CHAPTER 26—CONSTRUCTION DOCUMENTS AND INSPECTION

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26.1—Scope

R26.1—Scope

This chapter establishes the minimum requirements for information that must be included in the construction documents as applicable to the project. The requirements include information developed in the structural design that must be conveyed to the contractor, provisions directing the contractor on required quality, and inspection requirements to verify compliance with the construction documents.

This chapter is directed to the licensed design professional to address the necessary design and construction requirements for the contractor to achieve compliance with the Code. The contractor should not be required to read and interpret the Code.

A general reference in the construction documents requiring compliance with the Code or references to specific Code provisions should be avoided because it is the intention of the Code that all necessary provisions be appropriately restated in the construction documents. Reference to ACI and ASTM standards as well as to other documents is expected.

The provisions in this chapter for inclusion in construction documentsare not intended as an all-inclusive list; additional items may be applicable to the Work or required by the building official. ACI 301 is a reference construction specification that is written to be consistent with the requirements of the Code.

26.1.1 This chapter addresses (a) through (c):

(a) Design information that the licensed design professional shall specify in the construction documents, if applicable.
(b) Compliance requirements that the licensed design professional shall specify in the construction documents, if applicable.
(c) Inspection requirements that the licensed design professional shall specify in the construction documents, if applicable.

R26.1.1

(a) and (b) Except for the inspection requirements of 26.13, the provisions of this chapter are organized into design information and compliance requirements.

Design information is project specific and developed during the structural design. It describes the basis of the design or provides information regarding the construction of the Work. Only design information that is applicable to the Work need be provided.

Compliance requirements are general provisions that provide a minimum acceptable level of quality for construction of the Work. The licensed design professional is not required to incorporate verbatim the compliance requirements into the construction documents. Some of these requirements may not be applicable to a specific project.

Construction documents that incorporate the minimum applicable compliance requirements of this chapter are considered to comply with the Code, even if the requirements are stated differently, exceed these minimum requirements, or provide more detail.

(c) Section 26.13 provides inspection provisions to be used in the absence of general building code inspection provisions. These inspection requirements are intended to provide verification that the Work complies with the construction documents.

The inspection requirements of the governing jurisdiction or the general building code take precedence over those included in this chapter. ACI PRC-311.4 provides

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guidance for inspection of concrete construction, and ACI SPEC-311.6 is a reference specification for testing services for ready-mixed concrete.

26.2—Design criteria

26.2.1 Design information:

(a) Name and year of issue of the Code, general building code, and any supplements governing design.
(b) Loads used in design.

(c) Portion of the design delegated to the contractor including applicable design criteria.

R26.2—Design criteria

R26.2.1

(a) and (b) Refer to the applicable version of the documents that govern the design including essential loading information, such as gravity and lateral loading, to be included in the construction documents.
(c) Examples of design criteria include dimensions, loads, and assumptions used that may affect the portion of the design delegated to the contractor.

26.2.2 Compliance requirements:

(a) Design delegated to the contractor shall be performed by a specialty engineer.
(b) The contractor's specialty engineer, relying on the documents identifying the portion of delegated design, shall produce a design that is compatible with the construction documents and the design criteria provided by the licensed design professional in charge of the overall design.
(c) The contractor shall submit necessary information to the licensed design professional to confirm that the specialty engineer complied with the documents identifying the portion of the delegated design.

26.3—Member information

26.3.1 Design information:

(a) Member size, location, and related tolerances.
(b) Members to be constructed using shotcrete.
(c) Identify structural members for which modulus of elasticity testing of concrete mixtures is required.

26.3.2 Compliance requirements:

(a) Use of shotcrete for structural members not identified in the construction documents as required to be placed by shotcrete shall be permitted in accordance with the project contract documents.

R26.3—Member information

R26.3.1(a) Construction tolerances for member size and location can be incorporated in construction documents by referring to ACI SPEC-117 for cast-in-place construction or to ACI ITG-7 for precast construction. Specific project tolerances that are more restrictive or that are not covered in these references should be included in the construction documents.

R26.3.2(a) If the contractor submits a request to use shotcrete for portions of the structure, the licensed design professional should make the contractor aware that the proposal must take into consideration provisions governing shotcrete listed in R4.2.1.1.

26.4—Concrete materials, mixture requirements, and grouts

26.4.1 *Concrete materials*

26.4.1.1 *Cementitious materials*

26.4.1.1.1 Compliance requirements:

(a) Cementitious materials shall conform to the specifications in Table 26.4.1.1.1(a), except as permitted in 26.4.1.1.1(b).

R26.4—Concrete materials, mixture requirements, and grouts

R26.4.1 *Concrete materials*

R26.4.1.1 *Cementitious materials*

R26.4.1.1.1

(a) There are two types of ground-glass pozzolans that conform to ASTM C1866, Types GE and GS. Type GE

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Table 26.4.1.1.1(a)—Specifications for cementitious materials

Cementitious material	Specification
Portland cement	ASTM C150
Blended hydraulic cements	ASTM C595, excluding Type IS (≥70) and Type IT ($S \geq 70$)
Expansive hydraulic cement	ASTM C845
Hydraulic cement	ASTM C1157
Fly ash and natural pozzolan	ASTM C618
Slag cement	ASTM C989
Silica fume	ASTM C1240
Ground-glass pozzolan	ASTM C1866
Blended supplementary cementitious materials	ASTM C1697

(b) Alternative cementitious materials shall be permitted if approved by the licensed design professional and the building official. Approval shall be based upon test data documenting that the proposed concrete mixture made with the alternative cement meets the performance requirements for the application including structural, fire, and durability.

26.4.1.2 *Aggregates*

26.4.1.2.1 Compliance requirements:

(a) Aggregates shall conform to (1) or (2):

(1) Normalweight aggregate: ASTM C33.

(2) Lightweight aggregate: ASTM C330.

(b) Aggregates not conforming to ASTM C33 or ASTM C330 are permitted if they have been shown by test or actual service to produce concrete of adequate strength and durability and are approved by the building official.

(c) Crushed hydraulic-cement concrete or recycled aggregate shall be permitted if approved by the licensed design professional and the building official based on documentation that demonstrates compliance with (1) and (2).

(1) Concrete incorporating the specific aggregate proposed for the Work has been demonstrated to provide the mechanical properties and durability required in structural design.

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ground-glass pozzolan has a low total equivalent alkali content typically ranging from 0 to 1%, reported as Na_2O_{eq}, while Type GS ground-glass pozzolan has a high total equivalent alkali content typically ranging from 10 to 15%, reported as Na_2O_{eq}. Refer to 26.4.2.1(a)(11) for restrictions on the use of Type GS ground-glass pozzolan in concrete to be placed in W1 or W2 exposures.

(b) Provisions for strength and durability in Chapter 19 and many requirements in Chapter 26 are based on test data and experience using concretes made with cementitious materials meeting the specifications in Table 26.4.1.1.1(a). Some alternative cements may not be suitable for use in structural concrete covered by the Code. Therefore, requirements are included for evaluating the suitability of alternative cements. Recommendations for concrete properties to be evaluated are discussed in Becker et al. (2019), ACI ITG-10, and ACI ITG-10.1.

In addition to test data, documentation of prior successful use of the proposed alternative cement in structural concrete for conditions with essentially equivalent performance requirements as those of the project can be helpful to the licensed design professional determining whether to allow use of the material. As with all new technologies, a project owner should be informed of the risks and rewards.

R26.4.1.2 *Aggregates*

R26.4.1.2.1

(b) Aggregates conforming to ASTM specifications are not always economically available and, in some instances, materials that do not conform to ASTM C33 or C330 may have a documented history of satisfactory performance under similar exposure. Such nonconforming materials are permitted if acceptable evidence of satisfactory performance is provided.

(c) The Code requires that concrete made with crushed hydraulic-cement concrete or recycled aggregate be specifically approved for use in a particular project. Properties of fresh and hardened concrete made with these aggregates are influenced by the nature, quality, and variability of the source concrete that is crushed to produce aggregate; nature and variability of the waste-stream from

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(2) A testing program to verify aggregate consistency and a quality control program to achieve consistency of properties of the concrete are conducted throughout the duration of the project.

26.4.1.3 *Mineral fillers*

26.4.1.3.1 Compliance requirements:

(a) Mineral fillers shall conform to ASTM C1797.

26.4.1.4 *Water*

26.4.1.4.1 Compliance requirements:

(a) Mixing water shall conform to ASTM C1602.

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which recycled aggregate is extracted; and the grading, proportions, and uniformity of the resulting aggregate.

ASTM C33 notes that use of such aggregates "may require some additional precautions." Areas of special concern include evidence of alkali-silica reactivity, chloride content, and sulfate content of concrete. The Code requires documentation to verify that concrete made with crushed hydraulic-cement concrete or recycled aggregate can consistently provide the mechanical properties and durability required in design. Properties of concrete made with crushed hydraulic-cement concrete or recycled aggregate can be significantly more variable than those of comparable concretes made with conventional normalweight aggregates. (Bezerra Cabral et al. 2010). Such properties may have been calculated or assumed in the design process, but may not have been specified in contract documents. Specific criteria for approval of concrete made with recycled aggregates including crushed hydraulic-cement concrete are expected to be unique to each project and set of exposure conditions. The project-specific test program and acceptance criteria should be established by the licensed design professional.

ACI PRC-555 provides information on issues that should be considered in verifying required performance.

R26.4.1.3 *Mineral fillers*

R26.4.1.3.1

(a) Mineral fillers are finely ground products derived from aggregate that can be used in self-consolidating concrete or in any concrete mixture to improve the properties of fresh and hardened concrete by optimizing particle packing. ASTM C1797 defines Types A and B mineral fillers derived from carbonate aggregate and Type C mineral fillers derived from quarried stone of any mineralogy. Refer to 26.4.2 for restrictions on use of carbonate-based mineral filler in concrete exposed to sulfates.

R26.4.1.4 *Water*

R26.4.1.4.1 Potable water is acceptable for use as mixing water for making concrete. Excessive impurities in mixing water from non-potable sources may affect setting time, concrete strength, and volume stability, and may cause efflorescence or corrosion of reinforcement.

ASTM C1602 permits the use of potable water without testing and includes methods for qualifying nonpotable sources of water, such as from concrete production operations, with consideration of effects on setting time and strength. Testing frequencies are established to ensure continued monitoring of water quality.

ASTM C1602 includes optional limits for chlorides, sulfates, alkalis, and solids in mixing water that can be invoked if appropriate.

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26.4.1.5 *Admixtures*

26.4.1.5.1 Compliance requirements:

(a) Admixtures shall conform to (1) through (4):
(1) Water reduction and setting time modification: ASTM C494.
(2) Air entrainment: ASTM C260.
(3) Inhibiting chloride-induced corrosion: ASTM C1582.

(b) Admixtures that do not conform to the specifications in 26.4.1.5.1(a) shall be permitted if approved by the licensed design professional prior to use.

(c) Admixtures used in concrete containing expansive cements conforming to ASTM C845 shall be compatible with the cement and produce no deleterious effects.

26.4.1.6 *Steel fiber reinforcement*

26.4.1.6.1 Compliance requirements:

(a) Steel fiber reinforcement used for shear resistance shall satisfy (1) and (2):
(1) Be deformed and conform to ASTM A820.
(2) Have a length-to-diameter ratio of at least 50 and not exceeding 100.

26.4.2 *Concrete mixture requirements*

26.4.2.1 Design information:

(a) Requirements (1) through (13) for each concrete mixture, based on assigned exposure classes or design of members:
(1) Members to be constructed using each concrete mixture
(2) Minimum specified compressive strength of concrete, f_c'.
(3) Minimum modulus of elasticity of concrete, E_c, if specified in accordance with 19.2.2.2.
(4) Test age, if different from 28 days, for demonstrating compliance with f_c' and E_c if specified.
(5) Maximum *w*/*cm* applicable to most restrictive assigned durability exposure class from 19.3.2.1.

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R26.4.1.5 *Admixtures*

R26.4.1.5.1

(a) ASTM C494 includes Type S—specific performance admixtures—that can be specified if performance characteristics not listed in 26.4.1.5.1(a) are desired, such as viscosity-modifying admixtures. The basic requirement for a Type S admixture is that it will not have adverse effects on the properties of concrete when tested in accordance with ASTM C494. Meeting the requirements of Type S does not ensure that the admixture will perform its described function. The manufacturer of an admixture presented as conforming to Type S should be required to provide data that the product will meet the performance claimed.

The specification for producing flowing concrete, ASTM C1017, was withdrawn by ASTM in 2022. ASTM C494 covers water-reducing and high-range water-reducing admixtures.

(c) In some cases, the use of admixtures in concrete containing ASTM C845 expansive cements has resulted in reduced levels of expansion or increased shrinkage values. Refer to ACI PRC-223.

R26.4.1.6 *Steel fiber reinforcement*

R26.4.1.6.1

(a) Deformations in steel fibers enhance mechanical anchorage with the concrete. The limits for the fiber length-to-diameter ratio are based on available test data (Parra-Montesinos 2006).

R26.4.2 *Concrete mixture requirements*

R26.4.2.1

(a) The requirements for each concrete mixture used for the Work are to be stated in the construction documents. These are determined from applicable concrete design requirements in 19.2 and durability requirements in 19.3. The most restrictive requirements that apply are to be stated.

(a)(5) In accordance with Table 19.3.2.1, the *w*/*cm* is based on all cementitious and supplementary cementi-

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(6) Nominal maximum size of coarse aggregate not to exceed the least of (i) through (iii):

(i) One-fifth the narrowest dimension between sides of forms

(ii) One-third the depth of slabs

(iii) Three-fourths the minimum specified clear spacing between individual reinforcing bars or wires, bundles of bars, prestressed reinforcement, individual tendons, bundled tendons, or ducts

These limitations shall not apply if, in the judgment of the licensed design professional, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids.

(7) For shotcrete, nominal maximum size of coarse aggregate shall not exceed 1/2 in.

(8) For members assigned to Exposure Classes F1 or F2, applicable target air content from 19.3.3.1 or 19.3.3.3

(9) For members assigned to Exposure Class F2 or Exposure Classes F2 and C2, and that will be in a location susceptible to scaling, requirements to address scaling.

(10) For members assigned to Exposure Class S:

(i) Permitted cementitious materials from 19.3.2.1

(ii) If alternative combinations of cementitious materials are permitted, qualification shall be in accordance with 26.4.2.2(b).

(iii) For Exposure Class S1, S2 or S3, prohibition of mineral fillers derived from carbonate aggregate unless approved by the licensed design professional.

(iv) For Exposure Class S2 or S3, prohibition of calcium chloride.

(11) For members assigned to Exposure Class W1 or W2:

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tious materials in the concrete mixture. The *w/cm* of concrete made with alternative cements may not reflect the strength and durability characteristics of the concrete made with portland cement and supplementary cementitious materials permitted in Table 26.4.1.1.1(a). As noted in R26.4.1.1.1(b), it is imperative that testing be conducted to determine the performance of concrete made with alternative cements and to develop an appropriate project specification.

(a)(6) The size limitations on aggregates are provided to facilitate placement of concrete around the reinforcement without honeycombing due to blockage by closely spaced reinforcement. The licensed design professional should specify the appropriate nominal maximum size aggregate in the construction documents for each concrete mixture. Using a larger maximum aggregate size with a concurrent reduction in paste volume can beneficially impact concrete properties. Benefits include reduced potential for cracking due to shrinkage or thermal effects, reduced permeability, lower cost of concrete, and support of sustainable construction goals.

(a)(8) ASTM C94 and ASTM C685 include a tolerance for air content as delivered of ±1.5 percentage points. This same tolerance is acceptable for shotcrete.

(a)(9) The risk of scaling can be reduced by specifying appropriate materials, specifying appropriate air content for the exposure, testing to determine if specified air content is obtained, and requiring inspection to verify that appropriate finishing and curing procedures are followed. The licensed design professional should review local construction practice, consult local concrete producers, or both, to determine if any limitations are necessary for supplementary cementitious materials in placements where scaling may be a concern.

