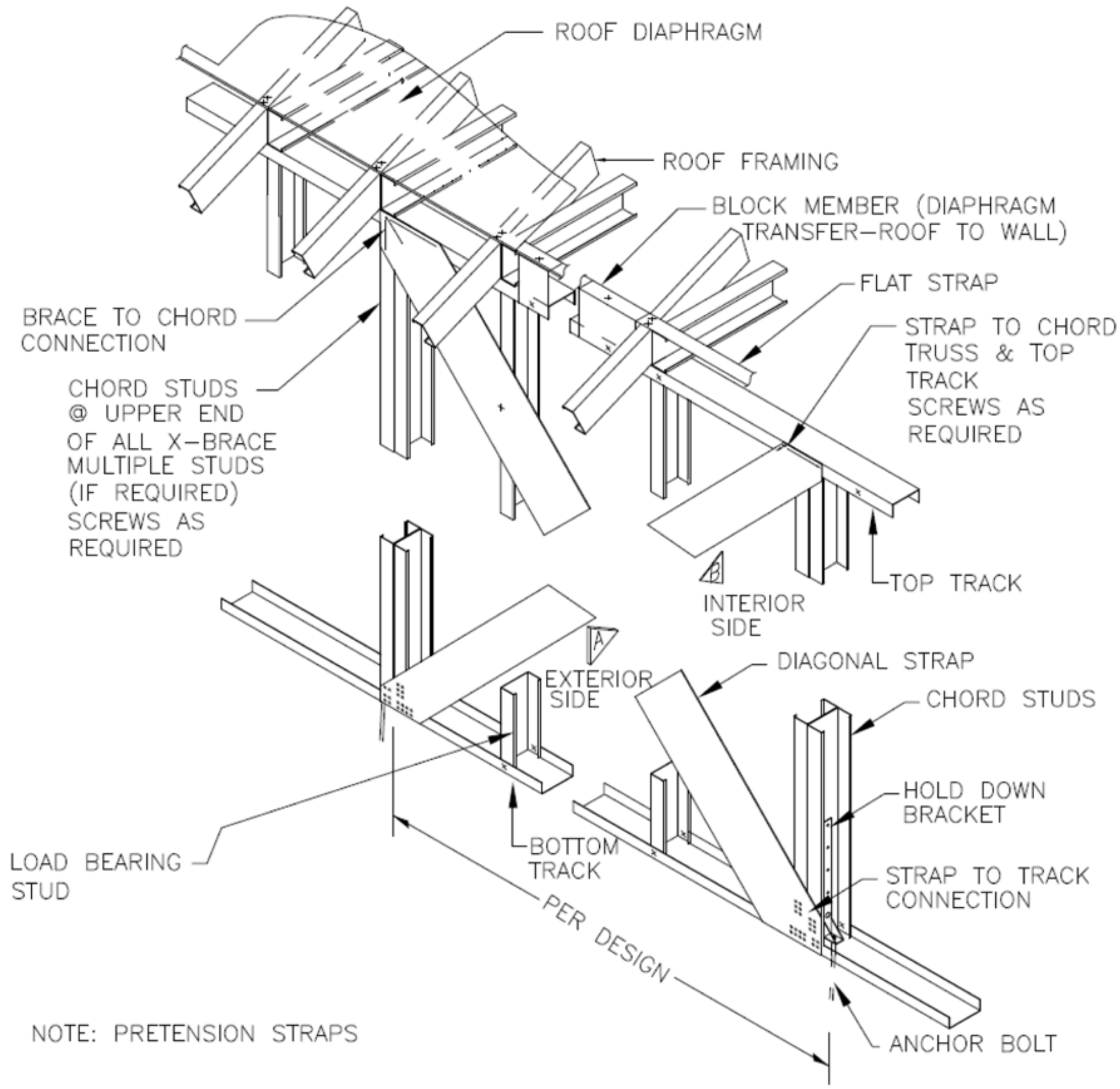


FIGURE 1

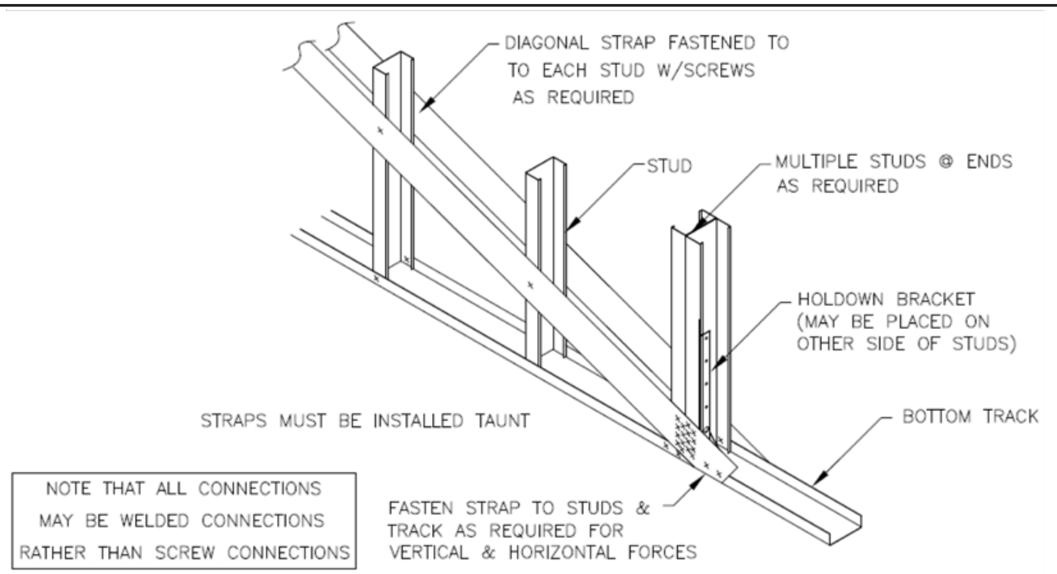


FIGURE 2

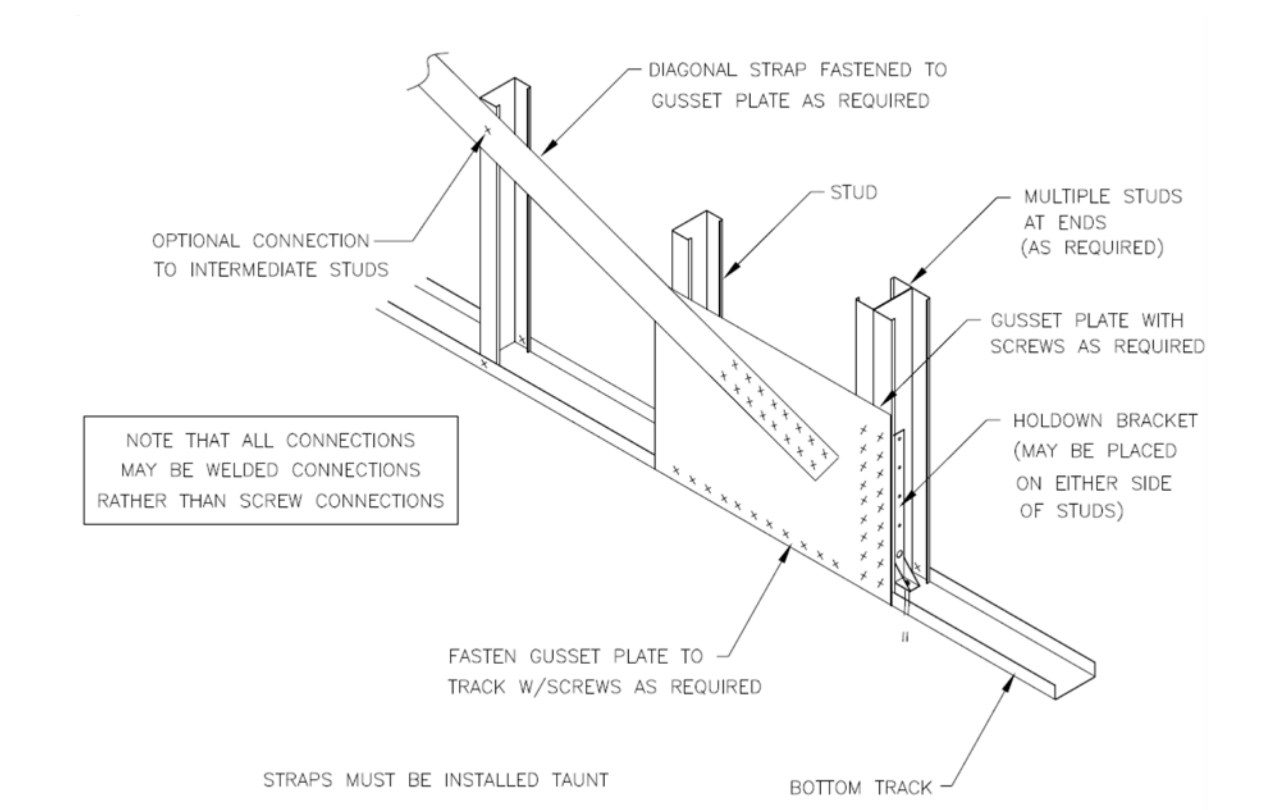


FIGURE 3

DESIGN CONSIDERATIONS

When designing diagonal strap bracing there are a number of items to be investigated which are influenced by the type and geometry of the diagonal strap bracing. The provisions of the NAS-01 can be used to design these elements.

The width of the brace will be primarily dependent on two things. First, it must be properly sized to resist the imposed tensile forces in the member. Second, if it is not desirable to use a gusset plate at each end of the strap a wider strap may be required to allow the strap to connect to both the stud and track.

Connections and members must also be adequately sized to transfer loads. Where the studs are load bearing the effects of gravity loads in resisting and adding to overturning loads must be considered. Other potential design checks include induced eccentricity in the wall from a single sided strap, material over strength, and axial capacity of the chord studs. Finally, it will be necessary to properly design overturning restraints (holdowns), collectors and boundary elements. These items are not included in the scope of this Technical Note.

