

CHAPTER 19

CONCRETE

SECTION BC 1901 GENERAL

1901.1 Scope. The provisions of this chapter shall govern the materials, quality control, design and construction of concrete used in structures.

1901.2 Plain and reinforced concrete. Structural concrete shall be designed and constructed in accordance with the requirements of this chapter and ACI 318 as amended in Section 1908 of this code. Except for the provisions of Sections 1904 and 1911, the design and construction of slabs on grade shall not be governed by this chapter unless they transmit vertical loads or lateral forces from other parts of the structure to the soil.

1901.3 Source and applicability. Sections 1902 through 1907 of this chapter are derived from the provisions for structural concrete in ACI 318. Where sections within Chapters 2 through 7 of ACI 318 are referenced in other chapters and appendices of ACI 318, the provisions of Sections 1902 through 1907 of this code shall apply.

1901.4 Construction documents. The construction documents for structural concrete construction shall include:

1. Specified compressive strength of concrete at the stated ages or stages of construction for which each concrete element is designed.
2. Specified strength or grade of reinforcement.
3. Size and location of structural elements, reinforcement, and anchors.
4. Provision for dimensional changes resulting from creep, shrinkage and temperature.
5. Magnitude and location of prestressing forces.
6. Anchorage length of reinforcement and location and length of lap splices.
7. Type and location of mechanical and welded splices of reinforcement.
8. Details and location of contraction or isolation joints specified for plain concrete.
9. Minimum concrete compressive strength at time of posttensioning.
10. Stressing sequence for posttensioning tendons.
11. For structures assigned to Seismic Design Category D, a statement if slab on grade is designed as a structural diaphragm (see Section 21.10.3.4 of ACI 318).
12. Freezing and thawing and deicing chemical exposure classifications (see Section 1904.2).
13. Sulfate exposure classification (see Section 1904.3).
14. Maximum water soluble chloride ion (CI) concentrations (see Section 1904.4).

1901.5 Special inspection. The special inspection of concrete elements of buildings and structures and concreting operations shall be in accordance with Chapter 17.

SECTION BC 1902 DEFINITIONS

1902.1 General. The following words and terms shall have the meanings shown herein.

ADMIXTURE. Material other than water, aggregate or hydraulic cement, used as an ingredient of concrete and added to concrete before or during its mixing to modify its properties.

AGGREGATE. Granular material, such as sand, gravel, crushed stone and iron blast-furnace slag, used with a cementing medium to form a hydraulic cement concrete or mortar.

AGGREGATE, LIGHTWEIGHT. Aggregate with a dry, loose weight of 70 pounds per cubic foot (pcf) (1120 kg/m³) or less.

CEMENTITIOUS MATERIALS. Materials as specified in Section 1903 that have cementing value when used in concrete either by themselves, such as portland cement, blended hydraulic cements and expansive cement, or such materials in combination with fly ash, other raw or calcined natural pozzolans, silica fume, and/or ground granulated blast-furnace slag.

COLUMN. A member with a ratio of height-to-least-lateral dimension exceeding three, used primarily to support axial compressive load.

CONCRETE. A mixture of portland cement or any other hydraulic cement, fine aggregate, coarse aggregate and water, with or without admixtures.

CONCRETE, SPECIFIED COMPRESSIVE STRENGTH OF, (f'_c). The compressive strength of concrete used in design and evaluated in accordance with the provisions of Section 1905, expressed in pounds per square inch (psi) (MPa). Whenever the quantity f'_c is under a radical sign, the square root of the numerical value only is intended, and the result has units of psi (MPa).

CONTRACTION JOINT. Formed, sawed or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure.

DEFORMED REINFORCEMENT. Deformed reinforcing bars, bar mats, deformed wire, welded plain wire fabric and welded deformed wire fabric conforming to ACI 318, Section 3.5.3.

DUCT. A conduit (plain or corrugated) to accommodate prestressing steel for postensioned installation.

EFFECTIVE DEPTH OF SECTION (d). The distance measured from extreme compression fiber to the centroid of tension reinforcement.

ISOLATION JOINT. A separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location such as to interfere least with performance of the structure, yet to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted.

PEDESTAL. An upright compression member with a ratio of unsupported height-to-average-least-lateral dimension of three or less.

