2. Basis of Design

C-PSW/CE designed in accordance with these provisions are expected to provide significant inelastic deformation capacity through yielding in the plate webs. The horizontal boundary elements (HBE) and vertical boundary elements (VBE) adjacent to the composite webs shall be designed to remain essentially elastic under the maximum forces that can be generated by the fully yielded steel webs along with the reinforced concrete webs after the steel web has fully yielded, except that plastic hinging at the ends of HBE is permitted.

3. Analysis

3a. Webs

The analysis shall account for openings in the web.

3b. Other Members and Connections

Columns, beams and connections in C-PSW/CE shall be designed to resist seismic forces determined from an analysis that includes the expected strength of the steel webs in shear, $0.6R_yF_yA_{sp}$, and any reinforced concrete portions of the wall active at the design story drift,

where

A_{sp} = horizontal area of the stiffened steel plate, in.^{2} (mm^2)

F_y = specified minimum yield stress, ksi (MPa)

R_y = ratio of the expected yield stress to the specified minimum yield stress, F_y

The VBE are permitted to yield at the base.

4. System Requirements

4a. Steel Plate Thickness

Steel plates with thickness less than ⅜ in. (10 mm) are not permitted.

4b. Stiffness of Vertical Boundary Elements

The VBEs shall satisfy the requirements of Section F5.4a.

4c. HBE-to-VBE Connection Moment Ratio

The beam-column moment ratio shall satisfy the requirements of Section F5.4b.

4d. Bracing

HBE shall be braced to satisfy the requirements for moderately ductile members.

4e. Openings in Webs

Boundary members shall be provided around openings in shear wall webs as required by analysis.

5. Members

5a. Basic Requirements

Steel and composite HBE and VBE shall satisfy the requirements of Section D1.1 for highly ductile members.

5b. Webs

The design shear strength, ϕV_n, for the limit state of shear yielding with a composite plate conforming to Section H6.5c, shall be:

$$V_n = 0.6A_{sp}F_y \tag{H6-1}$$

$$\phi = 0.90 \quad \text{(LRFD)}$$

where

F_y = specified minimum yield stress of the plate, ksi (MPa)

A_{sp} = horizontal area of the stiffened steel plate, in.^{2} (mm^2)

The available shear strength of C-PSW/CE with a plate that does not meet the stiffening requirements in Section H6.5c shall be based upon the strength of the plate determined in accordance with Section F5.5 and shall satisfy the requirements of *Specification* Section G2.

5c. Concrete Stiffening Elements

The steel plate shall be stiffened by encasement or attachment to a reinforced concrete panel. Conformance to this requirement shall be demonstrated with an elastic plate buckling analysis showing that the composite wall is able to resist a nominal shear force equal to V_n, as determined in Section H6.5b.

The concrete thickness shall be a minimum of 4 in. (100 mm) on each side when concrete is provided on both sides of the steel plate and 8 in. (200 mm) when concrete is provided on one side of the steel plate. Steel headed stud anchors or other mechanical connectors shall be provided to prevent local buckling and separation of the plate and reinforced concrete. Horizontal and vertical reinforcement shall be provided in the concrete encasement to meet or exceed the requirements in ACI 318 Sections 11.6 and 11.7. The reinforcement ratio in both directions shall not be less than 0.0025. The maximum spacing between bars shall not exceed 18 in. (450 mm).

5d. Boundary Members

Structural steel and composite boundary members shall be designed to resist the expected shear strength of steel plate and any reinforced concrete portions of the wall active at the design story drift. Composite and reinforced concrete boundary members shall also satisfy the requirements of Section H5.5b. Steel boundary members shall also satisfy the requirements of Section F5.

5e. Protected Zones

There are no designated protected zones.

6. Connections

6a. Demand Critical Welds

The following welds are demand critical welds and shall satisfy the requirements of Section A3.4b and I2.3:

(a) Groove welds at column splices

(b) Welds at the column-to-base plate connections

Exception: Welds need not be considered demand critical when both of the following conditions are met.

(1) Column hinging at, or near, the base plate is precluded by conditions of restraint.

(2) There is no net tension under load combinations including the overstrength seismic load.

(c) Welds at HBE-to-VBE connections

6b. HBE-to-VBE Connections

HBE-to-VBE connections shall satisfy the requirements of Section F5.6b.

6c. Connections of Steel Plate to Boundary Elements

The steel plate shall be continuously welded or bolted on all edges to the structural steel framing and/or steel boundary members, or the steel component of the composite boundary members. Welds and/or slip-critical high-strength bolts required to develop the nominal shear strength of the plate shall be provided.