It should be noted that because diagonal strap braces are tension only members the bottom track may be in compression between the diagonal strap and in tension outside of the brace. Often an anchor bolt is used to transfer shear loads from the bottom track to the foundation. If anchor bolts are in a compression area of the track, compressive axial capacity should be investigated. To resolve this anchor bolts may be placed in a tension area of the bottom track, or outside of the brace. Naturally this becomes an issue if the brace is located at a corner or end of a wall segment. Regardless of the anchor bolt location, bolt bearing on the web of the track and shear transfer shall be checked.

During construction it is important that the strap is installed taut. This is contained in section C5.5 of the AISI *Standard for Cold-Formed Steel Framing - Lateral Design, 2004 Edition*. A taut strap will ensure that the strapping immediately engages when a lateral load is applied. Section 2211.4.6 of the 2003 IBC suggests pre-tensioning as a means to guard against loose straps. It is important, however, to ensure the strap is not overly pre-tensioned. Doing so can potentially reduce the load carrying capacity of the strap.

Both the UBC and IBC use response modification factors, or R-Factors, to provide an appropriate level of strength design load based on the type of lateral system. The IBC and ASCE 7 assign an R-Factor of 4 to ordinary steel concentrically braced frames and the UBC gives a value of 2.8. It should be recognized there is a great deal of research available regarding the code assigned R-Factors and it may be beneficial to investigate this before using strap diagonal strap bracing, particularly in high seismic areas. This research is briefly discussed later.

The 2004 *North American Standard for Cold-Formed Steel Framing - Lateral Design* discusses the use of diagonal strap bracing and contains additional specific requirements for use in seismic areas. These special seismic requirements are contained in section C5 of the document and are included to ensure properly controlled ductility in the system. Specifically, the document gives additional requirements for connections, straps, studs and boundary members.

EXISTING RESEARCH

The *Shear Wall Design Guide* published by the Steel Framing Alliance in 1998 (Publication RG-9804) included diagonal strap bracing as one of the lateral systems investigated. This document highlights two important issues the designer must consider.

1. Straps are often constructed with material having yield strength higher than specified; therefore it is important to consider this in the design of the end connection. Ideally, to ensure ductile behavior the controlling design value should be the capacity of the strap. An over-strength strap will naturally be capable of transferring higher loads before reaching its yield point. This may result in a less ductile failure mode if the end connections are not sufficiently sized.