PLAIN CONCRETE. Structural concrete with no reinforcement or with less reinforcement than the minimum amount specified for reinforced concrete.

PLAIN REINFORCEMENT. Reinforcement that does not conform to the definition of "Deformed reinforcement" (see ACI 318, Section 3.5.4).

POSTTENSIONING. Method of prestressing in which prestressing steel is tensioned after concrete has hardened.

PRECAST CONCRETE. A structural concrete element cast elsewhere than its final position in the structure.

PRESTRESSED CONCRETE. Structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from loads.

PRESTRESSING STEEL. High-strength steel element such as wire, bar or strand, or a bundle of such elements, used to impart prestress forces to concrete.

PRETENSIONING. Method of prestressing in which prestressing steel is tensioned before concrete is placed.

REINFORCED CONCRETE. Structural concrete reinforced with no less than the minimum amounts of prestressing steel or nonprestressed reinforcement specified in ACI 318, Chapters 1 through 21 and ACI 318 Appendices A through C.

REINFORCEMENT. Material that conforms to Section 1903.5, excluding prestressing steel unless specifically included.

RESHORES. Shores placed snugly under a concrete slab or other structural member after the original forms and shores have been removed from a larger area, thus requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied prior to the installation of the reshores.

SHORES. Vertical or inclined support members designed to carry the weight of the formwork, concrete and construction loads above.

SPIRAL REINFORCEMENT. Continuously wound reinforcement in the form of a cylindrical helix.

STRIPPING OPERATIONS. Removal on the floor of any parts of the concrete formwork, including shoring, bracing and other supports.

STIRRUP. Reinforcement used to resist shear and torsion stresses in a structural member; typically bars, wires or welded wire fabric (plain or deformed) either single leg or bent into L,

U or rectangular shapes and located perpendicular, or at an angle to, longitudinal reinforcement. (The term "stirrups" is usually applied to lateral reinforcement in flexural members and the term "ties" to those in compression members.)

STRUCTURAL CONCRETE. Concrete used for structural purposes, including plain and reinforced concrete.

TENDON. In pretensioning applications, the tendon is the prestressing steel. In posttensioned applications, the tendon is a complete assembly consisting of anchorages, prestressing steel and sheathing with coating for unbonded applications or ducts with grout for bonded applications.

SECTION BC 1903 SPECIFICATIONS FOR TESTS AND MATERIALS

1903.1 General. Materials used to produce concrete and testing thereof shall comply with the applicable standards listed in ACI 318 and this section. Tests of concrete and the materials used in concrete shall be in accordance with ACI 318, Section 3.8. Where required, special inspections and tests shall be in accordance with Chapter 17.

1903.2 Cement. Cement used to produce concrete shall comply with ACI 318, Section 3.2.

1903.3 Aggregates. Aggregates used in concrete shall comply with ACI 318, Section 3.3.

1903.4 Water. Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials or other substances that are deleterious to concrete or steel reinforcement and shall comply with ACI 318, Section 3.4.

1903.5 Steel reinforcement. Reinforcement and welding of reinforcement to be placed in concrete construction shall conform to the requirements of this section.

1903.5.1 Reinforcement type. Reinforcement shall be deformed reinforcement, except plain reinforcement is permitted for spirals or prestressing steel, and reinforcement consisting of structural steel, steel pipe or steel tubing is permitted where specified in ACI 318. Reinforcement shall comply with ACI 318, Section 3.5.

1903.5.2 Welding. Welding of reinforcing bars shall conform to AWS D1.4. Type and location of welded splices and other required welding of reinforcing bars shall be indicated on the construction documents or in the project specifications. The ASTM reinforcing bar specifications, except for ASTM A 706, shall be supplemented to require a report of material properties necessary to conform to the requirements in AWS D1.4. A written welding procedure shall be provided to the registered design professional of record for approval prior to any welding. All welding shall be subject to special inspection by an approved agency.

1903.6 Admixtures. Admixtures to be used in concrete shall be subject to prior approval by the registered design professional of record and shall comply with ACI 318, Section 3.6.

1903.7 Storage of materials. The storage of materials for use in concrete shall comply with the provisions of Sections 1903.7.1 and 1903.7.2.

