CHAPTER 7

COMPOSITE STEEL AND CONCRETE STRUCTURE DESIGN REQUIREMENTS

7.1 SCOPE: Chapter 7 contains special requirements for the design and construction of composite members and systems combining structural steel and reinforced concrete in structures for which the design forces, generated by earthquake motions, have been determined according to the requirements of Chapter 2. Structures that do not meet the provisions in this chapter are permitted if substantiating evidence based on tests and analyses is provided that demonstrates that the structure has adequate strength, toughness, and seismic resistance for the intended purpose.

Except where modified by the provisions of this chapter, the provisions of Chapter 5, Steel Structure Design Requirements, and Chapter 6, Reinforced Concrete Structure Design Requirements, shall apply to this chapter where applicable.

7.2 REFERENCE DOCUMENTS: The quality and testing of composite steel-concrete materials and their design and construction to resist seismic forces shall conform to the relevant requirements of the following references except as modified by the provisions of this chapter.

Ref. 7-1 Load and Resistance Factor Design Specification for Structural Steel Buildings (LRFD), American Institute of Steel Construction (AISC), 1993

Ref. 7-2 Building Code Requirements for Reinforced Concrete, American Concrete Institute, ACI-318-89 (Revised 1992), excluding Appendix A

Ref. 7-3 Seismic Provisions for Structural Steel Buildings, American Institute of Steel Construction (AISC), June 15, 1992, excluding Part II

Ref. 7-4 Load and Resistance Factor Design Specification for Cold-formed Steel Structural Members,” American Iron and Steel Institute (AISI), March 16, 1991 Edition

Ref. 7-5 Standard for the Structural Design of Composite Slabs, ASCE 3-91

* This chapter introduces into the Provisions seismic design requirements for composite steel-concrete structures. Due to a lack of design experience with certain types of composite systems under earthquake conditions, many of the recommendations are of a conservative and qualitative nature. Users of the Provisions are strongly encouraged to review the underlying source documents and research papers referenced in the Chapter 7 Commentary.
7.3 DEFINITIONS AND SYMBOLS:

7.3.1 DEFINITIONS:

**Boundary Members**: Portions along wall and diaphragm edges strengthened by longitudinal and transverse reinforcement and/or steel structural members.

**Collector Elements**: Members that serve to transfer forces between floor diaphragms and members of the lateral-force-resisting system.

**Composite Beam**: A steel beam either fully encased in concrete or an unencased steel beam made to act integrally with a concrete or composite slab using shear connectors.

**Composite Brace**: A steel brace fabricated from rolled or built-up structural steel shapes and encased in structural concrete or fabricated from steel pipe or tubing and filled with structural concrete.

**Composite Column**: A steel column fabricated from rolled or built-up steel shapes and encased in structural concrete or fabricated from steel pipe or tubing and filled with structural concrete where the structural steel portion accounts for at least 4 percent of the gross column area.

**Composite Slab**: Slab system consisting of a concrete slab and deformed metal deck where the two act compositely in flexure and shear.

**Composite Shear Walls**: Walls consisting of steel plates with concrete encasement on one or both sides that provides out-of-plane stiffening to prevent buckling of the steel panel.

**Coupling Beam**: A steel or composite beam that is used to connect adjacent concrete wall piers to make them act together as a unit to resist lateral loads.

**Encased Composite Beam**: A steel beam totally encased in concrete cast integrally with the slab where full composite action is provided by bond between the steel and concrete without additional anchorage.

**Encased Shapes**: Structural steel members that are encased in structural concrete.

**Face Bearing Plates**: Stiffener plates that are attached to steel beams embedded in concrete walls or columns. The plates are located at the face of the concrete to provide confinement and transfer forces to the concrete through direct bearing.

**Filled Tubes**: Structural steel tubes or pipes that are filled with structural concrete.

**Fully Composite Beam**: A composite beam where the shear connectors are provided in sufficient numbers to develop the nominal plastic flexural strength of the composite section.
Load Carrying Bars: Reinforcing bars in composite members that are designed and detailed to resist calculated forces.

Partially Composite Beam: An unencased composite beam where the number and strength of shear connectors governs the flexural strength of the composite section.

Partially Restrained Composite Connection: Partially restrained connections as defined in Ref. 7-1 between partially or fully composite beams to steel columns where bending resistance is provided by a couple consisting of steel reinforcing bars in the slab and steel seat angles. The connections typically are designed to transmit moments less than the full capacity of the beams and columns.

Restraining Bars: Reinforcing bars in composite members that are provided primarily to facilitate erection of the reinforcement and to provide anchorage for stirrups or ties and are not designed to carry calculated forces. Generally, such bars are not spliced to be continuous.

Strength, Nominal: Strength of a member or cross section calculated in accordance with the provisions and assumptions of the strength design methods of these provisions (or the referenced standards) before application of any strength reduction factors.

Strength, Design: Nominal strength multiplied by a resistance factor, \( \phi \).

Strength, Required: Strength of a member, cross section, or connection required to resist factored loads or related internal moments and forces in such combinations as stipulated by these provisions.