(a)(10)(iii) If concrete members are assigned to Exposure Class S1, S2, or S3, the use of mineral fillers derived from carbonate aggregate in concrete mixtures can result in a form of sulfate attack. Information is provided in ACI PRC-201.2. ASTM C1797 Type C mineral fillers that are derived from noncarbonate quarried stone can be used in concrete exposed to sulfates. If the quantity of Type A, B, or C mineral filler derived from carbonate aggregate proposed for use is such that the total calcium carbonate content from cement and mineral filler is equal to or less than 15 percent by mass of the cementitious materials, then sulfate resistance can be evaluated by ASTM C1012 to comply with the expansion criteria in Table 26.4.2.2(c).

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(i) requirements for the evaluation of the potential for alkali-aggregate reactivity.

(ii) ASTM C1866 Type GS ground-glass pozzolan is prohibited in combination with potentially alkali-reactive aggregates unless approved by the licensed design professional.

(12) For members assigned to Exposure Category C, applicable water-soluble chloride ion limits from 19.3.2.1.

(13) For lightweight concrete:

(i) Equilibrium density.

(ii) If Table 19.2.4.1(b) is used as the basis for determining λ for design, requirement for submittal of volumetric fractions of aggregate.

(14) Requirements for steel fiber-reinforced concrete if used for shear resistance in accordance with 9.6.3.1.

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(a)(11)(i) Members assigned to exposure class W1 or W2 are potentially susceptible to two types of alkali-aggregate reaction. (1) alkali-silica reaction (ASR), which involves various types of reactive siliceous minerals; and (2) alkali-carbonate reaction (ACR), which involves certain types of aggregates that contain dolomite. Both types of reaction can result in expansion and cracking of concrete elements under prolonged exposure to moisture, leading to a reduction in the structural strength and service life of a concrete structure. Options for mitigating ASR, including use of supplementary cementitious materials or limiting alkali content of the concrete, are provided in ASTM C1778. There are no proven measures for effectively preventing damaging expansion with aggregates determined to be susceptible to ACR; therefore, they should not be used in concrete mixtures.

(a)(11)(ii) Because of its high alkali content, use of ASTM C1866 Type GS ground-glass pozzolan in concrete made with potentially alkali-silica reactive aggregates should be avoided in W1 and W2 exposures unless data showing satisfactory concrete prism expansion in accordance with ASTM C1293 are available following the guidance provided in ASTM C1778. Refer to R26.4.2.2(c). Additional information, including the use of ground-glass pozzolan in combination with other supplementary cementitious materials, is provided in the Appendix of ASTM C1866.

(a)(13) The equilibrium density of lightweight concrete is determined in accordance with ASTM C567 and is an estimate of the density of hardened lightweight concrete assuming some degree of drying after construction. Equilibrium density is used in determining a number of design parameters, including fire resistance ratings, static structural self-weight, dynamic seismic mass, modulus of elasticity, and the value of λ.

(a)(14) If steel fibers are used for shear resistance, there are specific requirements for the steel fiber-reinforced concrete: 26.4.1.6 provides fiber requirements; 26.4.2.2(h) provides minimum dosage requirements; and 26.12.8.1(a) provides acceptance criteria. Fibers are typically specified by fiber type, fiber length, aspect ratio (ℓ/d), and dosage rate (ACI PRC-544.3).

For structural applications, the Code only addresses the use of discontinuous deformed steel fibers in resisting shear. For other structural applications where it is desired to use discontinuous deformed steel fibers, Section 1.10 provides a procedure for approval. There are nonstructural applications or functional purposes where discontinuous steel fibers are used in concrete. The provisions of the Code that address use of steel

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(b) At the option of the licensed design professional, exposure classes based on the severity of the anticipated exposure of members.

(c) The required compressive strength at designated stages of construction for each part of the structure designed by the licensed design professional.

26.4.2.2 Compliance requirements:

(a) The required compressive strength at designated stages of construction for each part of the structure not designed by the licensed design professional shall be submitted for review.

(b) For concrete mixtures to be used in members identified in construction documents to be exposed to sulfate, alternative combinations of cementitious materials to those specified in 26.4.2.1(a)(9) are permitted if tests for sulfate resistance satisfy the criteria in Table 26.4.2.2(b).

Table 26.4.2.2(b)—Requirements for establishing suitability of combinations of cementitious materials for Exposure Category S

Exposure class		Maximum length change for tests in accordance with ASTM C1012, percent		
		At 6 months	At 12 months	At 18 months
S1		0.10	No requirement	No requirement
S2		0.05	0.10[1]	No requirement
S3	Option 1	No requirement	No requirement	0.10
S3	Option 2	0.05	0.10[1]	No requirement

[1]The 12-month expansion limit applies only if the measured expansion exceeds the 6-month maximum expansion limit.

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fibers for shear strength are not intended for such nonstructural applications.

(b) Section 19.3.1 requires the licensed design professional to assign exposure classes for different members in the structure. Concrete mixtures should be specified accordingly, but the Code does not require the assigned exposure classes to be stated in the construction documents. If the licensed design professional is requiring the contractor to determine requirements for concrete by specifying ACI SPEC-301, the assigned exposure classes for all members will need to be stated in the construction documents.

(c) If design or construction requirements dictate that in-place strength of concrete be achieved at specific ages or stages of construction, these requirements should be stated in the construction documents. Typical stages of construction when the required compressive strength of concrete should be specified include: at removal of formwork and shores, for precast concrete as provided in 26.9.1(d), and for post-tensioned concrete at the application of post-tensioning as provided in 26.10.2(h).

For portions of the structure that are not designed by the licensed design professional, refer to 26.4.2.2(a).

R26.4.2.2 Table 26.4.2.2(b) in previous editions of the Code, which provided maximum allowable amounts of supplementary cementitious materials, has been withdrawn from the 2025 Code because: 1) there is a lack of data to support the table; 2) the test method upon which the table was based (ASTM C672) has been withdrawn as not being representative of field conditions; and, 3) scaling depends upon finishing and curing practices as well as the materials used in the concrete.

(b) Mixture requirements for Exposure Category S are given in 19.3.2.1. ASTM C1012 may be used to evaluate the sulfate resistance of concrete mixtures using alternative combinations of cementitious materials to those listed in Table 19.3.2.1. More detailed guidance on qualification of such mixtures using ASTM C1012 is given in ACI PRC-201.2. The expansion criteria in Table 26.4.2.2(c) for testing in accordance with ASTM C1012 are the same as those in ASTM C595 and C1157 for moderate sulfate resistance (Optional Designation MS) in Exposure Class S1 and for high sulfate resistance (Optional Designation HS) in Exposure Class S2 and Exposure Class S3 Option 2. The 18-month expansion limit only applies for Exposure Class S3, Option 1.

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(c) For concrete mixtures to be used in members identified in construction documents to be exposed to water in service, evidence shall be submitted that the concrete mixture complies with (1) and (2).

(1) Aggregates are not alkali-silica reactive or measures to mitigate alkali-silica reactivity have been established.

(2) Aggregates are not alkali-carbonate reactive.

(d) Compliance with the specified limits on water-soluble chloride contributed by concrete materials shall be demonstrated by (1) or (2). In either case, the chloride content is expressed as a percentage by mass of the total cementitious materials. The mass of supplementary cementitious material used to determine the chloride content shall not exceed the mass of portland cement (ASTM C150) or portland-limestone cement (ASTM C595 Type IL).

(1) Calculating total chloride ion content of the concrete mixture on the basis of measured total chloride ion content from concrete materials and concrete mixture proportions.

(2) Determining water-soluble chloride ion content of hardened concrete in accordance with ASTM C1218 at age between 28 and 42 days.

(e) For prestressed concrete, admixtures containing intentionally added calcium chloride and any combination of admixtures causing the water-soluble chloride ion content to exceed the limits in Table 19.3.2.1 are prohibited.

(f) For concrete placed on or against stay-in-place galvanized steel forms, maximum water soluble chloride ion content shall be 0.30 percent by mass of cementitious materials unless a more stringent limit for the member is specified.

(g) Properties of lightweight concrete mixtures to be used in the Work shall be determined in accordance with (1) and (2):

(1) The specified equilibrium density shall be determined in accordance with ASTM C567.

(2) The fresh density for the same mixture shall be measured in accordance with ASTM C138.

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(c) Documentation that the potential for AAR has been evaluated can be provided by the concrete supplier. ASTM C1778 provides methods and criteria for determining the reactivity of aggregates and guidance for reducing the risk of deleterious alkali-aggregate reactions in concrete.

(d)(1) It is common practice for total chloride ion content of a proposed concrete mixture to be evaluated by summing the chloride ion content of the constituent materials based on the mixture proportions. The chloride content of solids is typically measured on a solution of the material obtained using a strong acid. Chloride ion content of cementitious materials is determined in accordance with ASTM C114. ASTM C1602 includes a test method to measure chloride content of batch water. Chloride ion content of aggregates can be determined on an aggregate sample prepared as specified for concrete samples and tested in accordance with ASTM C1152. Total chloride ion content of admixtures is reported by the supplier. Calculated total chloride ion content of the concrete mixture determined in this manner is conservative. If calculated total chloride ion content exceeds the limits in Table 19.3.2.1, the concrete materials can be adjusted until compliance is achieved, or water-soluble chloride ion content can be determined using 26.4.2.2(e)(2).

(d)(2) To estimate the water-soluble chloride ion content in the concrete that can impact corrosion, ASTM C1218 is used after a period of hydration. The chlorides in some materials, like aggregates, are not available as water-soluble chlorides. Furthermore, some chlorides initially in solution will be bound by hydration of cementitious materials. Chlorides insoluble in water are not considered to accelerate corrosion of embedded metals.

(f) Because of the critical nature of placements against stay-in-place galvanized steel forms, the Code requires a more stringent chloride ion limit than that required if the member was assigned to Exposure Class C0.

(g) In 26.12.6, the Code requires that the fresh density, determined and submitted for the same mixture, be used as the basis for acceptance of lightweight concrete. Acceptance is based on fresh density because determination of equilibrium density according to ASTM C567 can take more than 2 months. As noted by ASTM C94 (Note 7), "The density of fresh concrete is the only measurable density of lightweight concrete at the time of delivery. The density of fresh concrete is always higher than the equilibrium or oven-dry density." The difference between fresh

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(h) Steel fiber-reinforced concrete used for shear resistance shall satisfy (1) and (2):

(1) Conform to ASTM C1116.

(2) Contain at least 70 lb of deformed steel fibers per cubic yard of concrete for normalweight concrete and 100 lb of deformed steel fibers per cubic yard of concrete for lightweight concrete.

26.4.3 *Proportioning of concrete mixtures*

26.4.3.1 Compliance requirements:

(a) Concrete mixture proportions shall be established so that the concrete satisfies (1) through (4):

(1) Can be placed without segregation and fully encase reinforcement.

(2) Meets durability requirements given in the construction documents.

(3) Conforms to strength test requirements for standard-cured specimens for concrete applications or strength requirements for drilled cores taken from test panels for shotcrete.

(4) Conforms to modulus of elasticity requirements (i) through (iii) for mixtures requiring testing in accordance with construction documents.

(i) The modulus of elasticity shall be determined as the average modulus obtained from at least three cylinders made from the same sample of concrete and tested at 28 days or at test age designated for E_c.

(ii) Cylinders used to determine modulus of elasticity shall be made and cured in the laboratory in accordance with ASTM C192 and tested in accordance with ASTM C469.

(iii) Modulus of elasticity of a concrete mixture shall be acceptable if the measured value equals or exceeds the specified value.

(b) Concrete mixture proportions shall be established in accordance with Article 4.2.3 of ACI SPEC-301-20 or by an alternative method acceptable to the licensed design professional. Alternative methods shall have a probability of satisfying the strength requirements for acceptance tests of standard-cured specimens that meets or exceeds the probability associated with the method in Article 4.2.3 of ACI SPEC-301-20. If Article 4.2.3 of ACI SPEC-301-20 is used, the strength test records used for establishing and

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density and equilibrium density is specific to materials, proportions, and aggregate moisture.

(h) Minimum steel fiber dosage for lightweight concrete is specified at 100 lb per cubic yard of concrete due to limited experimental results.

R26.4.3 *Proportioning of concrete mixtures*

R26.4.3.1

(a) The concrete is required to be workable, cohesive, and conform to the durability and strength requirements of the Code. The required workability will depend on reinforcement congestion, member geometry, and the placement and consolidation methods to be used. Construction requirements of the contractor should be considered in establishing required workability of the concrete.

The Code does not include provisions for especially severe exposures, such as aggressive chemical contact (ACI PRC-201.2), high temperatures, temporary freezing-and-thawing conditions during construction, abrasive conditions, or other unique durability considerations pertinent to the structure. The Code also does not address aesthetic considerations such as surface finishes. If applicable, these items should be covered specifically in the construction documents. Strength test requirements for standard-cured specimens are given in 26.12.3. Strength requirements for drilled cores taken from test panels for acceptance testing of shotcrete are given in 26.12.5.

(a)(4) Modulus of elasticity testing may be required for the development of concrete mixtures to verify that specified modulus of elasticity can be obtained. It is necessary to specify both E_c and test age. Testing to verify that the specified modulus of elasticity is being attained during construction is at the discretion of the licensed design professional, including specification of acceptance criteria. Field testing may also be required by the local building official.

(b) Article 4.2.3 of ACI SPEC-301 contains the statistical procedures for selecting the required average strength. Alternatively, the concrete producer may provide evidence acceptable to the licensed design professional that the concrete can be proportioned by another method to meet the project requirements and the acceptance criteria of 26.12.3. The Code presumes that the probability of not meeting the acceptance criteria in 26.12.3 is not more than 1 in 100. Following the method of proportioning in ACI

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documenting concrete mixture proportions shall not be more than 24 months old.

(c) The concrete materials used to develop the concrete mixture proportions shall correspond to those to be used in the Work.

(d) If different concrete mixtures are to be used for different portions of the Work, each mixture shall comply with the concrete mixture requirements stated in the construction documents.

26.4.4 *Documentation of concrete mixture characteristics*

26.4.4.1 Compliance requirements:

(a) Documentation of concrete or shotcrete mixture characteristics shall be submitted for review by the licensed design professional before the mixture is used and before making changes to mixtures already in use. Evidence of the ability of the proposed concrete or shotcrete mixture to comply with the fresh and hardened concrete mixture requirements in the construction documents shall be included in the documentation. The evidence shall include records of consecutive strength tests, as defined in 26.12.1.1, of the same concrete mixture used in previous projects or the results of laboratory trial batches of the proposed mixture.

(b) If field or laboratory test data are not available, and $f_c' \leq 5000$ psi, concrete proportions shall be based on other experience or information, if approved by the licensed design professional. If $f_c' > 5000$ psi, test data documenting the characteristics of the proposed mixtures are required.

(c) It shall be permitted to modify mixtures during the course of the Work. Before using the modified mixture, evidence acceptable to the licensed design professional shall be submitted to demonstrate that the modified mixture complies with the concrete mixture requirements in the construction documents.

26.4.5 *Grout materials and construction requirements*

26.4.5.1 *Packaged hydraulic cement grout for use with steel base plates and steel shear lugs of columns*

26.4.5.1.1 Design information:

(a) Specified compressive strength of grout

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SPEC-301 will maintain this level of risk. A key factor in evaluating any proposed alternative proportioning method should be its ability to preserve this presumed level of risk. Refer to ACI PRC-214 for additional information.

(d) A change in concrete constituents, such as sources or types of cementitious materials, aggregates, or admixtures, is considered a different mixture. A minor change in mixture proportions made in response to field conditions is not considered a new mixture.