6d. Connections of Steel Plate to Reinforced Concrete Panel

The steel anchors between the steel plate and the reinforced concrete panel shall be designed to prevent its overall buckling. Steel anchors shall be designed to satisfy the following conditions:

1. Tension in the Connector

The steel anchor shall be designed to resist the tension force resulting from inelastic local buckling of the steel plate.

2. Shear in the Connector

The steel anchors collectively shall be designed to transfer the expected strength in shear of the steel plate or reinforced concrete panel, whichever is smaller.

6e. Column Splices

In addition to the requirements of Section D2.5, column splices shall comply with the requirements of this section. Where welds are used to make the splice, they shall be complete-joint-penetration groove welds. When column splices are not made with groove welds, they shall have a required flexural strength that is at least equal to the plastic flexural strength, M_{pcc}, of the smaller composite column. The required shear strength of column web splices shall be at least equal to $\sum M_{pcc}/H$, where $\sum M_{pcc}$ is the sum of the plastic flexural strengths at the top and bottom ends of the composite column and H is the height of story. For composite columns, the plastic flexural strength shall satisfy the requirements of *Specification* Chapter I with consideration of the required axial strength, P_{rc}.

H7. COMPOSITE PLATE SHEAR WALLS—CONCRETE FILLED (C-PSW/CF)

1. Scope

Composite plate shear walls-concrete filled (C-PSW/CF) shall be designed in conformance with this section. This section is applicable to composite plate shear walls that consist of two planar steel web plates with concrete fill between the plates, with or without boundary elements. Composite action between the plates and concrete fill shall be achieved using either tie bars or a combination of tie bars and shear studs. The two steel web plates shall be of equal thickness and shall be placed at a constant distance from each other and connected using tie bars. When boundary members are included, they shall be either a half circular section of diameter equal to the distance between the two web plates or a circular concrete-filled steel tube.

2. Basis of Design

C-PSW/CF with boundary elements, designed in accordance with these provisions, are expected to provide significant inelastic deformation capacity through developing plastic moment strength of the composite C-PSW/CF cross section, by yielding of the entire skin plate and the concrete attaining its compressive strength. The cross section shall be detailed such that it is able to attain its plastic moment strength. Shear yielding of the steel web skin plates shall not be the governing mechanism.

C-PSW/CF without boundary elements designed in accordance to these provisions are expected to provide inelastic deformation capacity by developing yield moment strength of the composite C-PSW/CF cross section, by flexural tension yielding of the steel plates. The walls shall be detailed such that flexural compression yielding occurs before local buckling of the steel plates.

3. Analysis

Analysis shall satisfy the following:

(a) Effective flexural stiffness of the wall shall be calculated per *Specification* Equation I2-12, with C_3 taken equal to 0.40.

(b) The shear stiffness of the wall shall be calculated using the shear stiffness of the composite cross section.

4. System Requirements

4a. Steel Web Plate of C-PSW/CF with Boundary Elements

The maximum spacing of tie bars in vertical and horizontal directions, w_1, shall be:

$$w_1 = 1.8t\sqrt{\frac{E}{F_y}} \tag{H7-1}$$

where

E = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)
F_y = specified minimum yield stress, ksi (MPa)
t = thickness of the steel web plate, in. (mm)

When tie bars are welded with the web plate, the thickness of the plate shall develop the tension strength of the tie bars.

4b. Steel Plate of C-PSW/CF without Boundary Elements

The maximum spacing of tie bars in vertical and horizontal directions, w_1, shall be:

$$w_1 = 1.0t\sqrt{\frac{E}{F_y}} \tag{H7-2}$$

where

t = thickness of the steel web plate, in. (mm)

4c. Half Circular or Full Circular End of C-PSW/CF with Boundary Elements

The D/t_{HSS} ratio for the circular part of the C-PSW/CF cross section shall conform to:

$$\frac{D}{t_{HSS}} \le 0.044\frac{E}{F_y} \tag{H7-3}$$

where

D = outside diameter of round HSS, in. (mm)
t_{HSS} = thickness of HSS, in. (mm)

4d. Spacing of Tie Bars in C-PSW/CF with or without Boundary Elements

Tie bars shall be distributed in both vertical and horizontal directions, as specified in Equations H7-1 and H7-2.