7.3.2 SYMBOLS:

\( A_s \) = cross sectional area of structural steel elements in composite members.

\( A_s/A_g \) = ratio of cross sectional area of structural steel portion to the gross area of a composite column (see Ref. 7-1).

\( A_{sc} \) = area of encased steel shape on the compression side of the plastic neutral axis in a composite column.

\( A_{st} \) = area of encased steel shape on the tension side of the plastic neutral axis in a composite column.

\( A_{sp} \) = horizontal area of the steel plate in composite shear wall (Eq. 7.4.7.1.1).

\( b \) = flange width of structural steel tubing.

\( b_w \) = effective width for shear strength calculation of reinforced concrete portion of composite column.
\( b/t \) = width to thickness ratio of either unstiffened or stiffened elements, as applicable, of steel members under compression stresses (see Ref. 7-1).

\( d \) = depth of steel beam (Eq. 7.5.2.2).

\( D \) = the effect of dead load (Chapter 2).

\( D/t \) = diameter to wall thickness ratio of steel pipes used for concrete filled composite columns (see Ref. 7-1).

\( E \) = the load effect of seismic (earthquake-induced) forces (Chapter 2).

\( E_s \) = elastic modulus of structural steel.

\( F_y \) = specified yield strength of structural steel.

\( F_{yh} \) = specified yield strength of reinforcing bar ties.

\( f_{c'} \) = specified compressive strength of concrete used in design.

\( h \) = the cross sectional dimension of reinforced concrete or composite columns.

\( h_c \) = the cross sectional dimension of the confined core region in composite columns measured center-to-center of the tie reinforcement.

\( h/t_w \) = height to thickness ratio of web elements of steel members (see Ref. 7-1).

\( P_n \) = nominal axial strength of column.

\( P_u \) = required axial design strength of column.

\( R \) = the response modification coefficient as given in Table 2.2.2.

\( V_c \) = portion of nominal shear strength provided by the concrete in reinforced concrete or composite columns (see Ref. 7-2).

\( V_s \) = shear yield strength of steel plate in composite shear wall (Eq. 7.4.7.1.1).

\( Y_{con} \) = distance from top of steel beam to top of concrete slab or encasement (Eq. 7.5.2.2).

\( \phi_c \) = resistance factor for composite columns (= 0.85).

\( \rho_v \) = ratio of vertical or horizontal reinforcement in walls (see Chapter 21 of Ref. 7-2).
7.4 COMPOSITE SYSTEMS: The use and height restrictions of composite building systems shall be as specified in Table 2.2.2. Except as noted in this section, structural steel and reinforced concrete members in composite systems shall satisfy the provisions of Chapters 5 and 6, respectively. Composite members shall meet the provisions of Sec. 7.5. Connections between steel, concrete, and composite members shall meet the provisions of Sec. 7.6.

7.4.1 COMPOSITE PARTIALLY RESTRAINED FRAMES (C-PRF): The provisions in this section apply to frames consisting of structural steel columns and composite beams, connected with partially restrained connections meeting the requirements of Type PR construction as defined in Ref. 7-1.

7.4.1.1 Limitations:

7.4.1.1.1: The effect of the connection flexibility shall be accounted for in determining the strength and drift of C-PRF.

7.4.1.1.2: The height restrictions in Table 2.2.2 for C-PRF may be exceeded if the strength and ductility of the structure are demonstrated through nonlinear analysis that includes both the geometric and connection nonlinearities.

7.4.1.2 Columns: Steel columns shall be designed according to Ref. 7-1 with the effect of the semi-rigid connections considered in evaluating the stability of individual columns and the frame. Required design strengths for columns shall include moments transferred into the columns through the semi-rigid connections. In Seismic Performance Category D, steel columns also shall meet the requirements of Ref. 7-3, Sec. 6.

7.4.1.3 Composite Beams: Composite beams shall be designed according to the requirements of Sec. 7.5.2. For analysis, beam stiffness shall be determined using an effective moment of inertia of the composite section.

7.4.1.4 Partially Restrained Connection: Beam-column moment connections shall be designed for the factored loads calculated according to the provisions in Chapter 2 and considering the connection flexibility.

7.4.2 COMPOSITE ORDINARY MOMENT FRAMES (C-OMF): The provisions in this section apply to moment resisting frames consisting of either steel, reinforced concrete, or composite columns and either steel or composite beams.

7.4.2.1 Columns: Steel columns shall meet the requirements for ordinary moment frames in Chapter 5.

In Seismic Performance Categories A, B and C, reinforced concrete columns shall meet the requirements for intermediate moment frames in Chapter 6. In Seismic Performance Categories D and E, reinforced concrete columns shall meet the requirements for special moment frames in Chapter 6.

Composite columns shall meet the requirements of Sec. 7.5.
7.4.2.2 Beams: Steel beams shall meet the requirements for ordinary moment frames in Chapter 5. Composite beams shall meet the requirements of Sec. 7.5.2.