R26.4.4 *Documentation of concrete mixture characteristics*

R26.4.4.1

(a) The licensed design professional typically reviews the documentation of proposed concrete or shotcrete mixtures to evaluate the likelihood that it will meet the strength-test acceptance requirements of 26.12.3 for conventional concrete applications or 26.12.5 for shotcrete and that acceptable materials are used. The statistical principles discussed in ACI PRC-214 can be useful in evaluating the likelihood that a proposed mixture will meet the strength-test requirements of 26.12.3 or 26.12.5.

(b) If $f_c' \leq 5000$ psi and test data are not available, concrete mixture proportions should be established to produce a sufficiently high average strength such that the likelihood that the concrete would not meet the strength acceptance criteria would be acceptably low. The purpose of this provision is to allow construction to continue when there is an unexpected interruption in concrete supply and there is not sufficient time for testing and evaluation. It also applies for a small project where the cost of trial mixture data is not justified.

(c) It is sometimes necessary or beneficial to adjust concrete mixtures during the course of a project. Conditions that could result in mixture adjustments include changes in concrete materials, seasonal temperature fluctuations, or changes in conveying and placing methods. Additionally, an adjustment to a concrete mixture may be required or appropriate if strength tests are lower or higher than required.

R26.4.5 *Grout materials and construction requirements*

R26.4.5.1 *Packaged hydraulic cement grout for use with steel base plates and steel shear lugs of columns*

R26.4.5.1.1 ACI PRC-351.1 provides an overview of current practices for grout placement and testing with an emphasis on various types of grouts used to support equip-

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(b) Limits on grout materials as required for durability and performance

(c) Grout consistency, if required

(d) Test method and age for demonstrating compliance with specified strength, if required

ment and machinery. ACI SPEC-351.4 can be used as a basis for specifying grouting at load transfer conditions. Mullins and Parker (2019) provide recommendations for the specification of grouted joints including grout types, placement procedures, and quality control.

(b) Packaged, hydraulic cementitious grout durability or performance requirements typically include limits on permissible shrinkage or expansion, chloride content, and calcium sulfate dihydrate (gypsum) content.

(d) Field testing of base plate grout is uncommon in most typical situations. If needed, the licensed design professional should specify the type of test, test age, and frequency of testing. Testing of unconfined 2 in. cube specimens may not correlate well to actual in-place strength due to aspect ratio and confinement of the in-situ grout placement.

26.4.5.1.2 Compliance requirements:

(a) Packaged, dry materials for hydraulic-cement grout specified for use in grout pads under steel base plates, or with steel shear lugs designed integrally with grout pads under column base plates, shall conform to ASTM C1107.
(b) Surface preparation of concrete substrate and mixing, placement, thermal control, and curing of grout shall conform to the manufacturer's instructions.

26.5—Concrete production and construction

R26.5—Concrete production and construction

Detailed recommendations for mixing, handling, transporting, and placing concrete are given in ACI PRC-304.

26.5.1 *Concrete production*

26.5.1.1 Compliance requirements:

(a) Cementitious materials and aggregates shall be stored to prevent deterioration or contamination.
(b) Material that has deteriorated or has been contaminated shall not be used in concrete.
(c) Equipment for mixing and transporting concrete shall conform to ASTM C94 or ASTM C685.
(d) Ready-mixed and site-mixed concrete shall be batched, mixed, and delivered in accordance with ASTM C94 or ASTM C685.

R26.5.1 *Concrete production*

R26.5.1.1

(d) ASTM C94 is a specification for ready mixed concrete whereby materials are primarily measured by mass (weight) and production is by batches. This is the more common method of concrete production, and it is also used in precast concrete plants. ASTM C685 is a specification for concrete where materials are measured by volume and the production is by continuous mixing. These specifications include provisions for capacity of mixers, accuracy of measuring devices, batching accuracy, mixing and delivery, and tests for evaluating the uniformity of mixed concrete.

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26.5.2 *Concrete placement and consolidation*

26.5.2.1 Design information:

(a) Requirements for acceptance of consolidation of concrete cast in insulating concrete forms (ICF).

26.5.2.2 Compliance requirements:

(a) Debris and ice shall be removed from spaces to be occupied by concrete before placement.

(b) Standing water shall be removed from place of deposit before concrete is placed unless a tremie is to be used or unless otherwise permitted by both the licensed design professional and the building official.

(c) Equipment used to convey concrete from the mixer to the location of final placement shall have capabilities to achieve the placement requirements.

(d) Concrete shall not be pumped through pipe made of aluminum or aluminum alloys.

(e) Concrete shall be placed in accordance with (1) through (5):

(1) At a rate to provide an adequate supply of concrete at the location of placement.

(2) At a rate so concrete at all times has sufficient workability such that it can be consolidated by the intended methods.

(3) Without segregation or loss of materials.

(4) Without interruptions sufficient to permit loss of workability between successive placements that would result in cold joints.

(5) Deposited as near to its final location as practicable to avoid segregation due to rehandling or flowing.

COMMENTARY

R26.5.2 *Concrete placement and consolidation*

R26.5.2.1 Consolidation of concrete in insulating concrete forms (ICF) can be achieved through a combination of placing concrete with adequate workability, limiting lift pour heights, and effective internal vibration. Consolidation may be verified by various means, including visually during placement, by probing, or by cutting sections of insulation at a specified frequency after concrete has hardened. Frequency may be based on wall length, wall square footage, or volume of wall concrete placed.

If probing, test cuts, or removal of insulation reveals poor consolidation, more extensive examination of the concrete should be required. Ground penetrating radar (GPR) has been reported to identify voids in concrete placed in ICF walls. (Gajda and Dowell 2003).

R26.5.2.2

(a) Forms need to be cleaned before beginning to place concrete. In particular, sawdust, nails, wood pieces, and other debris that may collect inside forms need to be removed.

(b) The tremie referred to in this provision is not a short tube or "elephant trunk." It is a full-depth pipe used in accordance with accepted procedures for placing concrete under water. Information regarding placing concrete using a tremie is given in ACI PRC-304.

(d) Loss of strength can result if concrete is pumped through pipe made of aluminum or aluminum alloy. This loss is caused by the formation of hydrogen gas generated by the reaction between the cement alkalies and the aluminum eroded from the interior of the pipe surface. The strength reduction has been shown to be as much as 50% (Newlon and Ozol 1969). Short chutes used to convey concrete from a truck mixer are not a concern.

(e) Concrete should be available at a supply rate consistent with the capacity of the placement equipment and the placement crew. Concrete supplied at a faster rate than can be accommodated by placement equipment or crew can result in loss of workability of concrete in equipment waiting to discharge. Excessive delays in the supply of concrete can cause previous placements to stiffen and result in the formation of cold joints.

Rehandling and transferring concrete over large distances from delivery vehicles to the point of placement in the structure can cause segregation of materials. The Code therefore requires that concrete be deposited as close to its final location as possible. However, self-consolidating concrete mixtures can be developed to flow longer distances and maintain their stability with minimal segregation. Guidance on self-consolidating concrete is provided in ACI PRC-237.

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(f) Concrete that has been contaminated or has lost its initial workability to the extent that it can no longer be consolidated by the intended methods shall not be used.

(g) Retempering concrete in accordance with the limits of ASTM C94 shall be permitted unless otherwise restricted by the licensed design professional.

(h) After starting, concreting shall be carried on as a continuous operation until the completion of a panel or section, as defined by its boundaries or predetermined joints.

(i) Concrete shall be consolidated by suitable means during placement and shall be worked around reinforcement and embedments and into corners of forms.

(j) For shotcrete, (1) through (7) shall apply:

(1) Before placement of a new layer of shotcrete, rebound and overspray from adjacent placements shall be removed.

(2) Cuttings and rebound shall not be incorporated into the Work.

(3) Shotcrete surfaces intended to receive subsequent shotcrete placement shall be roughened to a full amplitude of approximately 1/4 in. before the shotcrete has reached final set.

(4) Before placing additional material onto hardened shotcrete, laitance shall be removed, joints shall be cleaned, and the surface shall be dampened.

(5) In-place fresh shotcrete that exhibits sags, sloughs, segregation, honeycombing, or sand pockets shall be removed and replaced.

(6) A certified shotcrete nozzle operator shall place all shotcrete.

(7) If a shotcrete mockup panel is required, each nozzle operator shall demonstrate the ability to properly place shotcrete under similar placement conditions by satisfying (i) or (ii)

(i) Shoot an approved shotcrete mockup panel

(ii) Provide documentation of previous shotcrete placement acceptable to the licensed design professional.

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(g) ASTM C94 permits water addition to mixed concrete before concrete is discharged to bring it up to the specified slump range as long as prescribed limits on the maximum mixing time and *w/cm* are not violated.

(i) Detailed recommendations for consolidation of concrete are given in ACI PRC-309. Recommendations for consolidation of concrete in insulated concrete forms are given in ACI PRC-560.

(j)(1 and 2) Rebound material is aggregate and mortar that bounces off when shotcrete collides with formwork, reinforcement, or a hardened shotcrete surface.

Overspray is the paste-rich material that separates from the stream during shotcreting and adheres to nearby reinforcement and formwork. Adjacent surfaces are typically protected from overspray.

Cuttings refers to shotcrete that has been applied beyond the finish face and is cut off during trimming or rod finishing.

Rod finishing refers to the use of a hard-edged tool or rod to cut excess material by trimming, slicing, or scraping the exposed shotcrete to a true line and grade.

(j)(5) If the shotcrete sags because of improper consistency, adjacent vibration, or improper finishing, those sections should also be removed and replaced. ACI PRC-506.4 provides additional recommendations for repairing shotcrete.

(j)(6) Each shotcrete nozzle operator should be certified in accordance with the applicable ACI certification program for dry-mix or wet-mix shotcrete (both are covered by ACI CPP 660.1).

(j)(7) Documentation of previous experience may include records of past work with similar section thickness, reinforcement layout, shotcrete mixture, embedments, penetrations, and type of equipment. Refer to ACI PRC-506.4 and ACI SPEC-506.2 for additional information.

26.5.3 *Curing*

26.5.3.1 Design information:

(a) If supplementary tests of field-cured specimens are required to verify adequacy of curing and protection, the number and size of test specimens and the frequency of these supplementary tests.

R26.5.3 *Curing*

ACI PRC-308 presents basic principles of proper curing and describes the various methods, procedures, and materials for curing of concrete.

26.5.3.2 Compliance requirements:

R26.5.3.2

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(a) Except as provided in 26.5.3.2(b) and (c), concrete shall be maintained in a condition that retains water in the concrete for the duration given in (1), (2), or (3).

(1) For 7 days after placement with concrete maintained at a temperature of at least 50°F.

(2) For 3 days after placement with concrete maintained at a temperature of at least 50°F and proportioned to attain a strength of $0.7f_c'$ within 3 days.

(i) Strength shall be demonstrated by test specimens cured in accordance with ASTM C192 and tested in accordance with ASTM C39.

(ii) Results shall be documented in accordance with 26.4.4.

(3) Until the in-place concrete strength estimated by a method approved by the licensed design professional reaches at least $0.7f_c'$. If required by the licensed design professional, the correlation between compressive strength and the results of the in-place test method shall be submitted to the licensed design professional for review.

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(a) Curing methods involve maintaining an adequate temperature and sufficient water in the concrete so that its potential strength and durability properties can develop. Curing methods described in ACI PRC-308 include:

a. Application of sheet materials conforming to ASTM C171

b. Application of membrane-forming curing compound conforming to ASTM C309 or ASTM C1315

c. Ponding on horizontal surfaces

d. Continuous sprinkling of exposed surfaces

e. Continuous fogging of air surrounding exposed surfaces

f. Application of pre-wetted absorbent material that is kept continuously damp

g. Internal curing by using pre-soaked lightweight fine aggregates, conforming to ASTM C1761, in the concrete mixture as described in ACI PRC-308-213

Maintaining formwork in place may not be sufficient to ensure adequate curing of the surface concrete, especially if severe exposure is anticipated. Refer to ACI PRC-308 for recommendations on curing formed surfaces.

The curing durations in 26.5.3.2(a)(1) and (2) have been in the Code for many years and have a proven history of providing adequate curing. The 2025 edition of the Code introduced an alternative criterion for termination of curing based on in-place strength. The alternative criterion in 26.5.3.2(a)(3) is included in ACI SPEC-308.1 and takes advantage of the heat of hydration in reducing the time to achieve a sufficient degree of reaction of the cementitious material before curing procedure termination. This requirement is distinct from the in-place strength requirement for formwork removal or prestressing application, for which the required in-place strength depends on the loads to be resisted at that stage of construction.

Applicable methods for estimating in-place concrete strength as the basis for curing termination are the same as in R26.11.2.1(e) for evaluation of in-place strength before formwork removal. For methods requiring a correlation with the compressive strength of molded cylinders, the correlation basis should be included in the submittal. Refer to ACI PRC-228.1.

(b) Concrete in members assigned to Exposure Class C2 or S3 shall be maintained in a condition that retains water in the concrete for the duration given in (1) or (2).

(1) For 14 days after placement with concrete maintained at a temperature of at least 50°F.

(2) Until the in-place concrete strength estimated by a method approved by the licensed design professional reaches at least $0.9f_c'$. If required by the licensed design professional, the correlation between compressive strength and the results of the in-place test method shall be submitted to the licensed design professional for review.

(b) The durability of concrete assigned to Exposure Class C2 or S3 relies on the resistance to fluid penetration of the surface layer. Therefore, it is critical that exposed surfaces receive adequate curing. In practice, a curing period of 14 days or the time to achieve an in-place strength of $0.9f_c'$ is considered adequate to achieve a durable surface layer for these exposure classes.

(c) Curing methods to accelerate strength gain and reduce the time of curing are permitted using high-pressure

(c) This provision permits accelerated curing methods for precast or cast-in-place elements. EB-001.17, PCI MNL

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steam, steam at atmospheric pressure, heat and moisture, or other process acceptable to the licensed design professional. Accelerated curing shall not impair concrete durability. The concrete strength at curing termination shall be at least the strength required for that stage of construction.

(d) If required by the building official or licensed design professional, test results for cylinders made and cured in accordance with (1) and (2) shall be provided in addition to test results for standard-cured cylinders.

(1) At least two 4 x 8 in. or two 6 x 12 in. cylinders to be field cured shall be molded at the same time and from the same concrete sample as standard-cured cylinders.

(2) Field-cured cylinders shall be cured in accordance with the field curing procedure of ASTM C31 and tested in accordance with ASTM C39.

(e) Procedures for protecting and curing concrete shall be considered adequate if (1) or (2) are satisfied:

(1) Average strength of field-cured cylinders at test age designated for determination of f_c' is equal to or at least 85% of that of companion standard-cured cylinders.

(2) Average strength of field-cured cylinders at test age exceeds f_c' by more than 500 psi.

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116, and PCI MNL 117 provide general information on accelerated curing. Accelerated curing procedures require careful attention to obtain uniform, consistent, and satisfactory results. Preventing moisture loss during the curing is essential.

The compressive strength of accelerated-cured concrete is not as high at later ages as that of nominally identical concrete continuously cured under moist conditions at moderate temperatures. The modulus of elasticity, E_c, of accelerated-cured specimens may also vary from that of specimens moist-cured at normal temperatures. In addition, high concrete temperatures during curing can increase the risk of delayed ettringite formation (DEF). ACI PRC-201.2 and PCI MNL 116 provide guidance on mitigating the risk of DEF.

(d) Strengths of cylinders cured under field conditions may be required to evaluate the adequacy of curing and protection of concrete in the structure.

The Code provides a specific criterion in 26.5.3.2(e) for determining the adequacy of curing and protection afforded to the structure. For a valid comparison, field-cured cylinders and companion standard-cured cylinders need to be made from the same sample. Field-cured cylinders are to be cured, as nearly as possible, under the same conditions as the structure. The field-cured cylinders should not be treated more favorably than the structural members they represent.