2. Diagonal strap bracing on one side of a wall will introduce eccentric loading on the end chord and tracks.

Other research available includes McGill University's strap braced wall research program (2006) where the objective was to evaluate the ductility of diagonal strap bracing through monotonic and cyclic testing. This research discusses the difficulty in ensuring ductile behavior for diagonal strap bracing because of potential material over strength. In addition, the research suggests the ductility the system is also influenced by the stiffness of the holdown, anchor bolt and track detail. Also, the use of gusset plates will likely increase the wall stiffness compared to what flat straps alone would provide. The paper concludes that capacity based performance, where strap bracing would be selected as the "fuse" element, would improve the performance of the system. Additional design steps are required to achieve this.

In his paper *R-Factor Project Validation Test Plan* author Jim Wilcoski suggests the following regarding R-Factors: "These values are intended to represent the degree of ductility, overstrength, redundancy and energy dissipation capacity of the structural system. These factors have a tremendous impact on the design of buildings, yet there is a no rational basis for the establishment of these values. As was stated in FEMA 303, section 5.2 'the R values, contained in the current Provisions, are largely based on engineering judgment of the performance of the various materials and systems in past earthquakes. The values of R must be chosen and used with careful judgment."

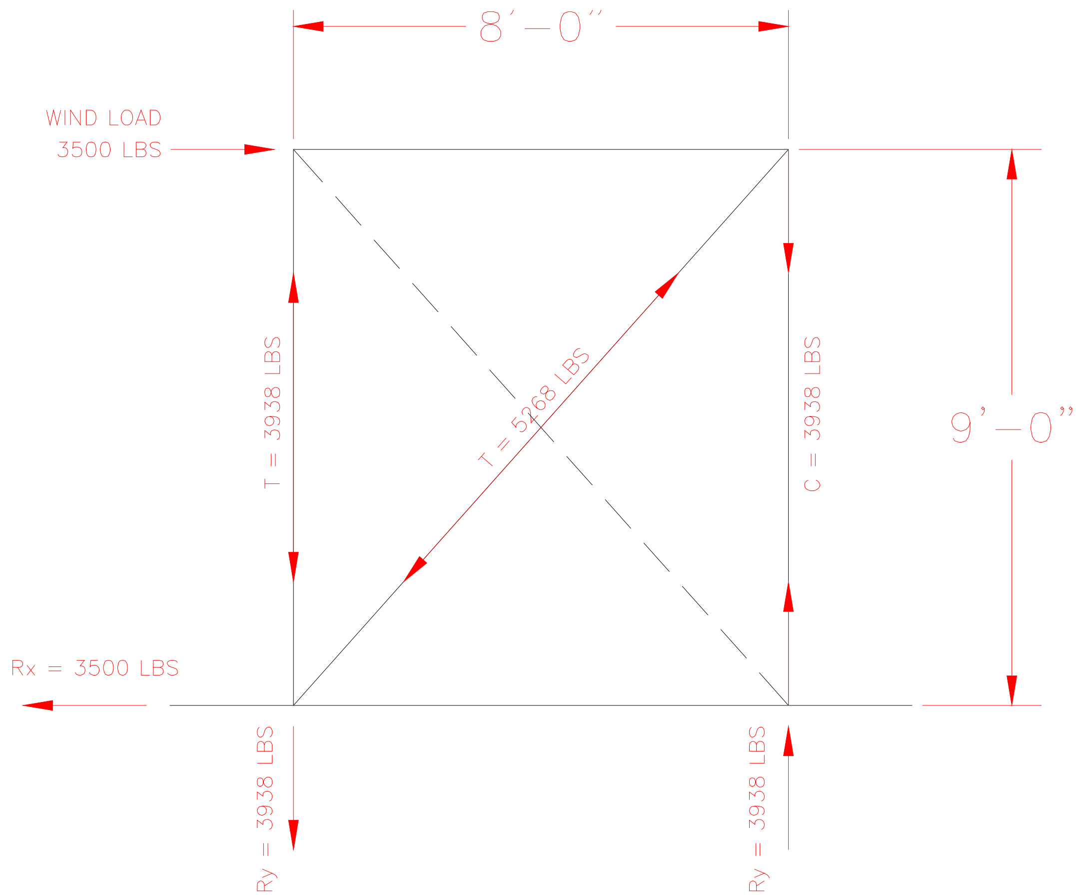
Wilcoski also points out that when straps yield during a cyclic event the slack developed will influence the response of the system. As the system cycles between each tension strap it is not providing any resistance until a strap become taut again. The acceleration developed in the system during the slack time will cause "shock loading" of the members and connections. During cyclic testing this is represented as a pinched hysteretic envelope.