7.4.2.3 Moment Connections: In Seismic Performance Categories A, B and C, beam-column moment connections shall be designed for the factored loads calculated according to Chapter 2. In Seismic Performance Categories D and E, moment connections also shall be designed to meet one of the following requirements:

a. The connection design strength shall meet or exceed the forces associated with plastic hinging of the beams adjacent to the connection,

b. The connection design strength shall meet or exceed the forces calculated using Eq. 2.2.6-3 and 2.2.6-4, or

c. The connections are demonstrated by cyclic tests to have adequate rotation capacity at a story drift calculated from an elastic analysis at a horizontal load of $2R/5 \times E$ where $2R/5$ is greater than or equal to 1.0.

7.4.3 COMPOSITE SPECIAL MOMENT FRAMES (C-SMF): The provisions in this section apply to moment resisting frames consisting of either steel, reinforced concrete or composite columns and either steel or composite beams. Members and connections in C-SMF shall be designed to provide ductility and toughness that permit the use of lower seismic design forces than C-OMF.

7.4.3.1 Columns: Steel columns shall meet the requirements for special moment frames in Chapter 5. Reinforced concrete columns shall meet all requirements for special moment frames in Chapter 6. Composite columns shall meet the requirements of Sec. 7.5.

7.4.3.2 Beams: Steel beams shall meet the requirements for special moment frames in Chapter 5. Composite beams shall meet the requirements of Sec. 7.5.2. Steel or composite trusses are not permitted for use as flexural members to resist lateral loads in composite SMF, unless it is shown by tests and analysis that the particular system provides adequate ductility and energy dissipation capacity.

7.4.3.3 Moment Connections: Moment connection design strengths shall meet or exceed the flexural and shear forces associated with plastic hinging of the beams adjacent to the connection.

7.4.3.4 Column-Beam Moment Ratio: When $P_n > 0.1P_n$ in reinforced concrete or composite columns, one of the following provisions shall be met:

a. The flexural strength of the columns shall meet the requirements of Sec. 21.4.2.2 of Ref. 7-2 or

b. For reinforced concrete columns the provisions of Sec. 21.4.2.3 of Ref. 7-2 shall be met, and for encased composite columns the hoop reinforcement specified in Sec. 7.5.3.8.3(b) shall extend over the full column height.
The provisions of Sec. 8.6 of Ref. 7-3 shall be met for steel columns.

7.4.4 COMPOSITE CONCENTRICALLY BRACED FRAMES (C-CBF): The provisions in this section apply to braced systems composed of concentrically connected members. Minor eccentricities are acceptable if accounted for in the design. Columns may be either reinforced concrete or composite. Beams and braces may be either steel or composite.

7.4.4.1 Limitations: C-CBF shall meet all requirements for steel CBF in Chapter 5 except as modified in this section.

7.4.4.2 Columns: Reinforced concrete columns shall meet all requirements for intermediate moment frames in Chapter 6. In Seismic Performance Categories D and E reinforcement in concrete columns also shall meet the requirements of Sec. 21.6.2.3 of Ref. 7-2.

   Composite columns shall meet the requirements of Sec. 7.5.

7.4.4.3 Beams: Composite beams shall meet the requirements of Sec. 7.5.2.

7.4.4.4 Braces: Composite braces shall meet the requirements for composite columns in Sec. 7.5. Unless evidence is provided to justify higher strengths, composite braces shall be designed in tension as steel braces according to the requirements for steel CBF in Chapter 5.

7.4.4.5 Bracing Connections: In addition to the requirements for steel CBF in Chapter 5, bracing connections shall meet all requirements of Sec. 7.6.

7.4.5 COMPOSITE ECCENTRICALLY BRACED FRAMES (C-EBF): The provisions in this section apply to braced systems where at least one end of each brace intersects a link beam at a prescribed eccentricity from the intersection of either the column and link-beam centerlines or the adjacent brace and link-beam centerlines. Eccentrically braced frames of composite steel-concrete shall be designed so that under earthquake loading, yielding will be primarily shear yielding and will occur in the links. The diagonal braces, columns and beam segments outside of the links shall be designed to remain essentially elastic under the maximum forces that can be generated by the fully yielded and strain hardened links. Columns may be either reinforced concrete or composite. Braces shall be structural steel. Links shall be as specified in 7.4.5.3.

7.4.5.1 Limitations: C-EBF shall meet all requirements for steel EBF as specified in Chapter 5 except as modified in this section.

7.4.5.2 Columns: Reinforced concrete columns shall meet the requirements for intermediate moment frames in Chapter 6. In Seismic Performance Categories D and E or where shear links are directly adjacent to the column, transverse reinforcement for concrete columns also shall meet the requirements of Sec. 21.6.2.3 of Ref. 7-2.

   Composite columns shall meet the requirements of Sec. 7.5. Additionally, where shear links are directly adjacent to the column, transverse reinforcement in composite columns shall meet the requirements of Sec. 7.5.3.8.3.

   All steel columns shall satisfy the strength requirements of Sec. 10.8 of Ref. 7-3.
7.4.5.3 **Link Beams:** Link portions of beams shall be unencased and shall meet the requirements for links in steel EBF in Chapter 5. Portions of the beams outside the link region may be encased in concrete. Link beams may be connected to the floor slab with shear connectors along all or any portion of their length provided that the composite action is considered in calculating the maximum nominal strength of the link.

