Chapter 10

COMPOSITE STEEL AND CONCRETE STRUCTURE DESIGN REQUIREMENTS

10.1 GENERAL

10.1.1 Scope. The design, construction, and quality of composite steel and concrete components that resist seismic forces shall comply with the requirements of the references in Sec. 10.1.2 and the additional requirements of this chapter.

10.1.2 References. The following documents shall be used as specified in this chapter.

- ACI 318 Building Code Requirements for Structural Concrete, American Concrete Institute, 2002, excluding Appendix C (Alternative Load and Strength Reduction Factors) and Chapter 22 (Structural Plain Concrete).

10.1.3 Definitions

Seismic Design Category: See Sec. 1.1.4.

Structure: See Sec. 1.1.4.

10.1.4 Notation

R See Sec. 4.1.4.

10.2 GENERAL DESIGN REQUIREMENTS

An R factor as set forth in Table 4.3-1 for the appropriate composite steel and concrete system is permitted when the structure is designed and detailed in accordance with the provisions of AISC Seismic, Part II.

10.3 SEISMIC DESIGN CATEGORIES B AND C

For structures assigned to Seismic Design Category B or C, the design of such systems shall comply with the requirements of AISC Seismic, Part II.

10.4 SEISMIC DESIGN CATEGORIES D, E, AND F

Composite structures assigned to Seismic Design Category D, E, or F are permitted, subject to the limitations in Table 4.3-1, where substantiating evidence is provided to demonstrate that the proposed system will perform as intended by AISC Seismic, Part II. The substantiating evidence shall be subject to approval by the authority having jurisdiction. Where composite elements or connections are required to sustain inelastic deformations, the substantiating evidence shall be based upon cyclic testing.

10.5 MODIFICATIONS TO AISC SEISMIC, PART II

10.5.1 Changes to nomenclature. Change throughout the document “Seismic Force Resisting System” to “Seismic Load Resisting System.”
10.5.2 Changes to definitions in the AISC Glossary.

"Composite Beam. A structural steel beam that is in contact with and acts compositely with reinforced concrete via bond or shear connectors.

Encased Composite Beam. A composite beam that is completely enclosed in reinforced concrete.

Unencased Composite Beam. A composite beam wherein the steel section is not completely enclosed in reinforced concrete and relies on mechanical connectors for composite action with a reinforced slab or slab on metal deck.”

10.5.3 Changes to Section 1 - SCOPE

“These Provisions shall be applied in conjunction with the AISC Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings, hereinafter referred to as the LRFD Specification. The applicable requirements in Part I shall be used for the design of structural steel components in composite Seismic Load Resisting Systems. The applicable requirements in ACI 318 shall be used for the design of reinforced concrete components in composite Seismic Load Resisting Systems, except as modified in these provisions. The applicable requirements in Part II shall be used for the design of composite components in composite Seismic Load Resisting Systems. When the design is based upon elastic analysis, the stiffness properties of the component members of composite systems shall reflect their condition at the onset of significant yielding of the building.”

10.5.4 Changes to Section 2 - REFERENCED SPECIFICATIONS, CODES AND STANDARDS

“The documents referenced in these provisions shall include those listed in Part I, Section 2, with the following additions and modifications:

American Society of Civil Engineers, Standard for the Structural Design of Composite Slabs, ASCE 3-91

American Welding Society, AWS D1.4-98 – Standard for the Welding of Reinforcement”

10.5.5 Changes to Section 3 - SEISMIC DESIGN CATEGORIES

“The required strength and other seismic provisions for Seismic Design Categories (SDCs), Seismic Use Groups or Seismic Zones and the limitations on height and irregularity shall be as specified in the Applicable Building Code (see Glossary).”

10.5.6 Changes to Section 4 - LOADS, LOAD COMBINATIONS AND NOMINAL STRENGTHS

“The loads and load combinations shall be as stipulated by the Applicable Building Code. Where Amplified Seismic Loads are required by these provisions, the horizontal earthquake load $E$ (as defined in the Applicable Building Code) shall be multiplied by the overstrength factor $\Omega$, prescribed by the Applicable Building Code. In the absence of a specific…”

10.5.7 Changes to Section 5.2 - Concrete and Steel Reinforcement

“Concrete and steel reinforcement used in composite components in composite Seismic Load Resisting Systems shall meet the requirements in ACI 318, Sections 25.4 through 25.8.