1903.7.1 Manner of storage. Cementitious materials and aggregates shall be stored in such a manner as to prevent deterioration or intrusion of foreign matter.

1903.7.2 Unacceptable material. Any material that has deteriorated or has been contaminated shall not be used for concrete.

1903.8 Glass fiber reinforced concrete. Glass fiber reinforced concrete (GFRC) and the materials used in such concrete shall be in accordance with the PCI MNL 128 standard.

**SECTION BC 1904
DURABILITY REQUIREMENTS**

1904.1 Water-cementitious materials ratio. The water-cementitious materials ratios specified in Tables 1904.2.2 and 1904.3 shall be calculated using the weight of cement meeting ASTM C 150, ASTM C 595, ASTM C 845 or ASTM C 1157, plus the weight of fly ash and other pozzolans meeting ASTM C 618, slag meeting ASTM C 989 and silica fume meeting ASTM C 1240, if any, except that where concrete is exposed to deicing chemicals, Section 1904.2.3 further limits the amount of fly ash, pozzolans, silica fume, slag or the combination of these materials.

1904.2 Freezing and thawing exposures. Concrete that will be exposed to freezing and thawing or deicing chemicals shall comply with Sections 1904.2.1 through 1904.2.3.

1904.2.1 Air entrainment. Normal-weight and lightweight concrete exposed to freezing and thawing or deicing chemicals shall be air entrained in accordance with Table 1904.2.1. Tolerance of air content as delivered shall be ± 1.5 percent. For specified compressive strength (f'_{c}) greater than 5,000 psi (34.47 MPa), reduction of air content indicated in Table 1904.2.1 by 1.0 percent is permitted.

1904.2.2 Concrete properties. Concrete that will be subject to the exposures given in Table 1904.2.2(1) shall conform to the corresponding maximum water-cementitious materials ratios and minimum specified concrete compressive strength requirements of that table. In addition, concrete that will be exposed to deicing chemicals shall conform to Section 1904.2.3.

Exception: For Group R and accessory occupancies that are in buildings less than four stories in height, normal-weight aggregate concrete that is subject to freezing and thawing or deicer chemicals shall comply with the requirements of Table 1904.2.2(2).

1904.2.3 Deicing chemicals. For concrete exposed to deicing chemicals, the maximum weight of fly ash, other pozzolans, silica fume or slag that is included in the concrete shall not exceed the percentages of the total weight of cementitious materials given in Table 1904.2.3.

**TABLE 1904.2.1
TOTAL AIR CONTENT FOR FROST-RESISTANT CONCRETE**

NOMINAL MAXIMUM AGGREGATE SIZE ^a (inches)	AIR CONTENT (percent)	
	Severe exposure ^b	Moderate exposure ^b
3/8	7 1/2	6
1/2	7	5 1/2
3/4	6	5
1	6	4 1/2
1 1/2	5 1/2	4 1/2
2 ^c	5	4
3 ^c	4 1/2	3 1/2

For SI: 1 inch = 25.4 mm.

- a. See ASTM C 33 for tolerance on oversize for various nominal maximum size designations.
- b. The severe and moderate exposures referenced in this table are not based on the weathering regions shown in Figure 1904.2.2. For the purposes of this section, severe and moderate exposures shall be defined as follows:
 1. Severe exposure occurs where concrete will be in almost continuous contact with moisture prior to freezing, or where deicing salts are used. Examples are pavements, bridge decks, sidewalks, parking garages and water tanks.
 2. Moderate exposure occurs where concrete will be only occasionally exposed to moisture prior to freezing, and where deicing salts are not used. Examples are certain exterior walls, beams, girders and slabs not in direct contact with soil.
- c. These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1 1/2 inches is removed by hand picking or sieving and air content is determined on the minus 1 1/2-inch fraction of the mix (tolerance on air content as delivered applies to this value). Air content of total mix is computed from value determined on the minus 1 1/2-inch fraction.

1904.3 Sulfate exposures. Where concrete will be exposed to sulfate-containing solutions, it shall comply with the provisions of Sections 1904.3.1 and 1904.3.2.