With this research in mind, it is important for the designer to recognize the potential limitations of diagonal strap bracing, particularly if used in seismic areas. Specifically, it is important that the capacity of the system is controlled by the yielding of the strap while the rest of the system remains elastic. Similarly, the potential for material overstrength should be considered. Depending on the specific application the design may find the use of shear panels to be more appropriate.

The 2007 edition of the AISI *Standard for Cold-Formed Steel Framing - Lateral Design* (S213-07) has added new special seismic requirements and commentary for diagonal strap bracing. Included in this are expected yield and tensile strength factors (R_y and R_t) which should be used in the absence of verified physical properties.

DESIGN EXAMPLE

Following is a design example for diagonal strap bracing using gusset plates to resist wind loads. The dimensions and load are shown in the drawing below. The flanges of the wall studs are considered to be braced and gravity loads are ignored.



Design Data

Loads: Horizontal wind load at top of wall from diaphragm = 3500 lb

Material Properties: ASTM A653 SS 33 (F_y = 33 ksi; F_u = 45 ksi)

Wall Dimensions: 8 ft. (length) by 9 ft. (height)

Member Sizes: Wall Studs: 600S162-43
Track: 600T125-43
Straps: 43 mil (0.0451" design thickness)

ASD Design

Resolution of forces considering a tension only strap:

Post load = 3938 lb
Track load = 3500 lb
Strap load = 5268 lb

Equations and code references shown are for the AISI NAS-01.

DESIGN EXAMPLE (CONT.)

Compression Post (Chord Stud)

Assume flexural buckling in the plane of the wall is prevented by bridging at 1/3 points and does not control.

$P = 3938$ lb

From Table III-5 of the 2002 AISI Manual, for 600S162-43, where $KL_x = 9$:

$P_n = 7100$ lb

For $\Omega = 1.80$

$P_a = 3944$ lb

Number of studs required = 3938/3944 = 1.0 **Use two studs**

Check the studs for combined axial load and bending:

$P = 1969$ lb each stud

$M_x = 1969 \cdot 6''/2 = 5907$ in $\cdot$ lb (due to straps on one side of 6" wall)

$\Omega_c \cdot P / P_n = 0.50 > 0.15$ Check eq. C5.2.1-1 and C5.2.1-2 (not eq. C5.2.1-3)

$\Omega_c \cdot P / P_n = 0.50$ (*C5.2.1-1*)

$\Omega_b \cdot C_{mx} \cdot M_x / M_{nx} \cdot \alpha_x = 0.38$

$0.50 + 0.38 < 1.0$ **o.k.**

$\Omega_c \cdot P / P_{no} = 0.23$ (*C5.2.1-2*)

$\Omega_b \cdot M_x / M_{nx} = 0.36$

$0.23 + 0.36 < 1.0$ **o.k.**

Two studs o.k.

Flat Tension Strap

For strap yielding:

$T_n = A_g \cdot F_y$ (*Eq. C2-1*)

Where:

T_a (req'd) = 5268 lb
$\Omega = 1.67$
$T_n = 5268 \cdot 1.67 = 8798$ lb

Solve for w (strap width)

$T_n = (w \cdot t) \cdot (F_y)$
$8798 = w \cdot 0.0451'' \cdot 33{,}000$ ksi
$w = 5.91$ in. **Use 6 in. wide strap**

For fracture away from connection:

$T_n = A_n \cdot F_u$ (*Eq. C2-2*)

Where:

$A_n = A_g$
T_a (req'd) = 5268 lb
$\Omega = 2.0$
$T_n = 5268 \cdot 2.0 = 10{,}536$ lb

DESIGN EXAMPLE (CONT.)