In evaluating test results of field-cured cylinders, it should be recognized that even if cylinders are protected in the same manner as the structure, they may not experience the same temperature history as the concrete in the structure. Heat of hydration may be dissipated differently in the cylinders than in the structural member.

(e) Research (Bloem 1968) has shown that the strength of cylinders protected and cured to simulate good field practice should be at least about 85% of standard-cured cylinders if both are tested at the age designated for f_c'. Thus, a value of 85% has been set as a rational basis for determining the adequacy of field curing. The comparison is made between the measured strengths of companion field-cured and standard-cured cylinders, not between the strength of field-cured cylinders and the value of f_c'. Test results for the field-cured cylinders are considered satisfactory, however, if the strength of field-cured cylinders exceeds f_c' by more than 500 psi, even though they fail to reach 85% of the strength of companion standard-cured cylinders.

The 85% criterion is based on the assumption that concrete is maintained above 50°F and in a moist condition for at least the first 7 days after placement, or high-early-strength concrete is maintained above 50°F and in a moist condition for at least the first 3 days after placement.

If the field-cured cylinders do not provide satisfactory strength by this comparison, steps need to be taken to improve the curing. If the tests indicate a possible serious deficiency in strength of concrete in the structure, core

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(f) Shotcrete shall be cured in accordance with (1) through (3).

(1) For 24 hours from completion of placement, initial curing shall be provided by one of the following methods:

(i) Ponding, fogging, or continuous sprinkling;

(ii) Absorptive mat, fabric, or other protective covering kept continuously moist;

(iii) Application of a membrane-forming curing compound.

(2) After 24 hours from completion of placement, final curing shall be provided by one of the following methods:

(i) Same method used in the initial curing process;

(ii) Sheet materials;

(iii) Other moisture-retaining covers kept continuously moist.

(3) Final curing shall be maintained for a minimum duration of:

(i) 7 days,

(ii) 3 days if either a high-early-strength cement or an accelerating admixture is used.

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tests may be required, with or without supplemental wet curing, to evaluate the structural adequacy, as provided in 26.12.7.

(f) If using a curing compound, it will usually be necessary to apply the compound at a higher rate than the manufacturer's recommendation because of the rougher surface of many shotcrete applications.

26.5.4 *Concreting in cold weather*

R26.5.4 *Concreting in cold weather*

Recommendations for cold weather concreting are given in ACI PRC-306 and recommendedspecifications are provided in ACI SPEC-301. ACI SPEC-301 provides recommended concrete temperature limits after placement based on section dimensions.

26.5.4.1 Design information:

(a) Temperature limits for concrete as delivered in cold weather.

(b) Minimum temperature for embedments, forms, and reinforcement before concrete placement in cold weather.

(c) Maximum allowable temperature decrease measured at the concrete surface during the first 24 hours after thermal protection removal.

R26.5.4.1

(a) ASTM C94, ACI PRC-306, and ACI SPEC-301 contain requirements and recommendations for concrete temperature based on section size.

(b) Cold embedments, forms, and reinforcement can freeze adjacent concrete and weaken the concrete locally where strength may be critical for anchoring the embedment or for bonding with reinforcement. ACI SPEC-301 and ACI PRC-306 provide recommended temperature limits for embedments, forms, and reinforcement in cold weather.

(c) ACI SPEC-301 and ACI PRC-306 provide maximum allowable temperature decreases during the first 24 hours after removal of thermal protection based on section minimum dimensions.

26.5.4.2 Compliance requirements:

(a) A cold weather concreting plan shall be submitted by the contractor to be reviewed by the licensed design professional.

R26.5.4.2

(a) The cold weather concreting plan should contain means and methods to: (i) retain water, (ii) provide or retain sufficient heat in the concrete during the curing period, such

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that cementitious materials react to develop required properties, and (iii) control the decrease in surface temperature during the first 24 hours after thermal protection removal.

(b) Aggregates that contain frozen lumps or ice shall not be used.

(c) Forms, fillers, and ground with which concrete is to come in contact shall be free from frost and ice.

26.5.5 *Concreting in hot weather*

R26.5.5 *Concreting in hot weather*

Recommendations for hot weather concreting are given in ACI PRC-305, which identifies factors that affect concrete properties and construction practices and recommends measures to mitigate undesirable effects. Recommended specifications for concreting in hot weather are provided in ACI SPEC-301 and ACI SPEC-305.1.

26.5.5.1 Design information:

(a) Temperature limits for concrete as delivered in hot weather.

(b) Maximum temperature for embedments, forms, and reinforcement before concrete placement in hot weather.

(c) Maximum allowable temperature decrease measured at the concrete surface during the first 24 hours after thermal protection removal.

R26.5.5.1

(a) ACI SPEC-301 and ACI SPEC-305.1 limit the maximum concrete temperature to 95°F at the time of placement, unless otherwise approved or specified by the licensed design professional.

(c) ACI SPEC-305.1 requires the concrete surface be protected from rapid temperature decreases and requires any protective materials to be removed in a manner to limit thermal cracking. The allowable maximum temperature decrease during the first 24 hours after protection removal in hot weather concreting should be the same as for cold weather concreting. ACI SPEC-301 and ACI PRC-306 provide recommended maximum allowable temperature decreases during the first 24 hours after removal of thermal protection based on section minimum dimensions.

26.5.5.2 Compliance requirements:

(a) A hot weather concreting plan shall be submitted by the contractor to be reviewed by the licensed design professional.

R26.5.5.2

(a) The hot weather concreting plan should contain means and methods to: (i) provide concrete mixtures that will retain the required workability during placement and consolidation, (ii) control concrete temperature at delivery, (iii) retain water, and (iv) control the decrease in surface temperature during the first 24 hours after thermal protection removal.

26.5.6 *Construction, contraction, and isolation joints*

R26.5.6 *Construction, contraction, and isolation joints*

Deviations of joint locations indicated in construction documents should be approved by the licensed design professional.

Construction or other joints should be located where they will cause the least weakness in the structure. Lateral force design may require additional consideration of joints during design.

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26.5.6.1 Design information:

(a) If required by the design, locations and details of construction, isolation, and contraction joints.
(b) Details required for transfer of shear and other forces through construction joints.
(c) Surface preparation, including identification of contact surfaces that are to be intentionally roughened.
(d) Locations where shear is transferred between structural steel and concrete using headed studs or welded reinforcing bars requiring steel to be clean and free of paint.
(e) Required surface preparation if composite topping slabs are to be cast in place on a precast floor or roof intended to act structurally with the precast members.
(f) For shotcrete, location of construction joints for which square joints are permitted.

26.5.6.2 Compliance requirements:

(a) Joint locations or joint details not shown or that differ from those indicated in construction documents shall be submitted for review by the licensed design professional before placement of concrete or shotcrete.

(b) Except for prestressed concrete, construction joints in floor and roof systems shall be located within the middle third of spans of slabs, beams, and girders unless otherwise approved by the licensed design professional.

(c) Construction joints in girders shall be offset a distance of at least two times the width of intersecting beams, measured from the face of the intersecting beam, unless otherwise approved by the licensed design professional.
(d) Construction joints shall be cleaned and laitance removed before new concrete is placed.
(e) If intentional roughening is specified, contact surfaces shall be clean, free of laitance, and roughened to a trough-to-peak amplitude of approximately 1/4 in.

(f) If contact surfaces that are at least lightly textured is specified, troweled or otherwise very smooth surfaces are not permitted.

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R26.5.6.1

(b) Shear keys, intermittent shear keys, diagonal dowels, or shear friction may be used where force transfer is required. If shear friction at a joint interface in accordance with 22.9 is invoked in the design, include applicable construction requirements in the construction documents.

(d) The locations referenced are those for which design for shear friction is in accordance with 22.9.

R26.5.6.2

(a) The contractor should submit joint locations not shown or that differ from those in construction documents to the licensed design professional for review to determine that the proposed locations do not impact the performance of the structure.
(b) Tendons of continuous post-tensioned slabs and beams are usually stressed at a point along the span where the tendon profile is at or near the centroid of the concrete cross section. Therefore, interior construction joints are usually located within the end thirds of the span rather than the middle third of the span. Construction joints located within the end thirds of continuous post-tensioned slab and beam spans have a long history of satisfactory performance; therefore, 26.5.6.2(b) is not applicable to prestressed concrete.

(e) ICRI Concrete Surface Profile comparison chips, as described in IRCI 310.2R, are useful for evaluation of contact surface roughness. The maximum distances between peaks and troughs of Concrete Surface Profile (CSP) 10 are approximately 1/4 in., and the chip can be used for comparison where 1/4 in. amplitude is specified. Roughness visually comparable to CSP 10 satisfies the requirement for intentional roughening in 26.5.6.2(e).
(f) Texture that is visually comparable to CSP 3 or greater satisfies the requirement forsurfaces specified to be at least lightly textured in accordance with Table 16.4.4.1.

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(g) Immediately before new concrete is placed, construction joints shall be prewetted and standing water removed.
(h) For shotcrete, construction joint surfaces shall be cut at a 45-degree angle to the finished surface, unless a square joint is designated in the construction documents.

26.5.7 *Construction of concrete members*

26.5.7.1 Design information:

(a) Details required to accommodate dimensional changes resulting from prestressing, creep, shrinkage, and temperature.
(b) Identify if a slab-on-ground is designed as a structural diaphragm or part of the seismic-force-resisting system.
(c) Details for construction of sloped or stepped footings designed to act as a unit.
(d) Locations where floor system and column concrete placements are required to be integrated during placement in accordance with 15.5.
(e) Locations where steel fiber-reinforced concrete is required for shear resistance in accordance with 9.6.3.1.

26.5.7.2 Compliance requirements:

(a) Beams, girders, or slabs supported by columns or walls shall not be cast until concrete in the vertical support members is no longer plastic.

(b) Beams, girders, haunches, drop panels, shear caps, and capitals shall be placed monolithically as part of a slab system, unless otherwise shown in construction documents.
(c) At locations where floor system and column concrete placements are required to be integrated during placement, column concrete shall extend full depth of the floor system at least 2 ft into the floor system from face of column and be integrated with floor system concrete.

(d) Saw cutting or construction of joints that can affect the integrity of a slab-on-ground identified in the construction documents as structural diaphragms or part of the seismic-force-resisting system shall not be permitted unless specifically indicated or approved by the licensed design professional.

26.5.8 *Construction of deep foundation members*

26.5.8.1 Compliance requirements:

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R26.5.7 *Construction of concrete members*

R26.5.7.1

(b) A slab-on-ground may be designed to act as a structural diaphragm or to provide required ties between foundations. The construction documents should clearly identify any slab on ground that is a structural diaphragm, and state that saw cutting or joints are prohibited unless approved by the licensed design professional. Joints can affect the integrity of the slab and its ability to act as a structural diaphragm, unless structural repairs are made. Refer also to 26.5.7.2(d).

R26.5.7.2

(a) Delay in placing concrete in members supported by columns and walls is necessary to minimize potential cracking at the interface of the slab and supporting member caused by bleeding and settlement of plastic concrete in the supporting member.
(b) Separate placement of slabs and beams, haunches, or similar elements is permitted if shown in the construction documents and if provision has been made to transfer forces as required in 22.9.
(c) Application of the concrete placement procedure described in 15.8 may require the placing of two different concrete mixtures in the floor system. It is the responsibility of the licensed design professional to indicate in the construction documents where the higher- and lower-strength concretes are to be placed.
(d) This restriction applies to slabs identified as structural diaphragms in 26.5.7.1(b).

R26.5.8 *Construction of deep foundation members*

R26.5.8.1 Unlike drilled cast-in-place concrete piles, caged reinforcement for augered cast-in-place piles cannot be installed prior to filling the deep foundation member hole

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(a) Reinforcement shall be assembled, tied, and installed in a deep foundation member as a unit before the reinforced portion of the member is filled with concrete or grout, except as permitted by (1), (2), or (3).

(1) Reinforcement dowels embedded 5 ft or less shall be permitted to be installed after concrete placement, while the concrete is still workable.

(2) For augered cast-in-place piles installed with a hollow-stem auger, reinforcement shall be installed after grout is placed while the grout is still workable. Longitudinal reinforcement without ties, shall be permitted to be placed through the hollow stem of the auger prior to grouting.

(3) For deep foundations supporting light frame construction of up to two stories in height for residential or utility occupancies, reinforcement shall be permitted to be installed after concrete placement, while the concrete is still workable. The concrete cover requirement is permitted to be reduced to 2 in., provided that the construction method can be demonstrated to the satisfaction of the building official.

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with grout because the hollow-stem auger must be positioned in the hole at all times during drilling and grouting operations. Grout placed in augered cast-in-place piles (also referred to as auger cast piles) is usually a mixture of cementitious materials, water, aggregate with a nominal maximum size of 3/8 in., and any admixtures. Use of larger aggregate may inhibit the installation of reinforcement after grout placement.

26.6—Reinforcement materials and construction requirements

26.6.1 *General*

26.6.1.1 Design information:

(a) ASTM designation, Supplementary Requirements S1, if ASTM A706 is specified, and grade of reinforcement

(b) Type, size, location requirements, detailing, and embedment length of reinforcement.

(c) Concrete cover to reinforcement.

(d) Location and length of lap splices.

(e) Class and location of mechanical splices.

(f) Type and location of end-bearing splices.

(g) Type and location of welded splices and other required welding of reinforcing bars.

(h) ASTM designation for protective coatings of nonprestressed reinforcement.

(i) Corrosion protection for exposed reinforcement intended to be bonded with extensions on future construction.

26.6.1.2 Compliance requirements:

(a) ASTM A706 reinforcement shall be specified to include ASTM A706, Supplementary Requirements S1.

(b) Mill test reports for reinforcement shall be submitted.

R26.6—Reinforcement materials and construction requirements

R26.6.1 *General*

R26.6.1.1

(a) For ASTM A706 reinforcement, specification of Supplementary Requirements S1 is required. ASTM A706 Supplementary Requirements S1 require reference in the construction documents. ASTM A706 requires the bar purchaser specify the Supplementary Requirements S1.

(d) Lap splices should, if possible, be located away from points of maximum tensile stress. The lap splice requirements of 25.5.2 encourage this practice.

(e) Refer to R25.5.7.2.

(g) Refer to R25.5.7.3 and R26.6.4.

R26.6.1.2

(a) Refer to R26.6.1.1.

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(c) Test reports or evaluation service reports for mechanical splices shall be submitted, demonstrating compliance with the tensile strength, compressive strength, tensile strain, elastic and inelastic cyclic endurance, and residual slip requirements applicable for the class of mechanical splice, and grade and size of bar being used.

(d) Mechanical splices shall be installed by qualified installers.

(e) Mechanical splicing devices shall be installed in accordance with construction documents and the manufacturer's published installation instructions.

(f) Nonprestressed reinforcement with rust, mill scale, or a combination of both shall be considered satisfactory, provided a hand-wire-brushed representative test specimen of the reinforcement complies with the applicable ASTM specification for the minimum dimensions (including height of deformations) and weight per unit length.

(g) Prestressing reinforcement shall be free of mill scale, pitting, and excessive rust. A light coating of rust shall be permitted.

(h) At the time concrete is placed, reinforcement to be bonded shall be clean of ice, mud, oil, or other deleterious coatings that decrease bond.

26.6.2 *Placement*

26.6.2.1 Design information:

(a) Tolerances on location of reinforcement taking into consideration tolerances on *d* and specified concrete cover in accordance with Table 26.6.2.1(a).

Table 26.6.2.1(a)—Tolerances on *d* and specified cover

d, in.	Tolerance on *d*, in.	Tolerance on specified concrete cover, in.[1]	
≤ 8	±3/8	Smaller of:	–3/8
			– (1/3) · specified cover
> 8	±1/2	Smaller of:	–1/2
			– (1/3) · specified cover

[1]Tolerance for cover to formed soffits is –1/4 in.