1904.3.1 Concrete quality. Concrete to be exposed to sulfate-containing solutions or soils shall conform to the requirements of Table 1904.3 or shall be concrete made with a cement that provides sulfate resistance and that has a maximum water-cementitious materials ratio and minimum compressive strength as set forth in Table 1904.3.

1904.3.2 Calcium chloride. Calcium chloride as an admixture shall not be used in concrete to be exposed to those severe or very severe sulfate-containing solutions defined in Table 1904.3.

1904.4 Corrosion protection of reinforcement. Reinforcement in concrete shall be protected from corrosion and exposure to chlorides as provided by Sections 1904.4.1 and 1904.4.2.

1904.4.1 General. For corrosion protection of reinforcement in concrete, the maximum water-soluble chloride ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cementitious materials and admixtures shall not exceed the limits of Table 1904.4.1. When testing is performed to determine water-soluble chloride ion content, test procedures shall conform to ASTM C 1218.

**TABLE 1904.2.2(1)
REQUIREMENTS FOR SPECIAL EXPOSURE CONDITIONS**

EXPOSURE CONDITION	MAXIMUM WATER-CEMENTITIOUS MATERIALS RATIO, BY WEIGHT, NORMAL-WEIGHT AGGREGATE CONCRETE	MINIMUM f'_c , NORMAL-WEIGHT AND LIGHTWEIGHT AGGREGATE CONCRETE (psi)
Concrete intended to have low permeability when exposed to water	0.50	4,000
Concrete exposed to freezing and thawing in a moist condition or to deicing chemicals	0.45	4,500
For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, saltwater, brackish water, seawater or spray from these sources	0.40	5,000

For SI: 1 pound per square inch = 0.00689 MPa.

**TABLE 1904.2.2(2)
MINIMUM SPECIFIED COMPRESSIVE STRENGTH (f'_c)**

TYPE OR LOCATION OF CONCRETE CONSTRUCTION	MINIMUM SPECIFIED COMPRESSIVE STRENGTH (f'_c at 28 days, psi)
Basement walls ^c and foundations not exposed to the weather	2,500 ^a
Basement slabs and interior slabs on grade, except garage floor slabs	2,500 ^a
Basement walls ^c , foundation walls, exterior walls and other vertical concrete surfaces exposed to the weather	3,000 ^b
Driveways, curbs, walks, patios, porches, carport slabs, steps and other flatwork exposed to the weather, and garage floor slabs	3,500 ^b

For SI: 1 pound per square inch = 0.00689 MPa.

- a. Concrete in these locations that can be subjected to freezing and thawing during construction shall be of air-entrained concrete in accordance with Table 1904.2.1.
- b. Concrete shall be air entrained in accordance with Table 1904.2.1.
- c. Structural plain concrete basement walls are exempt from the requirements for special exposure conditions of Section 1904.2.2 (see Section 1909.1.1).

**TABLE 1904.2.3
REQUIREMENTS FOR CONCRETE EXPOSED TO DEICING CHEMICALS**

CEMENTITIOUS MATERIALS	MAXIMUM PERCENT OF TOTAL CEMENTITIOUS MATERIALS BY WEIGHT ^{a, b}
Fly ash or other pozzolans conforming to ASTM C 618	25
Slag conforming to ASTM C 989	50
Silica fume conforming to ASTM C 1240	10
Total of fly ash or other pozzolans, slag and silica fume	50 ^c
Total of fly ash or other pozzolans and silica fume	35 ^c

- a. The total cementitious material also includes ASTM C 150, ASTM C 595, ASTM C 845 and ASTM C 1157 cement.
- b. The maximum percentages shall include:
 - 1. Fly ash or other pozzolans present in Type IP or I (PM) blended cement, ASTM C 595, or ASTM C 1157.
 - 2. Slag used in the manufacture of an IS or I (SM) blended cement, ASTM C 595, or ASTM C 1157.
 - 3. Silica fume, ASTM C 1240, present in a blended cement.
- c. Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