4e. Tie Bar Diameter in C-PSW/CF with or without Boundary Elements

Tie bars shall be designed to elastically resist the tension force, T_{req}, determined as follows:

$$T_{req} = T_1 + T_2 \tag{H7-4}$$

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T_1 is the tension force resulting from the locally buckled web plates developing plastic hinges on horizontal yield lines along the tie bars and at mid-vertical distance between tie-bars, and is determined as follows:

$$T_1 = 2\left(\frac{w_2}{w_1}\right)t_s^2 F_y \quad \text{(H7-5)}$$

where

t_s = thickness of steel web plate provided, in. (mm)

w_1, w_2 = vertical and horizontal spacing of tie bars, respectively, in. (mm)

T_2 is the tension force that develops to prevent splitting of the concrete element on a plane parallel to the steel plate.

$$T_2 = \left(\frac{t_s F_{y,plate} t_w}{4}\right)\left(\frac{w_2}{w_1}\right)\left[\frac{6}{18\left(\frac{t_w}{w_{min}}\right)^2 + 1}\right] \quad \text{(H7-6)}$$

where

t_w = total thickness of wall, in. (mm)

w_{min} = minimum of w_1 and w_2, in. (mm)

4f. Connection between Tie Bars and Steel Plates

Connection of the tie bars to the steel plate shall be able to develop the full tension strength of the tie bar.

4g. Connection between C-PSW/CF Steel Components

Welds between the steel web plate and the half-circular or full-circular ends of the cross section shall be complete-joint-penetration groove welds.

4h. C-PSW/CF and Foundation Connection

The connection between C-PSW/CF and the foundation shall be detailed such that the connection is able to transfer the base shear force and the axial force acting together with the overturning moment, corresponding to 1.1 times the plastic composite flexural strength of the wall, where the plastic flexural composite strength is obtained by the plastic stress distribution method described in *Specification* Section I1.2a assuming that the steel components have reached a stress equal to the expected yield strength, $R_y F_y$, in either tension or compression and that concrete components in compression due to axial force and flexure have reached a stress of f_c'.

5. Members

5a. Flexural Strength

The nominal plastic moment strength of the C-PSW/CF with boundary elements shall be calculated considering that all the concrete in compression has reached its specified compressive strength, f_c', and that the steel in tension and compression has reached its specified minimum yield strength, F_y, as determined based on the location of the plastic neutral axis.

The nominal moment strength of the C-PSW/CF without boundary elements shall be calculated as the yield moment, M_y, corresponding to yielding of the steel plate in flexural tension and first yield in flexural compression. The strength at first yield shall be calculated assuming a linear elastic stress distribution with maximum concrete compressive stress limited to $0.7f_c'$ and maximum steel stress limited to F_y.

User Note: The definition and calculation of the yield moment, M_y, for C-PSW/CF without boundary elements is very similar to the definition and calculation of yield moment, M_y, for noncompact filled composite members in *Specification* Section I3.4b(b).

5b. Shear Strength

The available shear strength of C-PSW/CF shall be determined as follows:

(a) The design shear strength, ϕV_{ni}, of the C-PSW/CF with boundary elements shall be determined as follows:

$$V_{ni} = \kappa F_y A_{sw} \tag{H7-7}$$

$$\phi = 0.90 \text{ (LRFD)}$$

where

$\kappa = 1.11 - 5.16\bar{\rho} \leq 1.0$ (H7-8)

$\bar{\rho}$ = strength adjusted reinforcement ratio

$$= \frac{A_{sw}F_{yw}}{A_{cw}\sqrt{1{,}000 f_c'}} \tag{H7-9}$$

$$= \frac{1}{12}\frac{A_{sw}F_{yw}}{A_{cw}\sqrt{f_c'}} \tag{H7-9M}$$

A_{sw} = area of steel web plates, in.^{2} (mm^2)
A_{cw} = area of concrete between web plates, in.^{2} (mm^2)
F_{yw} = specified minimum yield stress of web skin plates, ksi (MPa)
f_c' = specified compressive strength of concrete, ksi (MPa)

User Note: For most cases, $0.9 \leq \kappa \leq 1.0$.

(b) The nominal shear strength of the C-PSW/CF without boundary elements shall be calculated for the steel plates alone, in accordance with Section D1.4c.

Provisions

CHAPTER I

FABRICATION AND ERECTION

This chapter addresses requirements for fabrication and erection.

User Note: All requirements of *Specification* Chapter M also apply, unless specifically modified by these Provisions.