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(c) Requirements for mechanical splices are found in Table 25.5.7.2 and testing is described in 25.5.7.6.

(d) Installers should obtain instruction through product-specific training offered by manufacturers of mechanical splicing devices.

(f) Specific limits on rust are based on tests (Kemp et al. 1968) plus a review of earlier tests and recommendations. Kemp et al. (1968) provides guidance with regard to the effects of rust and mill scale on bond characteristics of deformed reinforcing bars. Research has shown that a normal amount of rust increases bond. Handling during construction activities generally removes any loosely-adhering rust on the reinforcing bars that may otherwise impair the bond of the bars with the surrounding concrete.

(g) Guidance for evaluating the degree of rusting on strand is given in Sason (1992).

(h) The use of epoxy coating in accordance with 20.5.2 is permitted. Materials used for the protection of prestressed reinforcement against corrosion in unbonded tendons are not considered to be contaminants as described in this provision.

R26.6.2 *Placement*

R26.6.2.1 Generally accepted practice, as reflected in ACI SPEC-117, has established tolerances on total depth (formwork or finish) and fabrication of closed ties, stirrups, spirals, and truss bent reinforcing bars. The licensed design professional should specify more restrictive tolerances than those permitted by the Code when necessary to minimize the accumulation of tolerances resulting in excessive reduction in effective depth or cover.

More restrictive tolerances have been placed on minimum clear distance to formed soffits because of their importance for durability and fire protection and because reinforcement is usually supported in such a manner that the specified tolerance is practical.

More restrictive tolerances than those required by the Code may be desirable for prestressed concrete. In such cases, the construction documents should specify the necessary tolerances. Recommendations are provided in ACI ITG-7.

The Code permits a reinforcement placement tolerance on effective depth *d* that is directly related to the flexural and shear strength of the member. Because reinforcement is placed with respect to edges of members and formwork surfaces, *d* is not always conveniently measured in the field. This provision is included in the design information section

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(b) Tolerance for longitudinal location of bends and ends of reinforcement in accordance with Table 26.6.2.1(b). The tolerance for specified concrete cover in Table 26.6.2.1(a) shall also apply at discontinuous ends of members.

(c) Tolerance for spacing of hoops in members of intermediate and special seismic systems:

(1) Lesser of +1-1/2 in. and +1.5d_b of the smallest longitudinal bar.

(2) Lesser of –1 in. per ft of least side dimension of member and –3 in.

(3) Spacing adjustments shall result in no more than two hoops being in contact with each other.

Table 26.6.2.1(b)—Tolerances for longitudinal location of bends and ends of reinforcement

Location of bends or reinforcement ends	Tolerances, in.
Discontinuous ends of brackets and corbels	±1/2
Discontinuous ends of other members	±1
Other locations	±2

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because tolerances on d should be considered in member design. Placement tolerances for cover are also provided.

Tolerances for placement of reinforcement should be specified in accordance with ACI SPEC-117 unless stricter tolerances are required. The more restrictive tolerance for spacing of hoops in members of intermediate and special seismic systems is to provide better control against premature buckling of longitudinal bars.

26.6.2.2 Compliance requirements:

R26.6.2.2

(a) Reinforcement, including bundled bars, shall be placed within required tolerances and supported to prevent displacement beyond required tolerances during concrete placement.

(a) Reinforcement, including bundled bars, should be adequately supported in the forms to prevent displacement by concrete placement or workers. Bundled bars should be tied or otherwise fastened together to maintain their position, whether vertical or horizontal. Beam stirrups should be supported on the bottom form of the beam by supports such as continuous longitudinal beam bolsters. If only the longitudinal beam bottom reinforcement is supported, construction traffic can dislodge the stirrups as well as any top beam reinforcement tied to the stirrups.

(b) Spiral units shall be continuous bar or wire placed with even spacing and without distortion beyond the tolerances for the specified dimensions.

(b) Spirals should be held firmly in place, at proper pitch and alignment, to prevent displacement during concrete placement. The Code has traditionally required spacers to hold the fabricated spiral cage in place, but alternate methods of installation are also permitted. If spacers are used, the following may be used for guidance: for spiral bar or wire smaller than 5/8 in. diameter, a minimum of two spacers should be used for spirals less than 20 in. in diameter, three spacers for spirals 20 to 30 in. in diameter, and four spacers for spirals greater than 30 in. in diameter. For spiral bar or wire 5/8 in. diameter or larger, a minimum of three spacers should be used for spirals 24 in. or less in diameter, and four spacers for spirals greater than 24 in. in diameter.

(c) Splices of reinforcement shall be made only as permitted in the construction documents, or as authorized by the licensed design professional.

(d) For longitudinal column bars forming an end-bearing splice, the bearing of square cut ends shall be held in concentric contact.

(d) Experience with end-bearing splices has been almost exclusively with vertical bars in columns. If bars are significantly inclined from the vertical, attention is required to ensure that adequate end-bearing contact can be achieved and maintained.

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(e) Bar ends shall terminate in flat surfaces within 1.5 degrees of a right angle to the axis of the bars and shall be fitted within 3 degrees of full bearing after assembly.

26.6.3 *Bending*

26.6.3.1 Design information:

(a) Nonstandard bend geometry.

26.6.3.2 Compliance requirements:

(a) Reinforcement shall be bent cold prior to placement, unless otherwise permitted by the licensed design professional.

(b) Field bending of reinforcement partially embedded in concrete shall not be permitted, except as shown in the construction documents or permitted by the licensed design professional.

(c) Offset bars shall be bent before placement in the forms.

26.6.4 *Welding*

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(e) These tolerances represent practice based on tests of full-size members containing No. 18 bars.

R26.6.3 *Bending*

R26.6.3.1 Bend radii larger than the minimums of Tables 25.3.1 and 25.3.2 may be required by geometric constraints or by 23.10 for discontinuity regions designed using the strut-and-tie method with curved-bar nodes. Nonstandard bends should be indicated on the drawings.

R26.6.3.2

(b) Construction conditions may make it necessary to bend bars that have been embedded in concrete. Such field bending should not be done without authorization of the licensed design professional. Construction documents should specify whether the bars will be permitted to be bent cold or if heating should be used. Bends should be gradual and should be straightened as required.

Tests (Black 1973; Stecich et al. 1984) have shown that ASTM A615 Grade 40 and Grade 60 reinforcing bars can be cold bent and straightened up to 90 degrees at or near the minimum diameter specified in 25.3. If cracking or breakage is encountered, preheating the reinforcing bar to between 1100 and 1200°F may avoid this condition for the remainder of the bars. Bars that fracture during bending or straightening can be spliced outside the bend region.

Heating should be performed in a manner that will avoid damage to the concrete. If the bend area is within approximately 6 in. of the concrete, some protective insulation may need to be applied. Heating of the bar should be controlled by temperature-indicating crayons or other suitable means. The heated bars should not be artificially cooled (with water or forced air) until after cooling to at least 600°F.

R26.6.4 *Welding*

If welding of reinforcing bars is required, the weldability of the steel and compatible welding procedures need to be considered. The provisions in AWS D1.4 cover aspects of welding reinforcing bars, including criteria to qualify welding procedures.

Weldability of the steel is based on its carbon equivalent (CE), calculated from the chemical composition of the steel. AWS D1.4 establishes preheat and interpass temperatures for a range of carbon equivalents and reinforcing bar sizes. AWS D1.4 has two expressions for calculating CE. The expression considering only the elements carbon and

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manganese is to be used for bars other than ASTM A706. A more comprehensive CE expression is given for ASTM A706 bars, which is identical to the CE formula presented in ASTM A706.

ASTM A706 covers low-alloy steel reinforcing bars intended for applications that require controlled tensile properties, welding, or both. Weldability is accomplished in ASTM A706 by requiring the CE not to exceed 0.55 percent and controlling the chemical composition. The manufacturer is required by ASTM A706 to report the chemical analysis and carbon equivalent (Gustafson and Felder 1991). When welding reinforcing bars other than ASTM A706, the construction documents should specifically require that the mill test report include chemical analysis results to permit calculation of the carbon equivalent.

It is often necessary to weld to existing reinforcing bars in a structure when no mill test report of the existing reinforcement is available. This condition is particularly common in alterations or building expansions. AWS D1.4 states for such bars that a chemical analysis may be performed on representative bars. If the chemical composition is not known or obtained, AWS D1.4 requires a minimum preheat. For bars other than ASTM A706, the minimum preheat required is 300°F for No. 6 bars or smaller, and 500°F for No. 7 bars or larger. The required preheat for all sizes of ASTM A706 bars is to be the temperature given in the Welding Code's table for minimum preheat corresponding to the range of CE "over 0.45 percent to 0.55 percent." Welding of the particular bars should be performed in accordance with AWS D1.4. It should also be determined if additional precautions are necessary, based on other considerations such as stress level in the bars, consequences of failure, and heat damage to existing concrete due to welding operations.

AWS D1.4 requires the contractor to prepare welding procedure specifications (WPSs) conforming to the requirements of the Welding Code. Appendix A in AWS D1.4 contains a suggested form that shows the information required for a WPS.

Welding of wire to wire, and of wire or welded wire reinforcement to reinforcing bars or structural steel elements is not covered by AWS D1.4. If welding of this type is required on a project, the construction documents should specify requirements or performance criteria for this welding. If cold-drawn wires are to be welded, the welding procedures should address the potential loss of yield strength and ductility achieved by the cold-working process (during manufacture) when such wires are heated by welding. These potential concerns are not an issue for machine and resistance welding as used in the manufacture of welded plain and deformed wire reinforcement covered by ASTM A1064.

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26.6.4.1 Design information:

(a) Details for welding of anchor bars at the front face of brackets or corbels designed by the licensed design professional in accordance with 16.5.6.3(a).

26.6.4.2 Compliance requirements:

(a) Welding of all nonprestressed bars shall conform to the requirements of AWS D1.4. ASTM specifications for bar reinforcement, except for ASTM A706, shall be supplemented to require a mill test report of material properties that demonstrate conformance to the requirements in AWS D1.4.

(b) Welding of crossing bars shall not be used for assembly of reinforcement except at the front face of brackets or corbels or as otherwise permitted by the licensed design professional.

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R26.6.4.2

(b) "Tack" welding (welding crossing bars) can seriously weaken a bar at the point welded by creating a metallurgical notch effect. This operation can be performed safely only when the material welded and welding operations are under continuous competent control, as in the manufacture of welded wire reinforcement. Welding of anchor bars at the front face of brackets or corbels is addressed in R16.5.6.3.

26.7—Anchoring to concrete

26.7.1 Design information:

(a) Requirements for assessment and qualification of anchors for the applicable conditions of use shall be in accordance with 17.1.2. Requirements for assessment and qualification of post-installed reinforcing bars shall be in accordance with 17.1.3.

(b) Type, size, location requirements, effective embedment depth, and installation requirements for anchors.

(c) Type, size, and location or location requirements for anchor reinforcement designed to develop the anchor strength in accordance with 17.5.2.1, as well as transverse confinement reinforcement for anchors installed in the tops of columns or pedestals in accordance with 10.7.6.1.5.

(d) Type, size, and location for shear lugs designed to develop shear strength in accordance with 17.11.

(e) Size and location of base plate holes to permit inspection and vent air when placing concrete or grout per 17.11.1.2.

(f) Minimum edge distance of anchors in accordance with 17.9.

(g) Corrosion protection for exposed anchors intended for attachment with future construction .

(h) For post-installed anchors, parameters associated with the design strength in accordance with 17.5, including anchor category, concrete strength, aggregate type, type of lightweight concrete, required installation torque, and requirements for hole drilling and preparation.

R26.7—Anchoring to concrete

R26.7.1 Minimum requirements for specification of anchors in the construction documents for conformance with the Code are listed.

(a) Post-installed anchor strength and deformation capacity are assessed by acceptance testing under ACI CODE-355.2 or ACI CODE-355.4. These tests are carried out assuming installation in accordance with the manufacturer's recommended procedures (in the case of adhesive anchors, the Manufacturer's Printed Installation Instructions [MPII]).

(h) Certain types of anchors can be sensitive to variations in hole diameter, cleaning conditions, orientation of the axis, magnitude of the installation torque, crack width, and other variables. Some of this indirectly accounted for in the assigned ϕ values for the different anchor categories, which depend in part on the results of the installation

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safety tests. If anchor components are altered or if anchor installation procedures deviate from those specified, the anchor may fail to comply with the acceptance criteria of ACI CODE-355.2 or ACI CODE-355.4.

(i) For adhesive anchors in tension, parameters associated with the characteristic bond stress used for design in accordance with 17.6.5, including concrete temperature range, moisture condition of concrete at time of installation, type of lightweight concrete, if applicable, and requirements for hole drilling and preparation.

(i) Due to the sensitivity of bond strength to installation, on-site quality control is important for adhesive anchors and post-installed reinforcing bars. The construction documents must provide all parameters relevant to the characteristic bond stress used in design. These parameters may include, but are not limited to:

(a) Acceptable anchor installation environment (dry or saturated concrete; concrete temperature range)
(b) Acceptable drilling methods
(c) Required hole cleaning procedures
(d) Anchor type and size range (threaded rod or reinforcing bar)

Hole cleaning is intended to ensure that drilling debris and dust do not impair bond. Depending on the Manufacturer's Printed Installation Instructions (MPII), type of qualified anchor, and on-site conditions, hole cleaning may involve operations to remove drilling debris from the hole with vacuum or compressed air mechanical brushing of the hole wall to remove surface dust, and a final step to evacuate any remaining dust or debris, usually with compressed air. If wet core drilling is used, holes may be flushed with water and then dried with compressed air. Compressed air must be free of oil and moisture. For post-installed anchors and reinforcing bars installed in locations where the concrete is saturated (for example, outdoor locations exposed to rainfall), the resulting drilling mud must be removed by other means. In all cases, the procedures used should be clearly described by the MPII accompanying the product. If the installation procedures are not clearly described, contact the manufacturer. These printed installation instructions, which also describe the limits on concrete temperature and the presence of water during installation as well as the procedures necessary for void-free adhesive injection and adhesive cure requirements, constitute an integral part of the adhesive anchor or post-installed reinforcing bar system and are part of the assessment performed in accordance with ACI CODE-355.4 or, for post-installed reinforcing bars, ACI CODE-355.5.

(j) Identification of adhesive anchors and post-installed reinforcing bars installed in a horizontal or upwardly inclined orientation to resist sustained tensile loads.

(k) Identification of adhesive anchors requiring proof loading in accordance with ACI CODE-355.4 or the inspection program established by the licensed design professional.

(l) Specify certification required for installers of adhesive anchors and post-installed reinforcing bars including adhesive anchors and post-installed reinforcing bars that are installed in a horizontal or upwardly inclined orientation to resist sustained tensile loads.

(l) Adhesive anchors and post-installed reinforcing bars are sensitive to installation orientation. This sensitivity, combined with variability in strength of adhesive anchors and post-installed reinforcing bars subjected to sustained tensile loading, requires installation by certified installers. Certification may also be appropriate for other

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safety-related applications. Installers can become certified through testing and training programs that include written and performance examinations as defined by the ACI Adhesive Anchor Installer Certification program (ACI CPP 680.1-17) or similar programs with equivalent requirements. The acceptability of certification other than the ACI Adhesive Anchor Installer Certification should be determined by the Licensed Design Professional. In addition, installers should obtain instruction through product-specific training offered by manufacturers of qualified adhesive anchor and post-installed reinforcing bar systems.

An equivalent certified installer program should test the installer's knowledge and skill by an objectively fair and unbiased administration and grading of a written and performance exam. Programs should reflect the knowledge and skill required to install available commercial anchor systems. The effectiveness of a written exam should be verified through statistical analysis of the questions and answers. An equivalent program should provide a responsive and accurate mechanism to verify credentials, which are renewed on a periodic basis.