Exception: Concrete and steel reinforcement used in the composite Ordinary Seismic Load Resisting Systems described in Sections 11, 12, and 15 shall meet the requirements in AISC LRFD Chapter I and ACI 318, excluding Chapter 21.”

10.5.8 Changes to Section 6.3 - COMPOSITE BEAMS

“Composite Beams shall meet the requirements in LRFD Specification Chapter I. Composite Beams that are part of C-SMF shall also meet the requirements of Section 9.3.”

10.5.9 Changes to Section 6.4 - Reinforced-Concrete-Encased Composite Columns

“This Section is applicable to columns that meet the limitations in LRFD Specification Section 12.1.
Such columns shall meet the requirements in LRFD Specification Chapter I, except as modified in this Section. Additional requirements, as specified for intermediate and special seismic systems in Sections 6.4b and 6.4c, shall apply as required in the descriptions of the composite seismic systems in Sections 8 through 17.

Columns that consist of reinforced-concrete-encased structural steel sections shall meet the requirements for reinforced concrete columns in ACI 318 except as modified for:

1. The steel shape shear connectors in Section 6.4a.2
2. The contribution of the reinforced-concrete-encased structural steel section to the strength of the column as provided in ACI 318.
3. The seismic requirements for reinforced concrete columns as specified in the description of the composite seismic systems in Sections 8 through 17.”

10.5.10 Changes to Section 6.4a - Ordinary Seismic System Requirements

“(5) Splices and end bearing details for reinforced-concrete-encased composite columns in ordinary systems shall meet the requirements in the LRFD Specification and ACI 318 Section 7.8.2. The design for intermediate and special systems shall also comply with ACI 318-02 Sections 21.2.6-7 and 21.10. The design shall consider any adverse behavioral effects due to abrupt changes in either the member stiffness or nominal tensile strength. Such locations shall include transitions to reinforced concrete sections without embedded structural steel members, transitions to bare structural steel sections, and column bases.”

10.5.11 Changes to Section 6.5 - CONCRETE-FILLED COMPOSITE COLUMNS

“This Section is applicable to columns that meet the limitations in LRFD Specification Section I2.1. Such columns shall be designed to meet the requirements in LRFD Specification Chapter I, except as modified in this Section.

6.5a. The design shear strength of the composite column shall be the design shear strength of the structural steel section alone.

6.5b. In addition to the requirements in Section 6.5a, in the special seismic systems described in Sections 9, 13 and 14, the design forces and column splices for concrete-filled composite columns shall also meet the requirements in Part I Section 8.

6.5c. Concrete-filled composite columns used in C-SMF shall meet the following requirements in addition to those in Sections 6.5a and 6.5b:
1. The minimum required shear strength of the column shall meet the requirements in ACI 318 Section 21.4.5.1.
2. The strong-column/weak-beam design requirements in Section 9.5 shall be met. Column bases shall be designed to sustain inelastic flexural hinging
3. The minimum wall thickness of concrete-filled rectangular HSS shall equal

\[ b \sqrt{\frac{F_y}{2E_s}} \]  

for the flat width \( b \) of each face, where \( b \) is as defined in LRFD Specification Table B5.1, unless adequate means to prevent local buckling of the steel shape is demonstrated by tests or analysis.”

10.5.12 Changes to Section 6.5a - CONCRETE-FILLED COMPOSITE COLUMNS

“6.5a. The design shear strength of the composite column shall be the design shear strength of the structural steel section alone, based on its effective shear area. The concrete shear capacity may be used in conjunction the shear strength from the steel shape provided the design includes an appropriate load transferring mechanism. “
10.5.13 Changes to Section 7.3 - NOMINAL STRENGTH OF CONNECTIONS

“The nominal strength of connections in composite structural systems shall be determined on the basis of rational models that satisfy both equilibrium of internal forces and the strength limitation of component materials and elements based upon potential limit states. Unless the connection strength is determined by analysis and testing, the models used for analysis of connections shall meet the requirements in Sections 7.3a through 7.3c.

7.3a. When required, force shall be transferred between structural steel and reinforced concrete through direct bearing of headed shear studs or suitable alternative devices, by other mechanical means, by shear friction with the necessary clamping force provided by reinforcement normal to the plane of shear transfer, or by a combination of these means. Any potential bond strength between structural steel and reinforced concrete shall be ignored for the purpose of the connection force transfer mechanism. The contribution of different mechanism can be combined only if the stiffness and deformation capacity of the mechanisms is compatible.

