Structural Design

design issues for structural engineers

Designing a Cold-Formed Steel Special Bolted Moment Frame

By Ken Wood, P.E.

Ken Wood, P.E. is the Principal of KL Wood Engineering, Inc. He is a member of the AISI COS Sub-32 committee responsible for the development of AISI-A110. Ken can be reached at ***klwoodengineerin@qwestoffice.net***.

As the result of extensive testing and peer review, the first cold-formed steel moment frame used as a seismic force resisting system was recently approved for adoption by the 2012 IBC *(Figure 1)*. While the seismic design parameters for the Cold-Formed Steel – Special Bolted Moment Frame (CFS-SBMF) are found in ASCE 7-10, the detailing requirements for this system can be found in the 2007 edition of the *AISI S110* standard including Supplement 1-09. Although newly adopted, this framing system has been used in the construction of free standing platforms (mezzanines), equipment support platforms, elevated office support platforms, portal frames and small buildings for many years. Structures built in high seismic areas have demonstrated good performance in seismic events; however, up until recently no test data was available to show why and how this system resisted seismic forces. A companion article in this issue details the testing and analysis performed at UCSD. (See Codes & Standards, page 8.)

The Analysis Concept

In structural steel systems, a strong column-weak beam concept was developed as a way to absorb the energy from a seismic event. However, in the CFS-SBMF, due to cold-formed steel components, the members cannot satisfy the compactness requirements to perform like a traditional structural steel system. The results of extensive cyclic testing at UCSD demonstrated that the connection did, in fact, perform consistently as an energy dissipation mechanism, which is a key element in developing a seismic force-resisting system. The design requirements in AISI S110, which were developed from the testing, allow the engineer to design a framing system based on the connection response, so the beams and columns will remain elastic during a significant seismic event. The capacity design for a yielding element – in this case the bolted connection – is required in order to determine the maximum seismic effect in the non-yielding members (beams and columns) at the design story (amplified) drift, Δ. The connection, when subjected to a seismic event, resists rotation by developing the expected moment resulting from two force resisting components (*Figure 2*) in the connection.

The first force resisting component is due to slip of the faying surfaces and, if the seismic event is significant enough, then the second force resisting component, the bearing component, develops in the connection to complete the total shear demand on the columns ($\sum^n(V_s+R_tV_b)$) (*Figure 3*). From this total column shear the expected moment ($M_e = h(V_s+R_tV_b)$(Eq. D1.2.3.1-1) can be computed.

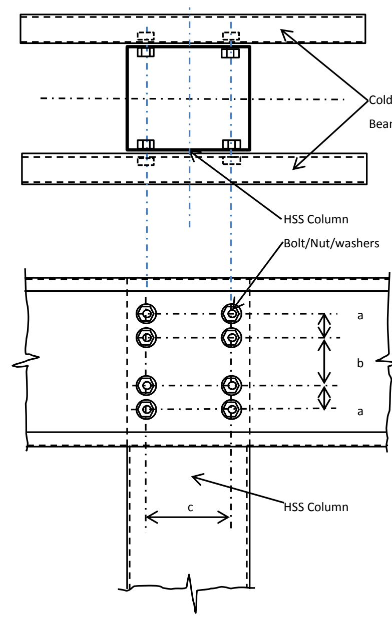

Figure 1: Bolted Connection-SBMF.

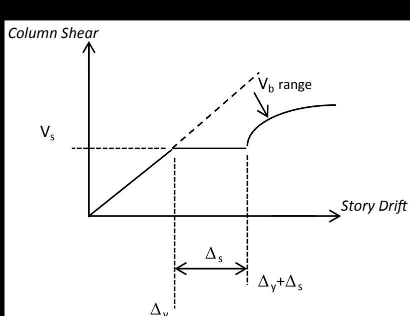

Figure 2: Structural Response of Bolted Connection.