The chapter is organized as follows:

I1. Shop and Erection Drawings
I2. Fabrication and Erection

I1. SHOP AND ERECTION DRAWINGS

1. Shop Drawings for Steel Construction

Shop drawings shall indicate the work to be performed, and include items required by the *Specification*, the AISC *Code of Standard Practice for Steel Buildings and Bridges*, the applicable building code, the requirements of Sections A4.1 and A4.2, and the following, as applicable:

(a) Locations of pretensioned bolts

(b) Locations of Class A, or higher, faying surfaces

(c) Gusset plates drawn to scale when they are designed to accommodate inelastic rotation

(d) Weld access hole dimensions, surface profile and finish requirements

(e) Nondestructive testing (NDT) where performed by the fabricator

2. Erection Drawings for Steel Construction

Erection drawings shall indicate the work to be performed, and include items required by the *Specification*, the AISC *Code of Standard Practice for Steel Buildings and Bridges*, the applicable building code, the requirements of Sections A4.1 and A4.2, and the following, as applicable:

(a) Locations of pretensioned bolts

(b) Those joints or groups of joints in which a specific assembly order, welding sequence, welding technique or other special precautions are required

3. Shop and Erection Drawings for Composite Construction

Shop drawings and erection drawings for the steel components of composite steel-concrete construction shall satisfy the requirements of Sections I1.1 and I1.2. The shop drawings and erection drawings shall also satisfy the requirements of Section A4.3.

User Note: For reinforced concrete and composite steel-concrete construction, the provisions of ACI 315 *Details and Detailing of Concrete Reinforcement* and ACI 315R *Manual of Engineering and Placing Drawings for Reinforced Concrete Structures* apply.

I2. FABRICATION AND ERECTION

1. Protected Zone

A protected zone designated by these Provisions or ANSI/AISC 358 shall comply with the following requirements:

(a) Within the protected zone, holes, tack welds, erection aids, air-arc gouging, and unspecified thermal cutting from fabrication or erection operations shall be repaired as required by the engineer of record.

(b) Steel headed stud anchors shall not be placed on beam flanges within the protected zone.

(c) Arc spot welds as required to attach decking are permitted.

(d) Decking attachments that penetrate the beam flange shall not be placed on beam flanges within the protected zone, except power-actuated fasteners up to 0.18 in. diameter are permitted.

(e) Welded, bolted, or screwed attachments or power-actuated fasteners for perimeter edge angles, exterior facades, partitions, duct work, piping or other construction shall not be placed within the protected zone.

Exception: Other attachments are permitted where designated or approved by the engineer of record. See Section D1.3.

User Note: AWS D1.8/D1.8M clause 6.18 contains requirements for weld removal and the repair of gouges and notches in the protected zone.

2. Bolted Joints

Bolted joints shall satisfy the requirements of Section D2.2.

3. Welded Joints

Welding and welded connections shall be in accordance with AWS D1.8/D1.8M and *Structural Welding Code—Steel* (AWS D1.1/D1.1M), hereafter referred to as AWS D1.1/D1.1M.

Welding procedure specifications (WPS) shall be approved by the engineer of record.

Weld tabs shall be in accordance with AWS D1.8/D1.8M clause 6.10, except at the outboard ends of continuity-plate-to-column welds, weld tabs and weld metal need not be removed closer than ¼ in. (6 mm) from the continuity plate edge.

AWS D1.8/D1.8M clauses relating to fabrication shall apply equally to shop fabrication welding and to field erection welding.

User Note: AWS D1.8/D1.8M was specifically written to provide additional requirements for the welding of seismic force-resisting systems, and has been coordinated wherever possible with these Provisions. AWS D1.8/D1.8M requirements related to fabrication and erection are organized as follows, including normative (mandatory) annexes:

1. General Requirements
2. Normative References
3. Terms and Definitions
4. Welded Connection Details
5. Welder Qualification
6. Fabrication

Annex A. WPS Heat Input Envelope Testing of Filler Metals for Demand Critical Welds
Annex B. Intermix CVN Testing of Filler Metal Combinations (where one of the filler metals is FCAW-S)
Annex D. Supplemental Welder Qualification for Restricted Access Welding
Annex E. Supplemental Testing for Extended Exposure Limits for FCAW Filler Metals

At continuity plates, these Provisions permit a limited amount of weld tab material to remain because of the reduced strains at continuity plates, and any remaining weld discontinuities in this weld end region would likely be of little significance. Also, weld tab removal sites at continuity plates are not subjected to MT.

AWS D1.8/D1.8M clause 6 is entitled "Fabrication," but the intent of AWS is that all provisions of AWS D1.8/D1.8M apply equally to fabrication and erection activities as described in the *Specification* and in these Provisions.

4. Continuity Plates and Stiffeners

Corners of continuity plates and stiffeners placed in the webs of rolled shapes shall be detailed in accordance with AWS D1.8/D1.8M clause 4.1.