7.4.5.4 **Braces:** Steel braces shall meet or exceed the requirements for steel EBF braces in Chapter 5.

7.4.5.5 **Connections:** In addition to the requirements for steel EBF connections in Chapter 5, connections shall meet requirements of Sec. 7.6.

7.4.6 **RC WALLS COMPOSITE WITH STEEL ELEMENTS:** The provisions in this section apply where reinforced concrete walls are composite with steel elements in any of the following ways:

a. Reinforced concrete walls are used as infill panels in structural steel frames and the steel members are either non-encased or encased,

b. Encased shapes are used to reinforce boundary members in reinforced concrete shear walls, or

c. Steel coupling beams are used to connect two or more reinforced concrete walls.

7.4.6.1 **Limitations** Except as modified in this section, reinforced concrete walls shall meet the requirements of Chapter 6.

7.4.6.2 **Boundary Elements:**

7.4.6.2.1 **Steel Shapes:** Where reinforced concrete infill panels are used and unencased steel shapes function as boundary elements, the steel columns shall meet the design provisions of Ref. 7-1 and Sec. 5 and 6 of Ref. 7-3. Element forces in the steel boundary members shall be calculated following the provisions in Sec. 21.6.5.3 of Ref. 7-2 where it shall be assumed that the reinforced concrete panel only resists shear forces and the steel columns carry 100 percent of the vertical forces due to gravity loads and overturning in the wall.

7.4.6.2.2 **Encased Steel Shapes:** Where steel shapes are fully encased to form composite boundary elements, boundary element forces shall be calculated following the provisions in Sec. 21.6.5.3 of Ref. 7-2. For purposes of stress calculations, the composite wall may be transformed into an equivalent concrete section using elastic material properties. Encased boundary elements shall meet the requirements of Sec. 7.5, 7.5.3.3, 7.5.3.4, and 7.5.3.6 of this document. In Seismic Performance Categories D and E, boundary elements also shall meet the boundary element requirements of Sec. 21.6.5 of Ref. 7-2 and Sec. 7.5.3.7 of this document. Transverse reinforcement for confinement of the composite boundary element shall extend a distance of $2h$ into the wall where $h$ is the overall depth of the boundary member in the plane of the wall.
7.4.6.2.3 Shear Connectors: Headed studs or welded reinforcing bar anchors shall be provided to transfer vertical shear forces between the reinforced concrete and structural steel members. The nominal strengths of headed studs may be calculated following the provisions of Ref. 7-1. For connection to unencased steel shapes in Seismic Performance Categories C, D and E, the nominal strengths of headed studs shall be reduced by 25 percent from those specified in Ref. 7-1 and the nominal strength of welded reinforcing bar anchors shall be reduced by 25 percent from their static yield strength.

7.4.6.3 Coupling Beams: Steel beams may be used to couple adjacent concrete walls or columns and shall meet the requirements of this section.

7.4.6.3.1: Coupling beams shall satisfy the provisions of the following sections of Ref. 7-3: 10.2.a through Sec. 10.2.f, Sec. 10.3.b where the coupling rotation shall be assumed as 0.09 radians, and Sec. 10.3.c. Full depth web stiffeners (face bearing plates) also shall be provided on both sides of the coupling beams at the face of the concrete wall. These stiffeners shall meet the detailing requirements of Sec. 10.3.a in Ref. 7-3.

7.4.6.3.2: Embedment length of coupling beams in concrete walls shall be sufficient to develop the maximum possible combination of moment and shear force that can be generated by the nominal strength of the coupling beam. Embedment length shall be considered to begin inside the first layer of confinement reinforcement in the wall boundary member. Connection strength for transfer of loads between coupling beams and concrete walls shall meet the requirements of Sec. 7.6.

7.4.6.3.3: Vertical wall reinforcement with an axial strength equal to the calculated nominal shear strength of the coupling beam shall be placed over the embedment length of the link beam with two thirds of the steel located over the first half of the embedment length. This wall reinforcing shall extend a distance of at least one tension development length above and below the flanges of the link beams. This vertical reinforcement shall be confined by transverse reinforcement at least equivalent to that required in Chapter 6 for boundary elements in reinforced concrete walls. The reinforcement required by this section is only a minimum amount which may be satisfied by vertical reinforcement provided to satisfy other requirements such as for reinforcing the wall boundary elements.

7.4.7 COMPOSITE SHEAR WALLS: The provisions in this section apply to structural walls consisting of steel plates with concrete encasement on one or both sides of the plate and steel or composite boundary elements.

7.4.7.1 Wall Element:

7.4.7.1.1 Calculation of Shear Strength: Where the stiffening requirements of Sec. 7.4.7.1.2 are met, the nominal shear strength of the wall shall be calculated as the following:
\[ V_s = \frac{A_{sp} F_y}{\sqrt{3}} \] (7.4.7.1.1)

where

\[ V_s \] = the shear yield strength of the steel plate,

\[ A_{sp} \] = the horizontal area of the steel plate, and

\[ F_y \] = the specified yield strength of the plate.