The Design Procedure

The first step in the design process is to select a beam and column combination (see Table C-D1.1-1 in AISI S110) and determine a standard beam to column connection from this selection. The standard connection based on the beam and column selection is in Table C-D1.2-1 or Table C-D1.2-2 of AISI S110. These are the only connection combinations for which coefficients have been developed to be used in the analysis of the column shear. Once the framing system has been selected, an analysis should be performed, using the applicable building code load combinations with R = 3.5 (ASCE 7-10, Table 12.2-1), of the system to establish the structural period. Using ASCE 7 Equation 12.8-3 ($C_s = S_{D1}/T(R/I)$ for $T \le TL$) times the appropriate seismic mass, W_s, for the structure use, the total base shear is calculated for the frame line being checked. Once the base shear is established, the drift can be calculated by dividing the total base shear by the structural framing lateral stiffness, K. This drift, Δ, when amplified by C_d, is the design story drift used in the first check to determine if the bearing component V_b of the connection is zero or not. In order for V_b to be zero, Δ must be less than $\Delta_s+\Delta_y$. If $V_b = 0$, then the expected connection moment is simply $M_e = V_sh$. If V_b is zero, then the value for V_s can be calculated using AISI S110, Equation D1.2.3.1-2. See *Figure 4* for a flow chart on the design process.

If Δ is greater than $\Delta_s+\Delta_y$, then Δ_b must be computed. In order to calculate Δ_b, the values for Δ_s, Δ_y, $\Delta_{B,max}$ and $V_{B,max}$ must be determined. The Δ_y value occurs at the point where slip shear force (V_s) takes place. Once the value of Δ_b is computed, then you must use AISI S110 Equation D1.2.3.1-3 and adjust the value of V_b until the equations is balanced. That is, the left side of the equation is approximately equal to 1.0 and, when this occurs, the computed V_b value is used in Equation D1.2.3.1-1 to calculate the expected moment developed at the bolted connection.

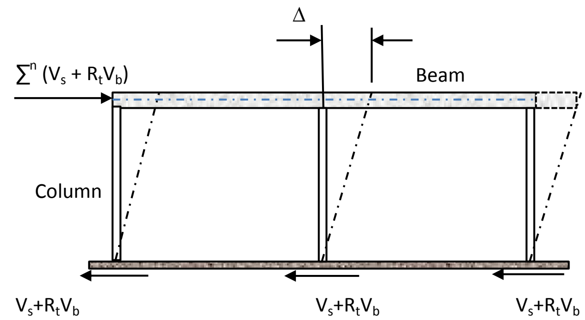

Figure 3: Column Vase Shear.

$V_s = C_s\ k\ N\ T/h$	Eq. D1.2.3.1-2
$\Delta_y = V_s n/K$	drift at connection slip (Fig.C-D1.3-1)
$\Delta_{B,max} = C_{B,O}\ C_{DB}\ h$	Eq. D1.2.3-1-5
$\Delta_s = C_{DS} h_{os} h$	Eq. D1.2.3.1-7
$V_{B,max} = C_B N R_o/h$	Eq. D1.2.3.1-4
C_B, C_{DS} and $C_{B,O}$ = values from Table D1-1	
$\Delta_b = [\Delta-(\Delta_s+\Delta_y)]K\ /\ (nV_{B,max}/\Delta_{B,max} + K)$	Eq. C-D1.2-9 from commentary section
$(V_b/V_{b,max})^2 + (1 - \Delta_b/\Delta_{b,max})^{1.43} = 1.0$	Eq. D1.2.3.1-3
$M_e = h(V_s + R_t V_b)$	Eq.D1.2.3.1-1

The expected moment (M_e) developed at the connection provides the lateral force that the framing components must resist when with the applicable building code load combinations are applied. Once the frame analysis is complete, using the load combinations, the beam and column capacities must be checked in accordance with the requirements found in AISI S100-2007.