Solve for w	$T_n = (w \cdot t) \cdot (F_u)$ $10536 = w \cdot 0.0451" \cdot 45{,}000$ ksi w = 5.91 in.	**Use 6 in. wide strap**

Strap to Gusset plate Connection

Assume:	#10 screws d = 0.190 in $P_{ns} = 735$ lb	
For Ω = 3.0		
	$P_a = 245$ lb	
Number of screws required =	5268/245 = 21.5	**Use 22 #10 screws**

Gusset to Post Connection

Number of screws required =	3938/245 = 16.1	**Use 17 #10 screws**

Gusset to Track Connection

Number of screws required =	3500/245 = 14.3	**Use 15 #10 screws**

For guidance on the design and detailing of diagonal strap bracings with gusset plates please reference the article *Detailing Help for Gusseted Flat Strap X-Braces* written by John Lyons in the September 2004 LGSEA Newsletter. Once the gusset plate has been dimensioned and the screw spacing determined, fracture at the connection can be checked with section E5.3.

Bottom Track
For bearing strength of the bottom track:

$$P_n = m_f \cdot C \cdot d \cdot F_u$$

Where:	$m_f = 1.0$ C = 2.5 d = 0.625 Ω = 2.5	(*Table E3.3.1-2*) (*Table E3.3.1-1*) 5/8 in. anchor bolts
	$P_n = 3023$ lb	
	$P_a = 1209$ lb	

Number of 5/8 in anchor bolts req. = 3500/1209 = 2.89	**Use 3 anchor bolts**

Note: The capacity of the embedded anchor bolts also needs to be checked

For track yielding (assuming tensile loads):

	$T_n = A_g \cdot F_y$	(*Eq. C2-1*)
Where:	$A_g = 0.383$ in^2 Ω = 1.67	
	$T_n = 0.383 \cdot 33{,}000 = 12{,}639$ lb	
	$T_a = 12{,}639$ lb > 3500 lb	**Track yielding is ok**

DESIGN EXAMPLE (CONT.)

For track fracture at anchor bolt:

$$T_n = A_e \cdot F_u \qquad (\textit{Eq. E3.2-8})$$

Where:

$A_e = A_n \cdot U$
$A_n = 0.383 - (0.043 \cdot 0.66) = 0.355\ in^2$
$U = 1.0$
$\Omega = 2.22$

$T_n = 0.355 \cdot 45{,}000 = 15{,}968\ lb$

$T_a = 7188\ lb$ **Track fracture is ok**

Depending on anchor bolt locations relative to the gusset plate compression of the bottom track may need to be checked instead.

Holdown Anchors

Holdown anchors must be either designed or selected from a manufacturers catalog to resist the uplift forces at the tension post of the resisting system. For this example the holdown would need an allowable capacity of 3938 lb. The anchor bolt used with the holdown will be in addition to the anchor bolts required for shear. Also, the deflection of the holdown device and its influence on the overall rotation of the system shall be checked.

References

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2. *Standard for Cold-Formed Steel Framing - General Provisions*, American Iron and Steel Institute, Washington, DC, 2004.
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6. *Shear Wall Design Guide*, Steel Framing Alliance, Washington, DC, 1998.
7. Wilcoski, J.,2004, *R-Factor Project Validation Test Plan*
8. Al-Kharat, M., Rogers, C. A., (2005) *Testing of Light Gauge Steel Strap Braced Walls*, Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Quebec, Canada
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10. *2004 Supplement to the North American Specification for the Design of Cold-Formed Steel Structural Members*, American Iron and Steel Institute, Washington, DC.
11. *AISI Manual - Cold-Formed Steel Design*. American Iron and Steel Institute, Washington, DC, 2002.
12. Lyons, John C. *Detailing Help for Gusseted Flat Strap X-Braces*, article in the *Newsletter of the Light Gauge Steel Engineers Association (LGSEA)*. September, 2004.
13. *North American Standard for Cold-Formed Steel Framing - Lateral Design* (S213-07). American Iron and Steel Institute, Washington, DC, 2007.

Primary Author of this Technical Note:
Greg Greenlee, P.E., USP Structural Connectors

CFSEI Technical Review Committee: Rob Madsen, P.E., Devco Engineering, Inc., chairman.