**TABLE 1904.3
REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS**

SULFATE EXPOSURE	WATER SOLUBLE SULFATE (SO ₄) IN SOIL, PERCENT BY WEIGHT	SULFATE (SO ₄) IN WATER (ppm)	CEMENT TYPE			MAXIMUM WATER-CEMENTITIOUS MATERIALS RATIO, BY WEIGHT, NORMAL-WEIGHT AGGREGATE CONCRETE ^a	MINIMUM f'_c , NORMAL-WEIGHT AND LIGHTWEIGHT AGGREGATE CONCRETE (psi) ^a
			ASTM C 150	ASTM C 595	ASTM C 1157		
Negligible	0.00 - 0.10	0 - 150	—	—	—	—	—
Moderate ^b	0.10 - 0.20	150 - 1,500	II	II, IP (MS), IS (MS), P (MS), I (PM)(MS), I (SM)(MS)	MS	0.50	4,000
Severe	0.20 - 2.00	1,500 - 10,000	V	—	HS	0.45	4,500
Very severe	Over 2.00	Over 10,000	V plus pozzolan ^c	—	HS plus pozzolan ^d	0.45	4,500

For SI: 1 pound per square inch = 0.00689 MPa.

- a. A lower water-cementitious materials ratio or higher strength may be required for low permeability or for protection against corrosion of embedded items or freezing and thawing (see Table 1904.2.2).
- b. Seawater.
- c. Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.
- d. Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type HS blended cement.

**TABLE 1904.4.1
MAXIMUM CHLORIDE ION CONTENT FOR CORROSION PROTECTION OF REINFORCEMENT**

TYPE OF MEMBER	MAXIMUM WATER SOLUBLE CHLORIDE ION (Cl) IN CONCRETE, PERCENT BY WEIGHT OF CEMENT
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

1904.4.2 Exposure to chlorides. Where concrete with reinforcement will be exposed to chlorides from deicing chemicals, salt, saltwater, brackish water, seawater or spray from these sources, the requirements of Table 1904.2.2(1) for water-cementitious materials ratio and concrete strength, and the minimum concrete cover requirements of Section 1907.7, shall be satisfied. For corrosion protection of unbonded tendons compliance with ACI 318, Section 18.16 shall be required. The limits on acid-soluble and water-soluble chlorides in fresh concrete that contains reinforcing steel or other metals shall conform to the requirements of ACI 222, Section 3.2.

**SECTION BC 1905
CONCRETE QUALITY, MIXING AND PLACING**

1905.1 General. The required strength and durability of concrete shall be governed by compliance with the proportioning, testing, mixing and placing provisions of Sections 1905.1.1 through 1905.13.

1905.1.1 Strength. Concrete shall be proportioned to provide an average compressive strength in accordance with Section 1905.3, and shall satisfy the durability criteria of Section 1904. Concrete shall be produced to minimize the frequency of strengths below f'_c in compliance with Section 1905.6.3.3. For concrete designed and constructed in accordance with this chapter, f'_c shall not be less than 2,500 psi (17.22 MPa). No maximum specified compressive strength shall apply unless restricted by a specific provision of this code or ACI 318.

1905.1.2 Cylinder tests. Requirements for f'_c shall be based on tests of cylinders made and tested in accordance with Section 1905.6.3.

1905.1.3 Basis of f'_c . Unless otherwise specified, f'_c shall be based on 28-day tests. If other than 28 days, test age for f'_c shall be as indicated in construction documents. If at any time during the concrete operations, the concrete is not in conformance with ASTM C 94 or is otherwise compromised, it shall be rejected. If it is placed, the location of the load shall be recorded and a pair of cylinders shall be

molded from the load per ASTM C 31 and included in the average f'_c .

1905.1.4 Lightweight aggregate concrete. Where design criteria in ACI 318, Sections 9.5.2.3, 11.2 and 12.2.4, provide for use of a splitting tensile strength value of concrete (f_{ct}), laboratory tests shall be made in accordance with ASTM C 330 to establish the value of f_{ct} corresponding to the specified value of f'_c .

1905.1.5 Field acceptance. Splitting tensile strength tests shall not be used as a basis for field acceptance of concrete.

1905.2 Selection of concrete proportions. Concrete proportions shall be determined in accordance with the provisions of Sections 1905.2.1 through 1905.2.3.

1905.2.1 General. Proportions of materials for concrete shall be established to provide:

1. Workability and consistency to permit concrete to be worked readily into forms and around reinforcement under the conditions of placement to be employed, without segregation or excessive bleeding.
2. Resistance to special exposures as required by Section 1904.
3. Conformance with the strength test requirements of Section 1905.6.