Frame Analysis and Design-Example

Given: Framing system: Beams – 2C20x3 ½ x .135; Columns – HSS10x10x¼
System: h = 8.25 feet; Frame Span = 18 feet; Bay Width = 19 feet
Loading: D = 12 psf; Live = 125 psf light storage
Lateral stiffness K = 22.22 kips/inch
$S_{ds} = 1.557$; $S_{d1} = .597$; Site class= D; Seismic mass = 14.8 kips
$C_b = 8.5$; $C_{B,O} = 0.46$; $C_s = 4.8$ From TableD1-1; $C_{DB} = 1.18$ from Table D1-2

Computed $\Delta = 1.52$ inches *design story drift*
$\Delta_s = C_{DS} h_{os} h = 1.33$ inches
$\Delta_y = V_s n/K = .346$ inches
$\Delta_s+\Delta_y = 1.68$ inches $> \Delta$ *Therefore* $M_e = hV_s$
$\Delta_{B,max} = C_{B,O}\ C_{DB}\ h = 4.47$ inches
$V_{B,max} = C_B N R_o/h = 19.47$ kips
$V_s = M_e / h = 3.84$ kips/column *This is the lateral demand at the column.*

The capacities for the beam and column were computed using AISI S100-07. The beam capacity is based on the beam being braced properly in all three axes.
Beams: 2C20x3 ½x.135 capacity ΦMn = 187 kip-ft
Max. demand Mu = 83.24 kip-ft Load combination: 1.2D+1.6L
Columns: HSS10x10x¼ capacity ΦMn = 113.5 kip-ft ΦPn = 336 kips
Max. demand Mu = 77.9 kip-ft Pu = 29.6 kips Load combination: (1.2+.2Sds)D+L+pQe

Summary

Because of the development of the connection (performance based), relative to the seismic moment demand, there is no need to apply any system over-strength factor Ω_o (see Table 1.2.1 in AISI S110 and Footnote o in Table 12.2-2 ASCE 7-10) to the seismic force component in the applicable building code load combinations.

The CFS-SBMF is the first lateral force-resisting system to be introduced in the new AISI S110 standard for seismic design of cold-formed steel structures. The design concept of this system is based on determining the maximum seismic force on the moment connection at the expected story drift when using the proper C_d (3.5) amplification factor. Once the seismic force has been determined, then the capacity design of the beams, columns and connections can be performed in accordance with the AISI S100-07.

Since this is a new approach and there are other possible connection types that can be developed, new designs in cold-formed steel systems should be submitted for inclusion in future editions of the AISI S110. Based on some preliminary connection concepts already presented for further testing, it would appear that some of these connections would provide for increased performance in resisting seismic events.▪

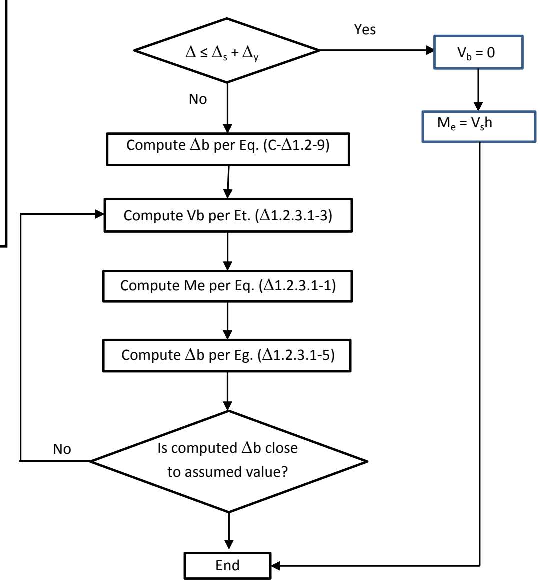

Figure 4: Design Flow Chart.

Symbols

h = Story height – centerline of beam
R_t = Ratio of expected tensile strength to specific tensile strength
V_s = Column shear corresponding to the slip strength of the bolt group
V_b = Column shear corresponding to the bearing strength of the bolt group
n = Number of columns in frame line
C_s = Value from Table D1-1
K = Slip coefficient = 0.33
N = 1 for single-channel beam or 2 for double-channel beam
T = 10 kips (44.5kN) for 1-in. diameter bolts