For cases where the stiffening requirements of Sec. 7.4.7.1.2 are not met, the shear strength of the steel plate shall be calculated following the provisions for steel shear members in Chapter 5 considering buckling of the steel plate. Shear strength of the reinforced concrete shall not be included in the strength calculation for the composite wall.

7.4.7.1.2 Concrete Stiffening: The steel plate may be considered to be sufficiently stiffened by concrete if an elastic plate buckling analysis shows that the composite wall can resist an applied shear force equal to its nominal shear strength. Additionally, the concrete thickness shall be a minimum of 4 in. (102 mm) when concrete is provided on both sides of the steel plate and a minimum of 8 in. (203 mm) when concrete is provided on one side of the steel plate. Headed studs or other mechanical connectors shall be provided to prevent local buckling and separation of the plate and concrete. Reinforcement equal to that specified in Sec. 14.3 of Ref. 7-2 shall be provided in the concrete encasement. In Seismic Performance Categories D and E, the reinforcement ratio in either the horizontal or vertical direction, \( \rho_v \), shall not be less than 0.0025 and the maximum spacing between bars shall not exceed 18 in. (457 mm).

7.4.7.1.3 Shear Transfer: The steel plate shall be continuously connected on all edges to steel boundary elements by welds and/or slip critical bolts to develop a shear force at least equal to the shear yield strength of the plate. The design strength of welded and bolted connectors shall meet the provisions of Ref. 7-1.

7.4.7.2 Boundary Members: Steel and composite boundary members shall be designed following the provisions in Sec. 7.4.6.2.

7.4.7.3 Openings in Composite Walls: Boundary members shall be provided around openings as required by analysis.

7.5 COMPOSITE MEMBERS: The design of composite members subjected to seismic forces acting alone or in combination with other prescribed loads shall be determined by the provisions of Ref. 7-1 through 7.5 except as modified in this section.

Structural steel in composite members shall meet the requirements of Ref. 7-1, Sec. A3.1. Additionally, for special moment frames and for all structures in Seismic Performance Categories D and E, structural steel in composite members shall meet the requirements of Ref. 7-3, Sec. 5.
Reinforcing steel in composite members shall meet the requirements of Ref. 7-2, Sec. 3.5.1, 3.5.2, and 3.5.3. Additionally, in Seismic Performance Categories C, D and E and in special moment frames, reinforcing steel shall meet the requirements of Ref. 7-2, Sec. 21.2.5 and 21.2.6.

Concrete in composite members shall have a specified compressive strength not less than 3 ksi (20.7 MPa). Additionally, in composite members and in composite columns in Seismic Performance Categories C, D and E, special moment resisting frames, the design compressive strength of normal weight concrete shall not exceed 10 ksi (68.9 MPa) and for lightweight concrete shall not exceed 4 ksi (27.6 MPa). Concrete with higher design compressive strengths may be allowed if demonstrated by experimental evidence that structural members made with that concrete provide sufficient strength and toughness for the intended purpose.

7.5.1 COMPOSITE SLABS: Composite and noncomposite floor slabs shall be designed to meet the requirements of Chapter 2. Steel deck diaphragms and concrete slab diaphragms shall be designed to meet the provisions of Chapters 5 and 6, respectively. Where concrete slab on steel deck diaphragms are used to resist seismic forces the requirements of this section shall be met.

7.5.1.1 Shear Fasteners: Provisions shall be made to transfer forces between the composite slab and the boundary members and collector elements of the diaphragm.

7.5.1.2 Shear Strength: The in-plane design shear strength of the composite diaphragms shall be calculated on the basis of established design procedures or tests of concrete filled diaphragms; or conservatively, on the basis of only the reinforced concrete slab above the top of the ribs of the metal deck. In the latter case, the nominal in-plane strength of the reinforced concrete slab shall meet the provisions of Chapter 6.

7.5.2 COMPOSITE BEAMS: The provisions in this section apply only to those composite beams that are part of the primary lateral load resisting system in the structure. Except as noted below, the design provisions in Chapter I of Ref. 7-1 shall apply.

7.5.2.1 Additional Requirements for Special Moment Frames: Design provisions for special moment frames in Sec. 8.8 of Ref. 7-3 shall apply except as modified in Sec. 7.5.2.2 through 7.5.2.3 of this chapter. In Seismic Performance Categories D and E, the provisions of Sec. 8.4 of Ref. 7-3 also apply.

7.5.2.2 Plastic Stress Distribution: The distance from the maximum concrete compression fiber to the plastic neutral axis shall not exceed:

$$\frac{Y_{con} + d}{1 + \left( \frac{1700F_y}{E_s} \right)}$$  \hspace{1cm} (7.5.2.2)

where

$$Y_{con} = \text{the distance from the top of the steel beam to the top of concrete},$$
\[ d = \text{the depth of the steel beam, and} \]
\[ F_y = \text{the specified yield strength of the steel beam, and} \]
\[ E_s = \text{the elastic modulus of the steel beam.} \]

7.5.2.3 Width-Thickness Ratios: Compression elements that are fully encased by a reinforced concrete cover of at least 2 in. (51 mm) do not need to meet the width-thickness ratios of Sec. 8.4 in Ref. 7-3 provided that concrete is confined by hoop reinforcement in regions where plastic hinges are expected to occur under seismic loading. Hoop reinforcement shall meet the requirements of Sec. 21.3.3 in Ref. 7-2.