26.7.2 Compliance requirements:

(a) Cast-in anchors, their attachments, and anchor reinforcement, shall be securely positioned in the formwork and oriented in accordance with the construction documents. Concrete shall be consolidated around anchors and anchor reinforcement using suitable means during placement.

(b) Proper consolidation of concrete or grout around shear lugs shall be verified by use of base plate inspection holes.

(c) Post-installed anchors and post-installed reinforcing bars shall be installed in accordance with the manufacturer's instructions. Post-installed adhesive anchors shall be installed in accordance with the Manufacturer's Printed Installation Instructions (MPII).

(d) Post-installed anchors and post-installed reinforcing bars shall be installed by qualified installers.

(e) Adhesive anchors and post-installed reinforcing bars identified in the construction documents as installed in a horizontal or upwardly inclined orientation to resist sustained tensile loads shall be installed by certified personnel. Certification shall be through an independent, third party program as defined by the ACI Adhesive Anchor Installer Certification Program (ACI CCP 680.1-17), or equivalent. The acceptability of certification other than the ACI Adhesive Anchor Installation Certification Program shall be the responsibility of the licensed design professional.

(f) Adhesive anchors and post-installed reinforcing bars shall be installed in concrete having a minimum age of 21 days at time of anchor installation.

R26.7.2

(c) The Manufacturer's Printed Installation Instructions (MPII) contain information required for the proper installation of post-installed adhesive anchors. Additional requirements may apply for specific cases in accordance with 26.7.1(f) and 26.7.1(g). For adhesive anchors, application-dependent requirements for qualification of installers and inspection requirements may apply.

(e) Many anchor performance characteristics depend on proper installation of the anchor. Horizontally or upwardly inclined adhesive anchors resisting sustained tension load are required to be installed by personnel certified for the adhesive anchor system and installation procedures being used. Construction personnel can establish qualifications by becoming certified through certification programs.

(f) Adhesive anchors qualified in accordance with ACI CODE-355.4 are tested in concrete with compressive strengths within two ranges: 2500 to 4000 psi and 6500 to

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8500 psi. Bond strength is, in general, not highly sensitive to concrete compressive strength. The design performance of adhesive anchors cannot be ensured by establishing a minimum concrete compressive strength at the time of installation in early-age concrete. Therefore, a minimum concrete age of 21 days at the time of adhesive anchor installation was adopted.

26.8—Embedments

26.8.1 Design information:

(a) Type, size, details, and location of embedments designed by the licensed design professional.
(b) Reinforcement required to be placed perpendicular to pipe embedments.
(c) Specified concrete cover for pipe embedments with their fittings.
(d) Corrosion protection for exposed embedments intended to be connected with future construction .

26.8.2 Compliance requirements:

(a) Type, size, details, and location of embedments not shown in the construction documents shall be submitted for review by the licensed design professional.
(b) If aluminum embedments are used, (1) though (3) shall apply:
 (1) Aluminum embedments shall be coated or covered to prevent aluminum-concrete reaction;
 (2) Aluminum embedments shall be electrically isolated from steel or other metals;
 (3) Calcium chloride and admixtures containing chlorides other than background amounts of chlorides as an impurity in the admixture ingredients are prohibited.
(c) Pipes and fittings not shown in the construction documents shall be designed to resist effects of the material, pressure, and temperature to which they will be subjected.
(d) No liquid, gas, or vapor, except water not exceeding 90°F or 50 psi pressure, shall be placed in the pipes until the concrete has attained its specified strength.
(e) In solid slabs, piping, except for radiant heating or snow melting, shall be placed between top and bottom reinforcement.
(f) Conduit and piping shall be fabricated and installed so that cutting, bending, or displacement of reinforcement from its specified location is not required.

26.9—Additional requirements for precast concrete

26.9.1 Design information:

(a) Dimensional tolerances for precast members and interfacing members.

R26.9—Additional requirements for precast concrete

R26.9.1

(a) Design of precast members and connections is particularly sensitive to tolerances on the dimensions of individual members and on their location in the structure. To prevent misunderstanding, the tolerances used in design should be specified in the construction documents. Instead of specifying individual tolerances, the standard industry tolerances assumed in design may be specified. It is important to specify any deviations from standard industry tolerances.

The tolerances required by 26.6.2 are considered to be a minimum acceptable standard for reinforcement in precast concrete. Industry-standard product and erection tolerances are provided in ACI ITG-7. Interfacing tolerances for precast concrete with cast-in-place concrete are provided in ACI SPEC-117.

(b) If designed by the licensed design professional, details of lifting devices, embedments, and related reinforcement required to resist temporary loads from handling, storage, transportation, and erection.

(b) If the devices, embedments, or related reinforcement are not designed by the licensed design professional, these details should be provided in shop drawings in accordance with 26.9.2(c).

(c) If designed by the licensed design professional, location, size, and jacking stress of pretensioned reinforcement.

(c) If location, size, and jacking stress of pretensioned reinforcement are not designed by the licensed design professional, these details should be provided in shop drawings.

(d) If designed by the licensed design professional, minimum specified compressive strength of concrete at transfer of prestress, f_{ci}', and at other designated stages of construction.

(d) Section 19.2.1.4 provides a minimum required compressive strength at transfer of prestress for pretensioned members. Additional designated stages of construction for precast concrete include stripping from the forms, handling, shipping, and erection. PCI MNL-116 and PCI MNL-120 provide guidance on minimum compressive strengths for these other stages.

26.9.2 Compliance requirements:

R26.9.2

(a) Members shall be marked to indicate location and orientation in the structure and date of manufacture.

(b) Identification marks on members shall correspond to erection drawings.

(c) Design and details of lifting devices, embedments, and related reinforcement required to resist temporary loads from handling, storage, transportation, and erection shall be provided if not designed by the licensed design professional.

(c) Refer to R26.9.1(b). At the option of the licensed design professional, specifications can require that shop drawings, calculations, or both be submitted for the items included in this provision when their design is delegated to the contractor.

(d) During erection, precast members and structures shall be supported and braced to ensure proper alignment, strength, and stability until permanent connections are completed.

(d) All temporary erection connections, bracing, and shoring as well as the sequencing of removal of these items should be shown in construction documents or erection drawings, depending on the assignment of responsibility for the means and methods of construction.

(e) If approved by the licensed design professional, items embedded while the concrete is in a plastic state shall satisfy (1) through (4):

(1) Embedded items shall protrude from the precast concrete members or remain exposed for inspection.

(2) Embedded items are not required to be hooked or tied to reinforcement within the concrete.

(3) Embedded items shall be maintained in the correct position while the concrete remains plastic.

(4) The concrete shall be consolidated around embedded items.

(e) Many precast products are manufactured in such a way that it is difficult, if not impossible, to position reinforcement that protrudes from the concrete before the concrete is placed. Such items as ties for horizontal shear and inserts can be placed while the concrete is plastic, if proper precautions are taken. This provision is not applicable to reinforcement that is completely embedded, or to embedded items that will be hooked or tied to embedded reinforcement.

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(f) Initial force in pretensioned reinforcement shall be verified by (1) and (2):

(1) Measured elongation of prestressed reinforcement compared with elongation calculated using the modulus of elasticity determined from tests or as reported by the manufacturer.

(2) Jacking force measured using calibrated equipment.

(g) A difference in force determined by (1) and (2) of 26.9.2(f) that exceeds 5% shall be ascertained and corrected, unless approved by the licensed design professional.

(h) Loss of prestress force due to unreplaced broken pretensioned reinforcement shall not exceed 2% of the total prestress force in prestressed concrete members, unless approved by the licensed design professional.

(i) Flame cutting or welding operations near prestressing reinforcement shall be performed in such a manner that prestressing reinforcement is not subject to welding sparks, ground currents, or temperatures that could affect the reinforcement properties.

(j) If the transfer of force from the anchorages of the pretensioning bed to the concrete is accomplished by flame cutting prestressed reinforcement, the cutting locations and cutting sequence shall be selected to avoid undesired temporary stresses in pretensioned members.

(k) Long lengths of exposed pretensioned strand shall be cut near the member to minimize shock to the concrete.

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(f) Verification of initial force in pretensioned reinforcement should be performed in accordance with PCI MNL-116. Equipment used to measure jacking force includes hydraulic pressure gauges, dynamometers, and load cells. PCI MNL-116 provides requirements for calibration and measurement resolution of this equipment.

(g) The 5% tolerance reflects experience with production of pretensioned members and accuracy of the verification methods. PCI MNL-116 provides guidance if the difference exceeds 5%.

26.10—Additional requirements for post-tensioned concrete

26.10.1 Design information:

(a) Magnitude and location of prestressing forces.

(b) Stressing sequence of tendons.

(c) Type, size, details, and location of post-tensioning anchorages for systems selected by the licensed design professional.

(d) Tolerances for placement of tendons and post-tensioning ducts in accordance with Table 26.6.2.1(a).

(e) Materials and details of corrosion protection for tendons, couplers, end fittings, post-tensioning anchorages, and anchorage regions.

R26.10—Additional requirements for post-tensioned concrete

R26.10.1

(b) The sequence of anchorage device stressing can have a significant effect on general zone stresses. Therefore, it is important to consider not only the final stage of a stressing sequence with all tendons stressed, but also intermediate stages during construction. The most critical bursting forces caused by each of the sequentially post-tensioned tendon combinations, as well as that of the entire group of tendons, should be taken into account.

(e) For recommendations regarding protection, refer to Sections 4.2 and 4.3 of ACI PRC-423.3, and Sections 3.4, 3.6, 5, 6, and 8.3 of ACI SPEC-423.7. Also refer to 20.5.1.4.2 for corrosion protection requirements.

Corrosion protection can be achieved by a variety of methods. The corrosion protection provided should be suitable for the environment in which the tendons are located. Some conditions will require that the prestressed reinforcement be protected by concrete cover or by cement grout in metal or plastic duct; other conditions will

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(f) Requirements for ducts for bonded tendons.

(g) Requirements for grouting of bonded tendons, including maximum water-soluble chloride ion (Cl^-) content requirements in 19.4.1.

26.10.2 Compliance requirements:

(a) Type, size, details, and location of post-tensioning anchorage systems not shown in the construction documents shall be submitted to the licensed design professional for review.
(b) Tendons and post-tensioning ducts shall be placed within required tolerances and supported to prevent displacement beyond required tolerances during concrete placement.
(c) Couplers shall be placed in areas approved by the licensed design professional and enclosed in housings long enough to permit necessary movements.
(d) Burning or welding operations in the vicinity of prestressing reinforcement shall be performed in such a manner that prestressing reinforcement is not subject to welding sparks, ground currents, or temperatures that degrade the properties of the reinforcement.
(e) Prestressing force and friction losses shall be verified by (1) and (2).

(1) Measured elongation of prestressed reinforcement compared with elongation calculated using the modulus of elasticity determined from tests or as reported by the manufacturer.
(2) Jacking force measured using calibrated equipment such as a hydraulic pressure gauge, load cell, or dynamometer.

(f) The cause of any difference in force determination between (1) and (2) of 26.10.2(e) that exceeds 7% shall be ascertained and corrected, unless approved by the licensed design professional.

(g) Loss of prestress force due to unreplaced broken prestressed reinforcement shall not exceed 2% of the total prestress force in prestressed concrete members, unless approved by the licensed design professional.

(h) Prestressing reinforcement shall not be stressed until the concrete compressive strength is at least 2500 psi for

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permit the protection provided by coatings such as paint or grease. Corrosion protection methods should meet the fire protection requirements of the general building code unless the installation of external post-tensioning is to only improve serviceability.
(f) Guidance for specifying duct requirements for bonded tendons is provided in PTI M50.3.
(g) Guidance for specifying grouting requirements for bonded tendons is provided in PTI M55.1.

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(e) Elongation measurements for post-tensioning should be in accordance with the procedures outlined in PTI M10.3 and PTI C30.4.

(f) Elongation measurements for post-tensioned construction are affected by several factors. The friction along prestressing reinforcement may be affected to varying degrees by placing tolerances and small irregularities in tendon profile due to tendon and concrete placement. The friction coefficients between the prestressing reinforcement and the duct are also subject to variation.
(g) This provision applies to all prestressed concrete members. For cast-in-place post-tensioned slab systems, a member should be that portion considered as an element in the design, such as the joist and effective slab width in one-way joist systems, or the column strip or middle strip in two-way flat plate systems. Some members can be shown to accommodate more than 2% loss of prestress due to unreplaced broken prestressed reinforcement.

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single-strand or bar tendons, 4000 psi for multistrand tendons, or a higher strength, if required. An exception to these strength requirements is provided in 26.10.2(i).

(i) Lower concrete compressive strength than required by 26.10.2(h) shall be permitted if (1) or (2) is satisfied:

(1) Oversized anchorage devices are used to compensate for a lower concrete compressive strength.

(2) Prestressing reinforcement is stressed to no more than 50% of the final prestressing force.

(j) The estimate of in-place concrete strength shall be based on tests of field-cured cylinders prepared in accordance with 26.5.3.2(d). Alternately, it may be based on other procedures approved by the licensed design professional and, when requested, approved by the building official.

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(i) To limit early shrinkage cracking, monostrand tendons are sometimes stressed at concrete strengths less than 2500 psi. In such cases, either oversized monostrand anchorages are used, or the strands are stressed in stages, often to levels one-third to one-half the final prestressing force.

(j) Acceptance criteria for field-cured cylinders are provided in 26.12.4.

26.11—Formwork

26.11.1 *Design of formwork*

26.11.1.1 Design information:

(a) Requirement for the contractor to design, fabricate, install, and remove formwork.

(b) Location of composite members requiring shoring.

(c) Requirements for removal of shoring of composite members.

26.11.1.2 Compliance requirements:

(a) Design of formwork shall consider (1) through (6):

(1) Method of concrete placement.

(2) Rate of concrete placement.

(3) Construction loads, including vertical, horizontal, and impact.

(4) Avoidance of damage to previously constructed members.

(5) For post-tensioned members, allowance for movement of the member during tensioning of the prestressing reinforcement without damage to the member.

(6) For post-tensioned members, allowance for load redistribution on formwork resulting from tensioning of the prestressing reinforcement.

R26.11—Formwork

R26.11.1 *Design of formwork*

Typically, the contractor is responsible for formwork design, and the Code provides the minimum formwork performance requirements necessary for public health and safety. Detailed information on design and construction of formwork for concrete is given in "Guide to Formwork for Concrete" (ACI PRC-347).

ACI SPEC-301-20 Section 2 provides specifications for design and construction of formwork. *Formwork for Concrete*, ACI SP-4, provides practical guidance for contractors, engineers, and architects on planning, building, and using formwork.

R26.11.1.1 Section 24.2.5 covers the requirements pertaining to deflections of shored and unshored members.

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(b) Formwork fabrication and installation shall result in a final structure that conforms to shapes, lines, and dimensions of the members as required by the construction documents.
(c) Formwork shall be sufficiently tight to inhibit leakage of paste or mortar.
(d) Formwork shall be braced or tied together to maintain position and shape.

26.11.2 *Removal of formwork*

26.11.2.1 Compliance requirements:

(a) Before starting construction, the contractor shall develop a procedure and schedule for removal of formwork and installation of reshores, and shall calculate the loads transferred to the structure during this process.
(b) Structural analysis and concrete strength requirements used in planning and implementing the formwork removal and reshore installation shall be furnished by the contractor to the licensed design professional and to the building official, when requested.
(c) No construction loads shall be placed on, nor any formwork removed from, any part of the structure under construction except when that portion of the structure in combination with remaining formwork has sufficient strength to support safely its weight and loads placed thereon and without impairing serviceability.
(d) Sufficient strength shall be demonstrated by structural analysis considering anticipated loads, strength of formwork, and an estimate of in-place concrete strength.

(e) The estimate of in-place concrete strength shall be based on tests of field-cured cylinders or on other procedures to evaluate concrete strength approved by the licensed design professional and, when requested, approved by the building official.