The nominal bearing and shear-friction strengths shall meet the requirements in ACI 318 Chapters 10 and 11.

7.3b. The required strength of structural steel components in composite connections shall not exceed the design strengths as determined in Part I and the LRFD Specification. Structural steel elements that are encased in confined reinforced concrete are permitted to be considered to be braced against out-of-plane buckling. Face Bearing Plates consisting of stiffeners between the flanges of steel beams are required when beams are embedded in reinforced concrete columns or walls unless tests or analysis demonstrates otherwise.

7.3c. The nominal shear strength of reinforced-concrete-encased steel panel-zones in beam-to-column connections shall be calculated as the sum of the nominal strengths of the structural steel and confined reinforced concrete shear elements as determined in Part I Section 9.3 and ACI 318 Section 21.5, respectively.

7.3d. Reinforcement shall be provided to resist all tensile forces in reinforced concrete components of the connections. Additionally, the concrete shall be confined with transverse reinforcement. All reinforcement shall be fully developed in tension or compression, as appropriate, beyond the point at which it is no longer required to resist the forces. Development lengths shall be determined in accordance with ACI 318 Chapter 12. Additionally, development lengths for the systems described in Sections 9, 13, 14, 16 and 17 shall meet the requirements in ACI 318 Section 21.5.4. Connections shall meet the following additional requirements:

1. When the slab transfers horizontal diaphragm forces, the slab reinforcement shall be designed and anchored to carry the in-plane tensile forces at all critical sections in the slab, including connections to collector beams, columns, braces and walls.

2. For connections between structural steel or composite beams and reinforced concrete or reinforced-concrete-encased composite columns, transverse hoop reinforcement shall be provided in the connection region to meet the requirements in ACI 318 Section 21.5, except for the following modifications:

   a. Structural steel sections framing into the connections are considered to provide confinement over a width equal to that of face bearing stiffener plates welded to the beams between the flanges.

   b. Lap splices are permitted for perimeter ties when confinement of the splice is provided by Face Bearing Plates or other means that prevents spalling of the concrete cover in the systems described in Sections 10, 11, 12 and 15.

3. The longitudinal bar sizes and layout in reinforced concrete and composite columns shall be detailed to minimize slippage of the bars through the beam-to-column connection due to high force transfer associated with the change in column moments over the height of the connection.”
10.5.14 Changes to Section 8.2 - COLUMNS
“Structural steel columns shall meet the requirements in Part I Section 8 and the LRFD Specification.”

10.5.15 Changes to Section 8.3 - COMPOSITE BEAMS
“Composite beams shall be unencased, fully composite, and shall meet the requirements in LRFD Specification Chapter I, except I.2. For the purposes of frame analysis, the stiffness of beams shall be determined with an effective moment of inertia of the composite section that accounts for the negative and positive moments along the composite beams.”

10.5.16 Changes to Section 8.4 - Partially Restrained (PR) Moment Connections
“The required strength for the beam-to-column PR moment connections shall be determined using strength load combinations considering the effects of connection flexibility and second-order moments. In addition, composite connections shall have a nominal strength that is at least equal to 50 percent of \( R_y M_p \), where \( M_p \) is the nominal plastic flexural strength of the connected structural steel beam ignoring composite action. Connections shall meet the requirements in Section 7 and shall have a minimum inelastic interstory drift angle of 0.025 radians and a total interstory drift angle of 0.04 radians that is substantiated by cyclic testing as described in Part I Section 9.2a.”

10.5.17 Changes to Section 9.3 - BEAMS
“Composite beams that are part of C-SMF as described in Section 9 shall also meet the following requirements:

1. The distance from the maximum concrete compression fiber to the plastic neutral axis shall not exceed:

\[
\frac{Y_{con} + d_b}{1 + \left( \frac{1700 F_y}{E_s} \right)}
\]

where

- \( Y_{con} \) = distance from the top of the steel beam to the top of concrete, in.
- \( d_b \) = depth of the steel beam, in.
- \( F_y \) = specified minimum yield strength of the steel beam, ksi.
- \( E_s \) = elastic modulus of the steel beam, ksi.

2. Beam flanges shall meet the requirements in Part I Section 9.4, except when fully reinforced-concrete-encased compression elements have a reinforced concrete cover of at least 2 in. and confinement is provided by hoop reinforcement in regions where plastic hinges are expected to occur under seismic deformations. Hoop reinforcement shall meet the requirements in ACI 318 Section 21.3.3.