7.5.3 ENCASED COMPOSITE COLUMNS: Columns consisting of structural concrete encased steel sections where the structural steel area comprises at least 4 percent of the total composite column cross section and meeting the additional limitations in Sec. 11.2.1 of Ref. 7-1 shall be designed according to provisions in Chapter I of Ref. 7-1 and the provisions in this section. Columns with encased shapes that do not meet these criteria shall be designed according to the provisions of Chapter 6 for reinforced concrete columns.

7.5.3.1 Shear Strength: The design shear strength of the column shall be determined by the shear strength of the structural shape plus the shear strength of tie reinforcement in the reinforced concrete encasement. The shear strength of the steel shape shall be calculated following the provisions of Ref. 7-1, Sec. F2. The shear strength of the tie reinforcement shall be calculated following the provisions of Ref. 7-2, Sec. 11.5.6.2 through 11.5.6.8. For Sec. 11.5.6.4 and 11.5.6.8, the dimension \( b_w \) shall be equal to the width of the concrete cross section minus the width of the structural shape measured perpendicular to the direction of shear.

7.5.3.2 Shear Connectors: Where a composite column is designed so that the steel shape and concrete share the applied loads, shear connectors shall be provided to meet the following requirements:

a. If external members are framed directly to the steel shape, provide shear connectors to transfer the sum of all applied forces along the axis of the member that are not able to be carried by the steel section alone.

b. If external members are framed directly to the concrete in direct bearing or shear, provide shear connectors to transfer the sum of all applied forces along the axis of the member that are not able to be carried by the reinforced concrete alone.

c. Where \( P_y/\phi_cP_n \leq 0.3 \) and a composite column is subjected to predominantly flexure, provide shear connectors along the axis of the embedded shape from the point of inflection to the point of maximum moment designed for a force equal to \( F_y(A_{sf} - A_{sc}) \) where \( F_y \) is the yield strength of the structural steel and \( A_{sf} \) and \( A_{sc} \) are the areas of embedded steel shape on the tensile and compression side of the plastic neutral axis, respectively.
d. The maximum spacing of shear connectors shall be 32 in. (813 mm) with attachment along the outside flange faces of the embedded shape.

7.5.3.3 Transverse Reinforcement: The maximum spacing of transverse ties shall be the smaller of the following:

a. 1/2 the least dimension of the section,

b. 16 diameters of the longitudinal bars, or

c. 48 tie bar diameters.

Ties shall be located vertically not more than 1/2 a tie spacing above the top of footing or lowest beam or slab in any story, and shall be spaced as provided herein to not more than 1/2 a tie spacing below the lowest beam or slab framing into the column.

Transverse bars shall have a diameter not less than 1/50 times the greatest side dimension of the composite members, except that ties shall not be smaller than No. 3 (10 mm diameter) bars and are not required to be larger than No. 5 (16 mm diameter) bars. Welded wire fabric of equivalent area is permitted as transverse reinforcement in Seismic Performance Categories A and B.

7.5.3.4 Longitudinal Reinforcement: All load carrying bars shall meet the detailing and splice provisions of Ref. 7-2, Sec. 7.8.1 and 12.17. As a minimum, load carrying bars must be provided at every corner of a rectangular cross section. Other load carrying or restraining longitudinal bars shall not be spaced farther apart than one-half of the least side dimension of the composite member.

7.5.3.5 Steel Core: Splices and end bearing details for the encased steel shape shall meet the requirements of Sec. 7.8.2 of Ref. 7-2 and Ref. 7-1.

7.5.3.6 Additional Requirements in Seismic Performance Category C: Concrete encased composite columns in Seismic Performance Category C shall meet the requirements in this section in addition to those in Sec. 7.5.3.1 through 7.5.3.5.

Maximum spacing of transverse bars at the top and bottom of a story shall not exceed the smaller of the following:

a. 1/2 the least dimension of the section,

b. 8 bar diameters of the longitudinal bars,

c. 24 tie bar diameters, or

d. 12 in. (305 mm).

These spacings shall be maintained at least over a vertical distance equal to the greater of the following lengths measured from each joint face and on both sides of any section where flexural yielding is likely to occur:

a. 1/6 the vertical clear height of the column,
b. the maximum cross-sectional dimension, and

c. 18 in. (457 mm).

Tie spacing over the rest of the column length shall not exceed twice the spacing defined above.

7.5.3.7 Additional Requirements in Seismic Performance Categories D and E: Encased columns in Seismic Performance Categories D and E shall meet the requirements in this section in addition to those in Sec. 7.5.3.1 through 7.5.3.6.

7.5.3.7.1 Columns: Seismic design forces for columns shall be calculated using Eq. 2.2.6-3 and 2.2.6-4.

7.5.3.7.2 Transverse Reinforcement: Ties shall be provided at the top and bottom of a column that meet the requirements of Sec. 7.5.3.6 and this section. The requirements of this section need not apply if the nominal strength of the encased steel section alone is greater than 1.0D plus 0.5L where D and L are defined in Chapter 2.