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R26.11.2 *Removal of formwork*

R26.11.2.1 In determining the time for removal of formwork, consideration should be given to the construction loads and load combinations , in-place strength of concrete, and possibility of deflections greater than acceptable to the licensed design professional (ACI PRC-347, ACI PRC-347.2, and ASCE/SEI 37). Construction loads may be greater than the specified live loads. Even though a structure may have adequate strength to support the applied loads at early ages, deflections can cause serviceability problems.

The removal of formwork for multistory construction should be a part of a planned procedure developed by the contractor that considers the temporary support of the entire structure as well as each individual member. Such a procedure should be planned before construction and should be based on a structural analysis taking into account at least (a) through (e):

(a) The structural system that exists at the various stages of construction, and the construction loads corresponding to those stages;
(b) The in-place strength of the concrete at the various stages during construction;
(c) The influence of deformations of the structure and shoring system on the distribution of dead loads and construction loads during the various stages of construction;
(d) The strength and spacing of shores or shoring systems used, as well as the method of shoring, bracing, shore removal, and reshoring including the minimum time interval between the various operations;
(e) Any other loading or condition that affects the safety or serviceability of the structure during construction.

ACI 347.2R provides information for shoring and reshoring multistory buildings.

(e) Evaluation of in-place concrete compressive strength during construction may be demonstrated by field-cured test cylinders in accordance with ASTM C31. Acceptance criteria for strength of field-cured cylinders are provided in 26.12.4. Alternative procedures to estimate in-place compressive strength include (a) through (e):

(a) Tests of cast-in-place cylinders in accordance with ASTM C873. This method is limited to use for slabs where the depth of concrete is between 5 to 12 in.
(b) Penetration resistance in accordance with ASTM C803

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(c) Pullout strength in accordance with ASTM C900
(d) Maturity index measurements and correlation in accordance with ASTM C1074
(e) Temperature-match curing of cylinders in accordance with AASHTO R72

Procedures (b), (c), and (d) require sufficient data for the materials used in the Work to demonstrate correlation of measurements on the structure with the compressive strength of molded cylinders or drilled cores. ACI 228.1R discusses the use of these methods to evaluate the in-place strength of concrete.

Procedure (e), temperature-match curing of cylinders in accordance with AASHTO R72, may be used to more closely represent the temperature within the concrete member during curing.

(f) Formwork shall be removed in such a manner not to impair safety and serviceability of the structure.
(g) Concrete exposed by formwork removal shall have sufficient strength not to be damaged by the removal.
(h) Formwork supports for post-tensioned members shall not be removed until sufficient post-tensioning has been applied to enable post-tensioned members to support their dead load and anticipated construction loads.
(i) No construction loads exceeding the combination of superimposed dead load plus live load including reduction shall be placed on any unshored portion of the structure under construction, unless analysis indicates adequate strength to support such additional loads and without impairing serviceability.

(i) The nominal live load specified on the drawings is frequently reduced for members supporting large floor areas, and the limit on construction loads needs to account for such reductions. Information on loads, load factors, and load combinations for construction is presented in ASCE/SEI 37.

26.12—Evaluation and acceptance of hardened concrete

26.12.1 *General*

26.12.1.1 Compliance requirements:

(a) Evaluation of hardened concrete shall be based on strength tests. A strength test is the average of the compressive strengths of at least two 4 x 8 in. or two 6 x 12 in. cylinders made from the same sample of concrete taken in accordance with ASTM C172 at the point of delivery, handled and standard-cured in accordance with ASTM C31, and tested in accordance with ASTM C39 at 28 days or at test age designated for f_c'.

(b) For shotcrete, a strength test shall be the average strength of at least three 3 in. nominal diameter cores taken from a test panel prepared in accordance with ASTM C1140 and tested at 28 days from time of placement or at test age designated for f_c'.
(c) The testing agency performing acceptance testing shall comply with ASTM C1077.

R26.12—Evaluation and acceptance of hardened concrete

R26.12.1 *General*

R26.12.1.1

(a) Previous editions of the Code required the use of at least three 4 x 8 in. cylinders for a strength test because available data for 4 x 8 in. cylinders made under laboratory conditions (Carino et al. 1994) indicated a higher within-test variability compared with 6 x 12 in. cylinders. Recent test data including cylinders prepared in the field, indicate the difference between the within-test variability of tests of 4 x 8 in. cylinders and 6 x 12 in. cylinders is not statistically significant (Day 1994; Detwiler et al. 2006, 2009). Accordingly, the Code now permits the use of at least two cylinders for a strength test for either 4 x 8 in. or 6 x 12 in. cylinders. Casting and testing more than the minimum number of cylinders may be desirable in case it becomes necessary to discard an outlying individual cylinder strength in accordance with ACI PRC-214. If individual cylinder strengths are discarded in accordance with ACI PRC-214, a strength test is valid provided the measured strength of at least two individual cylinders of the same size are averaged. All individual cylinder

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strengths that are not discarded in accordance with ACI PRC-214 are to be used to calculate the average strength. The size of specimens representing a strength test should be the same for each concrete mixture. The cylinder size should be agreed upon by the owner, licensed design professional, and testing agency before construction.

Representative concrete samples for making strength-test specimens are obtained from concrete as delivered to the project site. For example, samples of concrete delivered in a truck mixer would be obtained from the truck chute at discharge. ASTM C172 provides requirements for sampling concrete from different equipment used in the production or transportation of concrete.

Note that the term “strength test” does not apply to results of tests on cylinders field cured in or on the structure as described in ASTM C31, nor does it apply to results of tests on cylinders from laboratory trial batches.

(c) ASTM C1077 defines the duties, responsibilities, and minimum technical requirements of testing agency personnel and defines the technical requirements for equipment used in testing concrete and concrete aggregates. Agencies that test cylinders or cores to determine compliance with Code requirements should be accredited or inspected for conformance to the requirements of ASTM C1077 by a recognized evaluation authority.

(d) Certified field testing technicians shall perform tests on fresh concrete at the job site, prepare specimens for standard curing, prepare specimens for field curing, if required, and record the temperature of the fresh concrete when preparing specimens for strength tests.

(d) Technicians can become certified through testing and training programs that include written and performance examinations. Field technicians in charge of sampling concrete; testing for slump, density (unit weight), yield, air content, and temperature; and making and curing test specimens should be certified in accordance with the ACI Concrete Field Testing Technician—Grade 1 Certification Program (ACI CPP 610.1-18) or an equivalent program meeting the requirements of ASTM C1077.

(e) Certified laboratory technicians shall perform required laboratory tests.

(e) Concrete laboratory testing technicians performing strength testing should be certified in accordance with the ACI Concrete Strength Testing Technician Certification Program (ACI CPP 620.2-12) or an equivalent program meeting the requirements of ASTM C1077.

(f) All reports of acceptance tests shall be provided to the licensed design professional, contractor, concrete producer, and, if requested, to the owner and the building official.

(f) The Code requires testing reports to be distributed to the parties responsible for the design, concrete production, construction, and approval of the Work. Such distribution of test reports should be indicated in contracts for inspection and testing services. Prompt distribution of testing reports allows for timely identification of either compliance or the need for corrective action. A complete record of testing allows the concrete producer to reliably establish appropriate mixture proportions for future projects .

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26.12.2 *Frequency of testing*

26.12.2.1 Compliance requirements:

(a) For concrete evaluated and accepted based upon standard-cured cylinders, (1) through (3) shall apply:

(1) Samples for preparing strength-test specimens of each concrete mixture placed each day shall be taken in accordance with (i) through (iii):

(i) At least once a day.

(ii) At least once for each 150 yd^3 of concrete.

(iii) At least once for each 5000 ft^2 of surface area for slabs or walls.

(2) On a given project, if total volume of concrete is such that frequency of testing would provide fewer than five strength tests for a given concrete mixture, strength test specimens shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used.

(3) If the total quantity of a given concrete mixture is less than 50 yd^3, strength tests are not required if evidence of satisfactory strength is submitted to and approved by the building official.

(b) For shotcrete evaluated and accepted based on drilled cores taken from test panels, prepare a shotcrete test panel for each mixture and each nozzle operator at least once per day or for every 50 yd^3 placed, whichever results in the greater number of panels.

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R26.12.2 *Frequency of testing*

R26.12.2.1

(a)(1) Concrete samples for preparing strength-test specimens are to be taken on a strictly random basis if they are to measure properly the acceptability of the concrete. To be representative within the period of placement, the choice of sampling times, or the concrete batches to be sampled, is to be made on the basis of chance alone. Batches are not sampled on the basis of appearance, convenience, or another possibly biased criterion, because the statistical analyses will lose their validity. ASTM D3665 describes procedures for random selection of the batches to be tested. Specimens for one strength test (as defined in 26.12.1.1(a)) are to be made from a single batch, and ASTM C172 requires that the sample be taken only after all adjustments to the batch are made.

In calculating surface area, only one side of the slab or wall is considered. Criterion (iii) will require more frequent sampling than once for each 150 yd^3 placed if average wall or slab thickness is less than 9-3/4 in.

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26.12.3 *Acceptance criteria for standard-cured specimens*

26.12.3.1 Compliance requirements:

(a) Strength level of a concrete mixture shall be acceptable if (1) and (2) are satisfied:

(1) Every average of any three consecutive strength tests equals or exceeds f_c'.

(2) No strength test falls below f_c' by more than 500 psi if f_c' is 5000 psi or less; or by more than $0.10f_c'$ if f_c' exceeds 5000 psi.

(b) If either of the requirements of 26.12.3.1(a) is not satisfied, steps shall be taken to increase subsequent strength tests.

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R26.12.3 *Acceptance criteria for standard-cured specimens*

R26.12.3.1 Evaluation and acceptance of the concrete can be determined as test results are received during the course of the Work. Strength tests failing to meet these criteria will occur occasionally, with a probability of approximately once in 100 tests (ACI PRC-214) even though concrete strength and uniformity are satisfactory. Allowance should be made for such statistically expected variations in deciding whether the strength being produced is adequate. The strength acceptance criteria of 26.12.3.1(a) apply to test results from either 4 x 8 in. or 6 x 12 in. test cylinders permitted in 26.12.1.1(a). The average difference (Carino et al. 1994) between test results obtained by the two specimen sizes is not considered to be significant in design.

(b) The steps taken to increase the values of subsequent strength tests will depend on the particular circumstances but could include one or more of (a) through (g):

(a) Increase in cementitious materials content;

(b) Reduction in or better control of water content;

(c) Use of a water-reducing admixture to improve the dispersion of cementitious materials;

(d) Other changes in mixture proportions;

(e) Reduction in delivery time;

(f) Closer control of air content;

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(c) Requirements of 26.12.7 for investigating strength tests shall apply if the requirements of 26.12.3.1(a)(2) are not met.

26.12.4 *Acceptance criteria for field-cured specimens*
26.12.4.1 *Compliance requirements*

(a) Before application of prestressing forces or removal of shoring and formwork supporting beams and slabs, the compressive strength of field-cured cylinders shall be acceptable if the strengths of all cylinders made from the same sample and tested in accordance with ASTM C39 equal or exceed the strength required for that stage of construction, unless otherwise approved by the licensed design professional.

26.12.5 *Acceptance criteria for shotcrete*

26.12.5.1 Compliance requirements:

(a) Specimens for acceptance tests shall be in accordance with (1) and (2):
 (1) Test panels shall be prepared in the same orientation and by the same nozzle operator placing shotcrete.
 (2) Cores shall be obtained, conditioned, and tested in accordance with ASTM C1604.
(b) Strength of a shotcrete mixture shall be acceptable if the average compressive strength of three cores from a single test panel is not less than $0.85f_c'$ with no core having a strength less than $0.75f_c'$.
(c) If the requirement of 26.12.5.1(b) is not satisfied, steps shall be taken to increase the average of subsequent strength results.
(d) Requirements for investigating low strength-test results shall apply if the requirement of 26.12.5.1(b) is not met.

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(g) Improvement in the quality of the testing, including strict compliance with ASTM C172, ASTM C31, and ASTM C39.

Such changes in operating procedures or small changes in cementitious materials content or water content should not require a formal resubmission of mixture proportions; however, changes in sources of cement, aggregates, or admixtures should be accompanied by evidence submitted to the licensed design professional that the concrete strength will be improved.

R26.12.4 *Acceptance criteria for field-cured specimens*
R26.12.4.1 *Compliance requirements*

Typically, the required in-place compressive strengths at designated construction stages are minimum values. Therefore, the strengths of all field-cured cylinders made from the same concrete sample must be at or above the required strength, rather than using the average strength. Criteria provided in 26.5.3.2(e) for the strength of field-cured cylinders are intended for evaluating the adequacy of procedures for protecting and curing concrete and are not appropriate for determining the adequacy of in-place strength at designated construction stages. Criteria provided in 26.12.3.1 for concrete acceptance based on strength tests of standard-cured cylinders are also not applicable to field-cured cylinders. The Code allows for exceptions to requiring all cylinders meet or exceed the required strength when approved by the licensed design professional, such as in cases where there is evidence that one or more cylinders have been mishandled. Other exceptions may be approved by the licensed design professional to suit project-specific conditions.

R26.12.5 *Acceptance criteria for shotcrete*

R26.12.5.1

(a) Cores taken from shotcrete test panels, made in accordance with ASTM C1140, typically have length-to-diameter ratios less than 1.75. Therefore the core strengths used for comparison with the acceptance criteria are the values after correction for the length to diameter ratio in accordance with ASTM C1604.

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26.12.6 *Acceptance criteria for density of lightweight concrete*

26.12.6.1 Compliance requirements:

(a) Frequency of sampling for determining fresh density shall be according to 26.12.2.

(b) Sampling of lightweight concrete for determining fresh density shall be at the point of delivery in accordance with ASTM C172.

(c) Fresh density of lightweight concrete shall be determined in accordance with ASTM C138.

(d) Acceptance of lightweight concrete for density shall be based on the submitted fresh concrete density in accordance with 26.4.2.2g.

(e) Unless otherwise permitted by the licensed design professional, fresh density of lightweight concrete shall be acceptable if within ±4.0 lb/ft^3 of the fresh density corresponding to the specified equilibrium density.

26.12.7 *Investigation of strength tests*

26.12.7.1 Compliance requirements:

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R26.12.6 *Acceptance criteria for density of lightweight concrete*

R26.12.6.1

(e) The permitted tolerance for fresh density of a lightweight concrete mixture designed for the specified equilibrium density, w_c, is intended to account for variations in aggregate moisture, air content, batch quantities, and type of lightweight concrete. The impact of the density tolerance on the value of λ assumed in design is deemed to be acceptable. The licensed design professional can consider permitting a different tolerance on fresh density to accommodate expected variations if appropriate.

R26.12.7 *Investigation of strength tests*

R26.12.7.1 Requirements are provided if strength tests have failed to meet the acceptance criterion of 26.12.3.1(a)(2) or if the average strengths of field-cured cylinders do not comply with 26.5.3.2(e). These requirements are applicable only for evaluation of in-place strength at the time of construction. Strength evaluation of existing structures is covered by Chapter 27. The licensed design professional and building official should apply judgment as to the significance of low test results and whether they indicate need for concern. If further investigation is deemed necessary, such investigation may include in-place tests as described in ACI PRC-228.1 or, in extreme cases, measuring the compressive strength of cores taken from the structure.

In-place tests of concrete, such as probe penetration (ASTM C803), rebound hammer (ASTM C805), or pullout test (ASTM C900), may be useful in determining whether a portion of the structure actually contains low-strength concrete. Unless these in-place tests have been correlated with compressive strength using accepted procedures, such as described in ACI PRC-228.1, they are of value primarily for comparisons within the same structure rather than as quantitative estimates of strength.