1905.2.2 Different materials. Where different materials are to be used for different portions of proposed work, each combination shall be evaluated.

1905.2.3 Basis of proportions. Concrete proportions shall be established in accordance with Section 1905.3 or Section 1905.4, and shall comply with the applicable requirements of Section 1904.

1905.3 Proportioning on the basis of field experience and/or trial mixtures. Concrete proportioning determined on the basis of field experience or trial mixtures shall be done in accordance with ACI 318, Section 5.3. If the required f'_c is obtained for trial batch mixes prior to the date specified, the trial mix design may be approved. All mixes shall be approved by the registered design professional of record, prior to construction.

1905.4 Proportioning without field experience or trial mixtures. Concrete proportioning determined without field experience or trial mixtures shall be done in accordance with ACI 318, Section 5.4. This method of proportioning shall not be permitted for load-carrying structural concrete or concrete mix proportions that are required to conform with Section 1904.

1905.5 Average strength reduction. As data become available during construction, it is permissible to reduce the amount by which the average compressive strength (f'_c) is required to exceed the specified value of f'_c in accordance with ACI 318, Section 5.5.

1905.6 Evaluation and acceptance of concrete. The criteria for evaluation and acceptance of concrete shall be as specified in Sections 1905.6.2 through 1905.6.5.5.

1905.6.1 Qualified technicians. Concrete shall be tested in accordance with the requirements in Sections 1905.6.2 through 1905.6.5. An approved agency shall perform tests

on fresh concrete at the job site, prepare specimens required for curing under field conditions, prepare specimens required for testing in the laboratory and record the temperature of the fresh concrete when preparing specimens for strength tests. All field sampling and testing, including the testing of aggregates, concrete mixes, and strength testing of specimens, shall be subject to special inspection by an approved agency. All testing laboratories shall be approved testing agencies and shall employ qualified special inspectors to perform all required laboratory tests. Test results shall be promptly distributed by the testing laboratory to the registered design professional of record, concrete producer, owner and contractor.

1905.6.2 Frequency of testing. The frequency of conducting strength tests of concrete shall be as specified in Sections 1905.6.2.1 through 1905.6.2.4.

1905.6.2.1 Minimum frequency. Samples for strength tests of each class of concrete placed each day shall be taken not less than once a day, nor less than once for each 50 cubic yards (38 m³) of concrete nor less than once for each 5,000 square feet (465 m²) of surface area for slabs or walls. For concrete mixes proportioned for durability requirements specified in Section 1904, the registered design professional of record shall specify additional field testing of the concrete for unit weight, air and water content. At the discretion of the registered design professional of record, the frequency of testing may be reduced, but not less than once for each 150 cubic yards (115 m³).

1905.6.2.2 Minimum number. On a given project, if the total volume of concrete is such that the frequency of testing required by Section 1905.6.2.1 would provide less than five strength tests for a given class of concrete, tests shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used.

1905.6.2.3 Small volume. When the total volume of a given class of concrete is less than 50 cubic yards (38 m³), and the concrete is nonstructural and is not subject to the durability requirements of Section 1904, testing may be waived by the registered design professional of record.

1905.6.2.4 Strength test. A strength test shall be the average of the strengths of two cylinders made from the same sample of concrete and tested at 28 days or at the test age designated for the determination of f'_c . Consideration shall be given specifying an f'_c at 56 days or later for concrete utilizing pozzolans in the mix proportions. At the discretion of the registered design professional of record or the approved agency performing the testing, additional pairs of test cylinders may be taken at the time of sampling for testing at a later date. The additional cylinders may be tested at a later date should the strength at the specified date not meet the required f'_c .

1905.6.3 Laboratory-cured specimens. Laboratory-cured specimens shall comply with the provisions of Sections 1905.6.3.1 through 1905.6.3.4.

1905.6.3.1 Sampling. Samples for strength tests shall be taken in accordance with ASTM C 172.

1905.6.3.2 Cylinders. Cylinders for strength tests shall be molded and laboratory-cured in accordance with ASTM C 31. The contractor shall be responsible for providing the specified field storage curing facility and for monitoring the temperature as defined in ASTM C 31. The cylinders shall be tested in accordance with ASTM C 39.