The minimum area of reinforcement, $A_{sh}$, shall be at least equal to the following:

$$A_{sh} = 0.09 h_c s \left(1 - \frac{F_y A_s}{P_n} \right) \left( \frac{f_{c'}'}{F_{yh}} \right)$$  \hspace{1cm} (7.5.3.7.2)

where

- $h_c$ = the cross-sectional dimension of the confined core region measured center-to-center of the tie reinforcement,
- $F_y$ = the specified yield strength of the structural steel core,
- $A_s$ = the cross sectional area of the structural steel core,
- $P_n$ = the nominal compressive axial strength of the composite column calculated according to Ref. 7-1,
- $f_{c'}'$ = the specified concrete compressive strength, and
- $F_{yh}$ = the specified yield strength of the ties.

7.5.3.7.3 Longitudinal Bars: Design of load carrying longitudinal reinforcing bars shall meet the requirements of Ref. 7-2, Sec. 21.4.3.

7.5.3.7.4 Steel Core: Splices of the encased structural steel core shall meet the requirements of Ref. 7-3, Sec. 6.2.
7.5.3.7.5 Columns Supporting Discontinuous Walls: Composite columns supporting reactions from discontinued stiff members, such as walls, shall be provided with transverse reinforcement as specified in Sec. 7.5.3.6 over the full height beneath the level at which the discontinuity occurs if the axial compression exceeds 0.10P_n (where P_n is the nominal compressive axial strength of the composite column). Transverse reinforcement shall extend into the discontinued member for at least the length required to develop full yielding in the encased shape and longitudinal reinforcing bars.

7.5.3.7.6 Columns Supported by Walls or Footings: Where the column terminates on a wall, the transverse reinforcement as specified in Sec. 7.5.3.5 shall extend into the wall for at least the length required to develop full yielding in the encased shape and longitudinal reinforcing bars. Where the column terminates on a footing or mat, the transverse reinforcement as specified in Sec. 7.5.3.5 shall extend into the footing or mat at least 12 in. (305 mm).

7.5.3.8 Additional Requirements in Special Moment Frames: Encased columns used in special moment frames in all Seismic Performance Categories shall meet the requirements in this section in addition to those in Sec. 7.5.3.1 through 7.5.3.7.

7.5.3.8.1 Strong Column/Weak Beam: The strong-column/weak-beam design requirements of Sec. 7.4.3.4 shall be satisfied to limit plastic hinge formations in the columns. Column bases shall be detailed to sustain inelastic flexural hinging.

7.5.3.8.2 Shear Strength: The minimum required nominal shear strength of the column shall meet the provisions of Sec. 21.4.5.1 of Ref. 7-2.

7.5.3.8.3 Transverse Reinforcement: Transverse reinforcement shall be detailed as hoop reinforcement (Chapter 21 of Ref. 7-2) and shall meet the more severe of the requirements of Sec. 7.5.3.3, 7.5.3.6 and 7.5.3.7 and the following:

a. The maximum spacing of transverse reinforcement along the entire length of the column shall not exceed 6 diameters of the longitudinal load carrying bars or 6 in. (152 mm).

b. At the top and bottom of the column over the region specified in Sec. 7.5.3.6 the maximum spacing of transverse reinforcement shall not exceed 1/4 of the minimum member dimension or 4 in. (102 mm). In these regions, crossties, legs of overlapping hoops, or other confining reinforcement shall not be spaced more than 14 in. (356 mm) on center in the transverse direction.

7.5.4 FILLED COMPOSITE COLUMNS: Columns consisting of concrete filled steel tubes or pipes where the structural steel area comprises at least 4 percent of the total composite column cross section and meeting the additional limitations of Sec. 12.1 in Ref. 7-1 shall be designed according to provisions in Chapter I of Ref. 7-1 and the provisions in this section.

7.5.4.1 Shear Strength: The shear strength of column shall be calculated as the strength of the steel section alone.
7.5.4.2 Additional Requirements in Seismic Performance Categories D and E: Filled columns in Seismic Performance Categories D and E shall meet the requirements in this section in addition to those in Sec. 7.5.4.1.

7.5.4.2.1 Columns: Seismic design forces in columns shall be calculated using Eq. 2.2.6-3 and 2.2.6-4.

7.5.4.2.2 Steel Tube: Splices of the structural steel tube or pipe shall meet the requirements of Ref. 7-3, Sec. 6.2.

7.5.4.3 Additional Requirements for Special Moment Frames: Filled columns used in special moment frames in all Seismic Performance Categories shall meet the requirements in this section in addition to those in Sec. 7.5.4.1 and 7.5.4.2.

7.5.4.3.1 Shear Strength: The minimum required shear strength of the column shall meet the provisions of Sec. 21.4.5.1 of Ref. 7-2.

7.5.4.3.2 Strong Column/Weak Beam: The strong-column/weak-beam design requirements of Sec. 7.4.3.4 shall be satisfied to limit plastic hinge formations in the columns. Column bases shall be detailed to sustain inelastic flexural hinging.