For cores, if required, conservative acceptance criteria are provided that should ensure structural adequacy for virtually any type of construction (Bloem 1965, 1968; Malhotra 1976, 1977). Lower-than-specified strength may be tolerated under many circumstances, but this is a matter of judgment on the part of the licensed design professional and building

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(a) If any strength test of standard-cured cylinders falls below f_c' by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized.

(b) If the likelihood of low-strength concrete is confirmed and calculations indicate that structural adequacy is significantly reduced, tests of cores drilled from the area in question in accordance with ASTM C42 shall be permitted. In such cases, three cores shall be taken for each strength test that falls below f_c' by more than the limit allowed for acceptance.

(c) The licensed design professional or the building official shall be permitted to modify details of core tests as stated in ASTM C42.

(d) Cores shall be obtained, moisture-conditioned by storage in watertight bags or containers, transported to the testing agency, and tested in accordance with ASTM C42. Cores shall be tested between 5 days after last being wetted and 7 days after coring unless otherwise approved by the licensed design professional or building official.

(e) Concrete in an area represented by core tests shall be considered structurally adequate if (1) and (2) are satisfied:

(1) The average of three cores is equal to at least 85% of f_c'.

(2) No single core is less than 75% of f_c'.

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official. If time and conditions permit, an effort may be made to improve the strength of the concrete in place by supplemental wet curing. Effectiveness of supplemental curing should be verified by further strength evaluation using procedures previously discussed.

The Code, as stated, concerns itself with achieving structural safety, and the requirements for investigation of low strength-test results (26.12.7) are aimed at that objective. It is not the function of the Code to assign responsibility for strength deficiencies.

(a) If the strength of field-cured cylinders does not conform to 26.5.3.2(e), steps need to be taken to improve the curing. If supplemental in-place tests confirm a possible deficiency in strength of concrete in the structure, core tests may be required to evaluate structural adequacy.

(c) Some default requirements in ASTM C42 are permitted to be altered by the "specifier of the tests," who is defined in ASTM C42 as "the individual responsible for analysis or review and acceptance of core test results." For the purposes of ACI CODE-318, the "specifier of the tests" is the licensed design professional or the building official.

(d) The use of a water-cooled core barrel or a water-cooled saw for end trimming results in a core with a moisture gradient between the exterior surface and the interior. This gradient lowers the apparent compressive strength of the core (Bartlett and MacGregor 1994). The requirement of at least 5 days between the time of last being wetted and time of testing provides time for the moisture gradient to be reduced. The maximum time of 7 days between coring and testing is intended to ensure timely testing of cores if strength of concrete is in question.

Research (Bartlett and MacGregor 1994) has also shown that other moisture conditioning procedures, such as soaking or air drying, affect measured core strengths and result in conditions that are not representative of the in-place concrete. Therefore, to provide reproducible moisture conditions that are representative of in-place conditions, a standard moisture conditioning procedure that permits dissipation of moisture gradients is prescribed for cores. ASTM C42 permits the specifier of the tests to modify the default duration of moisture conditioning before testing. The specifier of the tests, however, must be aware of the potential reduction in strength if cores are tested before moisture gradients are allowed to dissipate.

(e) An average core strength of 85% of the specified strength is realistic (Bloem 1968). It is not realistic, however, to expect the average core strength to be equal to f_c', because of differences in the size of specimens,

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conditions of obtaining specimens, degree of consolidation, and curing conditions. The acceptance criteria for core strengths have been established with consideration that cores for investigating low strength-test results will typically be extracted at an age later than specified for f_c'. For the purpose of satisfying 26.12.7.1(e), the Code does not intend that core strengths be adjusted for the age of the cores.

(f) Additional testing of cores extracted from locations represented by erratic core strength results shall be permitted.

(g) If criteria for evaluating structural adequacy based on core strength results are not met, and if the structural adequacy remains in doubt, the responsible authority shall be permitted to order a strength evaluation in accordance with Chapter 27 for the questionable portion of the structure or take other appropriate action.

26.12.8 *Acceptance of steel fiber-reinforced concrete*

26.12.8.1 Compliance requirements:

(a) Steel fiber-reinforced concrete used for shear resistance shall satisfy (1) through (3):

(1) The compressive strength acceptance criteria for standard-cured specimens

(2) The residual strength obtained from flexural testing in accordance with ASTM C1609 at a midspan deflection of 1/300 of the span length is at least the greater of (i) and (ii):

(i) 90% of the measured first-peak strength obtained from a flexural test and

(ii) 90% of the strength corresponding to $7.5\sqrt{f_c'}$

(3) The residual strength obtained from flexural testing in accordance with ASTM C1609 at a midspan deflection of 1/150 of the span length is at least the greater of (i) and (ii):

(i) 75% of the measured first-peak strength obtained from a flexural test and

(ii) 75% of the strength corresponding to $7.5\sqrt{f_c'}$

R26.12.8 *Acceptance of steel fiber-reinforced concrete*

R26.12.8.1 The performance criteria for the ASTM C1609 tests are based on results from flexural tests (Chen et al. 1995) conducted on steel fiber-reinforced concretes with fiber types and contents similar to those used in the tests of beams that served as the basis for 9.6.3.1.

The term "residual strength" is defined in ASTM C1609 and is related to the ability of cracked fiber-reinforced concrete to resist tension. The strength of $7.5\sqrt{f_c'}$ is consistent with the design modulus of rupture of the concrete provided by Eq. (19.2.3.1).

26.13—Inspection

26.13.1 *General*

R26.13—Inspection

R26.13.1 *General*

Inspection is necessary to verify that construction is in accordance with construction documents.

Some general building codes have incorporated inspection requirements based upon established procedures such as PCI Plant Certification.

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26.13.1.1 Concrete construction shall be inspected as required by the general building code, and as a minimum, the inspection shall comply with the requirements provided in 26.13. In the absence of a general building code, concrete construction shall be inspected in accordance with the provisions of this Code.

26.13.1.2 Inspection of concrete construction shall be conducted by the licensed design professional responsible for the design, a person under the supervision of the licensed design professional, or a qualified inspector. The inspection shall verify conformance with construction documents throughout the various stages of construction. If an inspector conducts inspection of formwork, concrete placement, reinforcement, and embedments, the inspector shall be certified.

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R26.13.1.1 By inspection, this Code does not intend that the inspector should supervise the construction. Rather, it means the inspector should visit the project as necessary to observe the various stages of construction and determine if it is being performed in general conformance with the construction documents. The frequency of inspections should follow 26.13.3 for items requiring continuous or periodic inspection.

Inspection does not relieve the contractor from the obligation to follow the construction documents and to provide the designated quality and quantity of materials and workmanship for all stages of the Work.

This Code prescribes minimum requirements for inspection of all structures within its scope. This Code is not a construction specification and any user of this Code may require higher standards of inspection than cited in the general building code or this Code if additional requirements are necessary. ACI PRC-311.4 describes the recommended procedure for organizing and conducting concrete inspection. ACI MNL-2 describes methods of inspecting concrete construction.

R26.13.1.2 The licensed design professional responsible for the design is in the best position to determine if construction is in conformance with the construction documents. However, if the licensed design professional responsible for the design is not retained, inspection of construction through other licensed design professionals or through separate inspection organizations with demonstrated capability for performing the inspection may be used.

Inspectors should be certified to inspect and record the results of concrete construction, including pre-placement, placement, and post-placement through the ACI Concrete Construction Special Inspector Certification Program (ACI CPP 630.1-15) or equivalent.

In some jurisdictions, legislation has established registration or licensing procedures for persons performing certain inspection functions. The general building code should be reviewed, or the building official should be consulted to determine if any such requirements exist within a specific jurisdiction. The building official may be contacted for clarification of the inspection requirements if not clearly identified in the general building code.

If inspection is conducted independently of the licensed design professional responsible for the design, it is recommended that the licensed design professional responsible for the design review inspection reports and observe portions of the Work to verify that the design requirements are properly executed.

Inspection reports should be distributed promptly to the owner, licensed design professional responsible for the design, contractor, appropriate subcontractors, appropriate suppliers, and the building official to allow timely identification of compliance or the need for corrective action.

Inspection responsibility and the degree of inspection required should be set forth in the contracts between

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26.13.1.3 Inspection of concrete placement and reinforcement for special moment frames, boundary elements of special structural walls, coupling beams, and precast concrete diaphragms assigned to SDC C, D, E, or F using moderate or high-deformability connections, shall be performed under the supervision of the licensed design professional responsible for the design, by a person under the supervision of a licensed design professional with demonstrated capability to supervise inspection of these elements or by a certified inspector. Installation tolerances of precast concrete diaphragm connections shall be inspected for compliance with ACI CODE-550.5.

26.13.1.4 Inspection of reinforcement welding shall be performed by a qualified welding inspector in accordance with AWS D1.4. The weldability of reinforcement other than ASTM A706 shall be confirmed by documentation in accordance with 26.6.4.

26.13.1.5 Inspection of the installation of post-installed expansion (torque-controlled and displacement-controlled), screw, and undercut anchors shall be performed by a certified inspector or a qualified inspector specifically approved for that purpose by the Licensed Design Professional and the building official.

26.13.1.6 The installation inspection of all adhesive anchors shall be performed by a certified inspector.

26.13.2 *Inspection reports*

26.13.2.1 Inspection reports shall document inspected items and be developed throughout each stage of the

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the owner, architect, engineer, contractor, and inspector. Adequate resources should be provided to properly perform and oversee the inspection.

R26.13.1.3 Installed reinforcement for elements in special seismic systems is required to be inspected by personnel who are certified to inspect these elements. Certification of inspectors should be acceptable to the jurisdiction enforcing the general building code and as described in R26.13.1.2.

Continuous construction inspection is needed for completion of connections for precast concrete diaphragms designed in accordance with 18.12.1.1 to verify the tolerances specified in ACI CODE-550.5 are met.

R26.13.1.5 The International Building Code (IBC 2021) requires inspection of all post-installed anchors. For post-installed expansion (torque-controlled and displacement-controlled), screw, and undercut anchors, monitoring of installation by a certified inspector is recommended to ensure required installation procedures are followed. Certification is established through an independent assessment such as the ACI Post-Installed Concrete Anchor Installation Inspector program (ACI CPP 681.2-19), or similar program with equivalent requirements.

R26.13.1.6 The installation of all adhesive anchors requires inspection by a certified inspector. Certification is established through an independent assessment such as the ACI Adhesive Anchor Installation Inspector program (ACI CPP 681.1-17), the ACI Post-Installed Concrete Anchor Installation Inspector program (ACI CPP 681.2-19), or similar program with equivalent requirements.

The installation of adhesive anchors identified in the construction documents as resisting sustained tensile loads in horizontal or upwardly inclined orientations (clockwise from 9 o'clock to 3 o'clock) poses challenges to the installer and requires particular attention to execution quality as well as an enhanced level of oversight. It is required that these anchor installations be inspected by a certified inspector who is continuously present when and where the installations are being performed.

R26.13.2 *Inspection reports*

R26.13.2.1 A record of inspection is required in case questions subsequently arise concerning the performance

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construction. Records of the inspection shall be preserved by the party performing the inspection for at least 2 years after completion of the project.

26.13.2.2 Inspection reports shall document (a) through (f):

(a) General progress of the Work.
(b) Any significant construction loadings on completed floors, members, or walls.
(c) The date and time of mixing, quantity of concrete placed, identification of mixtures used, approximate placement location in the structure, and results of tests for fresh and hardened concrete properties for all concrete mixtures used in the Work.
(d) Concrete temperatures and protection given to concrete during placement and curing if the ambient temperature falls below 40°F or rises above 95°F.
(e) Placement of reinforcement and tensioning of prestressing reinforcement including measurement and recording of tendon elongation and force from a calibrated gauge.
(f) Post-tensioning tendon finishing operations, including: 1) trimming the tendon tail, 2) installation of the encapsulation cap or permanent grout cap, 3) preparation and filling of the stressing pocket, and 4) closure of grout vents.

26.13.2.3 For ASTM A615 deformed reinforcement used in special seismic systems, verify mill test reports for compliance with the construction documents.

26.13.2.4 Test reports shall be verified to confirm weldability of reinforcement other than ASTM A706, if weldability is required.

26.13.2.5 For post-installed expansion (torque-controlled and displacement-controlled), screw, and undercut anchors and adhesive anchors, materials, and installation procedures shall be verified for conformance with the approved construction documents and the manufacturer's recommended procedures, which are the Manufacturer's Printed Installation Instructions (MPII) in the case of adhesive anchors. Confirm procedures and results of proof loading where required in accordance with 26.7.1(k).

26.13.3 *Items requiring inspection*

26.13.3.1 Unless otherwise specified in the general building code, items shall be continuously or periodically inspected in accordance with 26.13.3.2 and 26.13.3.3, respectively.

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or safety of the structure or members. Photographs documenting construction progress are also desirable.

The general building code or other legal documents may require these records be preserved longer than two years after completion of the project.

R26.13.2.2

(d) The term "ambient temperature" means the temperature of the environment to which the concrete is directly exposed. Concrete temperature as used in this section may be taken as the surface temperature of the concrete. Surface temperatures may be determined by placing temperature sensors in contact with concrete surfaces or between concrete surfaces and covers used for curing, such as insulation blankets or plastic sheeting.

R26.13.2.3 If ASTM A615 reinforcement is used for special seismic applications, it is important that the inspector review the mill certificates for compliance with the applicable requirements provided in the construction documents.

R26.13.3 *Items requiring inspection*

R26.13.3.1 Table 1705 in Chapter 17 of the 2024 IBC was used to determine which items require continuous or periodic inspection.

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26.13.3.2 Items requiring verification and continuous inspection shall include (a) through (e):

(a) Prior to placement, concrete mixture for intended location.
(b) Tensioning of prestressing reinforcement and grouting of bonded tendons.
(c) Placement of reinforcement for special moment frames, boundary elements of special structural walls, and coupling beams.
(d) Welding of reinforcement for special moment frames, boundary elements of special structural walls, and coupling beams.
(e) Post-installed anchor installation, if required as a condition of the anchor assessment or if adhesive anchors are installed in horizontal or upwardly inclined orientations to resist sustained tensile loads.

26.13.3.3 Items requiring verification and periodic inspection shall include (a) through (m):

(a) Placement of reinforcement, embedments, and post-tensioning tendons.
(b) Welding of reinforcement except as required in 26.13.3.2(d).
(c) Curing method and duration of curing for each member.
(d) Construction and removal of forms and reshoring.
(e) Consolidation of concrete placed in insulating concrete forms (ICF).
(f) Sequence of erection and connection of precast members.
(g) Verification of in-place strength of concrete before stressing post-tensioned tendons and before removal of shores and formwork from beams and structural slabs.
(h) Placement of cast-in-anchors and anchor reinforcement, including tolerances required for location of anchor reinforcement.
(i) Installation of post-installed expansion (torque-controlled and displacement-controlled) screw, and undercut anchors.
(j) Installation of adhesive anchors, except as required in 26.13.3.2(e).
(k) Proof loading of anchors if required in accordance with 26.13.2.5.

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(f) Some jurisdictions may require continuous inspection of sequence of erection and connection of precast members, and also may require inspection of the shoring, bracing, or other temporary measures.

(j) Inspection requirements for adhesive anchors are different from other post-installed anchors and are derived from four sources: a) the general building code, which requires periodic inspection for anchors in concrete; b) the assessment and qualification of the anchor under the provisions of ACI CODE-355.4, which may require either periodic inspection or continuous inspection with proof loading depending on the strength reduction factors assigned to the anchor; c) the requirements of 26.13.3.2(e), which mandate continuous inspection for anchors in a horizontal or upwardly inclined orientation to resist sustained tension loads; and d) the proof loading requirement of 26.13.2.5.

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(l) Tendon finishing at post-tensioned tendon anchorages.

(m) Placement of grout for steel base plates and steel shear lugs of columns.

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(l) Guidance on tendon finishing is provided in PTI M10.2, PTI M10.3, PTI/ASBI M50.3 and PTI M55.1.