Neither structural steel nor composite trusses are permitted as flexural members to resist seismic loads in C-SMF unless it is demonstrated by testing and analysis that the particular system provides adequate ductility and energy dissipation capacity.”

10.5.18 Changes to Section 9.4 - MOMENT CONNECTIONS
“The required strength of beam-to-column moment connections shall be determined from the shear and flexure associated with the expected plastic flexural strength, \( R_y M_n \), of the beams framing into the connection. The nominal connection strength shall meet the requirements in Section 7. In addition, the connections shall be capable of sustaining a minimum inelastic interstory drift angle of 0.025 radians and a total interstory drift angle of 0.04 radians. When the beam flanges are interrupted at the
connection, the inelastic rotation capacity shall be demonstrated as specified in Part I Section 9 for connections in SMF. For connections to reinforced concrete columns with a beam that is continuous through the column so that welded joints are not required in the flanges and the connection is not otherwise susceptible to premature fractures, the inelastic rotation capacity shall be demonstrated by testing or other substantiating data.”

10.5.19 Changes to Section 9.5 - COLUMN-BEAM MOMENT RATIO

“The minimum flexural strength of reinforced concrete columns shall meet the requirements in ACI 318 Section 21.4.2. The column-to-beam moment ratio of composite columns shall meet the requirements in Part I Section 9.6 with the following modifications:

1. The flexural strength of the composite column $M_{pc}$ shall meet the requirements in LRFD Specification Chapter I with consideration of the applied axial load, $P_w$.
2. The force limit for the exceptions in Part I Section 9.6a shall be $P_u < 0.1P_o$.
3. Composite columns exempted by Part I Section 9.6 shall have transverse reinforcement that meets the requirements in Section 6.4c.3.”

10.5.20 Changes to Section 10.2 - COLUMNS

“Reinforced concrete columns shall meet the requirements for intermediate seismic systems in Section 6.4 or 6.5. Reinforced concrete columns shall meet the requirements in ACI 318 Section 21.12.”

10.5.21 Changes to Section 10.4 - MOMENT CONNECTIONS

“10.4 Beam-to-Column Moment Connections

The nominal connection strength shall meet the requirements in Section 7. The required strength of beam-to-column connections shall meet 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 connections shall demonstrate an interstory drift angle of at least 0.02 radians in cyclic tests.”

10.5.22 Changes to Section 11.4 - MOMENT CONNECTIONS

“Connections shall be designed for the applicable factored load combinations and their design strength shall meet the requirements in Section 7 and Section 11.2 of Part I.”

10.5.23 Changes to Section 12.4 - BRACES

“12. COMPOSITE SPECIAL CONCENTRICALLY BRACED FRAMES (C-SCBF)

12.4. Braces

Structural steel braces shall meet the requirements for SCBF in Part I Section 13. Composite braces shall meet the requirements for composite columns in Section 12.2.

13. COMPOSITE ORDINARY BRACED FRAMES (C-OBF)

13.1. Scope

This section is applicable to concentrically braced frame systems that consist of either composite or reinforced concrete columns, structural steel or composite beams, and structural steel or composite braces. C-OBF shall be designed assuming that under the Design Earthquake limited inelastic action will occur in the beams, columns, braces, and/or connections.”
10.5.24 Change title for Section 15.3 to “15.3 Steel Coupling Beams.”

10.5.25 Change title for Section 16.3 to “16.3 Steel Coupling Beams.”

10.5.26 Add new Section 15.4 as follows:

“15.4. Encased Composite Coupling Beams

Encased composite sections serving as Coupling Beams shall meet the requirements in Section 15.3 as modified in this Section:

15.4a. Coupling Beams shall have an embedment length into the reinforced concrete wall that is sufficient to develop the maximum possible combination of moment and shear capacities of the encased steel Coupling Beam.

15.4b. The nominal shear capacity of the encased steel Coupling Beam shall be used to meet the requirement in Section 15.3b.

15.4c. The stiffness of the encased steel Coupling Beams shall be used for calculating the shear wall and Coupling Beam design forces.”

10.5.27 Add new Section 16.4 as follows:

“16.4. Encased Composite Coupling Beams

Encased composite sections serving as Coupling Beams shall meet the requirements in Section 16.3, except the requirements in Part I Section 15.3 need not be met.
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