7.5.4.3.3 Structural Steel Pipe and Tubing: The minimum wall thickness of structural steel pipe or tubing filled with concrete shall be equal to \( b \sqrt{\frac{F_{y}}{2E_{s}}} \) for each face of width \( b \) in rectangular sections and \( D \sqrt{\frac{F_{y}}{5E_{s}}} \) for circular sections of outside diameter \( D \).

7.6 COMPOSITE CONNECTIONS: The requirements in this section apply to connections in structures with composite or dual steel-concrete systems where the interaction of structural steel and reinforced concrete components is relied upon for transfer of seismic force between members. Where the interaction between structural steel and reinforced concrete is not required for the transfer of seismic forces between members, the connections shall be designed for seismic forces according to the provisions in Chapter 5 or Chapter 6.

Composite connections shall be demonstrated to have strength, ductility, and toughness at least equal to those for similar structural steel or reinforced concrete connections that meet the provisions of Chapter 5 and Chapter 6. Methods for calculating the connection strength shall meet the provisions in this section.

7.6.1 GENERAL REQUIREMENTS: All connections in the structure shall have adequate deformation capacity to resist their critical factored design loads under the design story drifts calculated according to the requirements of Chapter 2. Additionally, connections that are required for lateral stability under seismic forces shall meet the provisions of this chapter.

Connections shall be designed for the required strengths specified in Sec. 7.4 based on the specific system in which the connection is used. Where minimum connection design forces are based on the flexural and/or axial capacity of connected members, the forces shall be determined based on specified nominal material strengths and nominal dimensions of the members. In such cases, the minimum connection strength calculations shall account for effects that may increase
the ultimate strengths of members above the nominal strengths calculated for design of the member.

7.6.2 STRENGTH DESIGN CRITERIA: Calculated connection strengths shall be based on rational models that satisfy equilibrium of internal forces and strength limitations of component materials and elements based on potential failure modes. Unless the connection strength is determined by tests and analysis, connection design models shall follow the criteria presented in Sec. 7.6.2.1 to 7.6.2.5.

7.6.2.1 Force Transfer Between Structural Steel and Concrete: Force transfer between structural steel and concrete shall only be considered to occur through direct bearing and/or shear friction. Force transfer shall be calculated based on direct bearing forces and/or clamping forces provided by reinforcement, shear studs, or other mechanical devices. Bond between steel and concrete is not to be considered as a connection force transfer mechanism.

7.6.2.2 Structural Steel Elements: The design strength of steel components of connections shall not exceed those prescribed in Ref. 7-1 and 7-3. Steel elements are permitted to be considered to be braced against out-of-plane buckling effects when they are encased in confined concrete. Face bearing plates that consist of stiffeners between the flanges of steel beams are required where beams are embedded into concrete columns or walls.

7.6.2.3 Shear Friction and Bearing Stresses in Concrete: Ultimate bearing and shear friction design strengths shall not exceed those prescribed in Chapters 10 and 11 of Ref. 7-2. In Seismic Performance Categories D and E, unless higher values are substantiated by cyclic tests, the bearing and friction design strengths calculated on the basis of Ref. 7-2 shall be reduced by 25 percent.

7.6.2.4 Panel Zones: The panel zone shear strength may be calculated as the sum of the strengths of the structural steel and reinforced concrete shear elements where each is calculated following the provisions of Sec. 8 of Ref. 7-3 and Sec. 21.5 of Ref. 7-2.

7.6.2.5 Reinforcing Bar Detailing Provisions: Reinforcing bars shall be provided to resist all calculated tensile forces in reinforced concrete components of the connections. Transverse reinforcement also shall be designed to provide confinement of the concrete. All reinforcement shall be fully developed in tension or compression beyond the section where it is required for resisting forces. Development lengths shall be determined following the provisions of Chapter 12 of Ref. 7-2. In Seismic Performance Categories D and E, development lengths also shall meet the requirements of Sec. 21.5.4 of Ref. 7-2.

7.6.2.5.1 Slab Reinforcement in Connection Region: Where the slab is used to transfer horizontal diaphragm forces, the slab reinforcement shall be designed and anchored to carry the calculated in-plane tensile forces at all critical sections in the slab including connections to collector beams, columns, braces and walls.

7.6.2.5.2 Transverse Reinforcement in Columns or Walls Near Joint: For connections to reinforced concrete or encased composite columns, transverse hoop reinforcement shall be
provided in the joint region according to the provisions of Sec. 21.5 of Ref. 7-2 with the following modifications:

a. Steel members framing into the connection shall be considered to provide confinement over a width equal to that of face bearing stiffener plates welded to the beams between the flanges and

b. In Seismic Performance Categories A, B and C and for ordinary composite moment frames in Seismic Performance Categories D and E, lap splices may be used for perimeter ties where confinement of the splice is provided by face bearing plates or other means to prevent spalling of the concrete cover.

7.6.2.5.3 Longitudinal Reinforcement in Columns Near Joints: The longitudinal bar sizes and layout shall be detailed to minimize slippage of the bars through the joint due to high force transfer associated with the change in column moments over the height of the joint.