1905.6.3.3 Acceptance of results. The strength level of an individual class of concrete shall be considered satisfactory if both of the following requirements are met:

1. Every arithmetic average of any three consecutive strength tests equals or exceeds f'_c .
2. No individual strength test (average of two cylinders) falls below f'_c by more than 500 psi (3.45 MPa) when f'_c is 5,000 psi (34.50 MPa) or less, or by more than $0.10f'_c$ when f'_c is more than 5,000 psi (34.50 MPa).

1905.6.3.4 Correction. If either of the requirements of Section 1905.6.3.3 is not met, steps shall be taken to increase the average of subsequent strength test results. The requirements of Section 1905.6.5 shall govern if the requirement of Section 1905.6.3.3, Item 2†, is not met.

1905.6.4 Field-cured specimens. Field-cured specimens shall comply with the provisions of Sections 1905.6.4.1 through 1905.6.4.4.

1905.6.4.1 When required. Where required by the commissioner, the results of strength tests of cylinders cured under field conditions shall be provided to the department.

1905.6.4.2 Curing. Field-cured cylinders shall be cured under field conditions in accordance with ASTM C 31.

1905.6.4.3 Sampling. Field-cured test cylinders shall be molded at the same time and from the same samples as laboratory-cured test cylinders.

1905.6.4.4 Correction. Procedures for protecting and curing concrete shall be improved when the strength of field-cured cylinders at the test age designated for determination of f'_c is less than 85 percent of that of companion laboratory-cured cylinders. The 85-percent limitation shall not apply if the field-cured strength exceeds f'_c by more than 500 psi (3.45 MPa).

1905.6.5 Low-strength test results. The investigation of low-strength test results shall be in accordance with the provisions of Sections 1905.6.5.1 through 1905.6.5.5.

1905.6.5.1 Precaution. If any strength test of laboratory-cured cylinders performed in accordance with Section 1905.6.2.4 falls below the specified value of f'_c by more than the values given in Section 1905.6.3.3, Item 2†, or if tests of field-cured cylinders performed in accordance with Section 1905.6.4.4 indicate deficiencies in protection and curing, steps shall be taken to assure that the load-carrying capacity of the structure is not jeopardized.

1905.6.5.2 Core tests. Where calculations indicate that load-carrying capacity is significantly reduced, tests of cores drilled from the area in question in accordance with ASTM C 42 shall be permitted. In such cases, three cores shall be taken for each strength test that falls below the values given in Section 1905.6.3.3, Item 2†.

1905.6.5.3 Condition of cores. Cores shall be prepared for transport and storage by wiping drilling water from their surfaces and placing the cores in water-tight bags or containers immediately after drilling. Cores shall be tested not earlier than 48 hours nor later than seven days after coring unless approved by the registered design professional of record.

1905.6.5.4 Test results. Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of f'_c and if no single core is less than 75 percent of f'_c . Additional testing of cores extracted from locations represented by erratic core strength results is permitted.

1905.6.5.5 Strength evaluation. If the criteria of Section 1905.6.5.4 are not met and the structural adequacy remains in doubt, the commissioner may order a strength evaluation in accordance with ACI 318, Chapter 20, for the questionable portion of the structure, or take other appropriate action. The registered design professional of record shall present to the commissioner a complete analysis showing the final safe load-carrying capacity of the questionable portion of the structure including any proposed remedial actions necessary for review and approval.

1905.7 Preparation of equipment and place of deposit. Preparation before concrete placement shall include the following:

1. Equipment for mixing and transporting concrete shall be clean.
2. Debris and ice shall be removed from spaces to be occupied by concrete.
3. Forms shall be properly coated.
4. Masonry filler units that will be in contact with concrete shall be well drenched.
5. Reinforcement shall be thoroughly clean of ice or other deleterious coatings.
6. Water shall be removed from the place of deposit before concrete is placed unless a tremie is to be used or unless otherwise permitted by the commissioner.
7. Laitance and other unsound material shall be removed before additional concrete is placed against hardened concrete.

1905.8 Mixing. Mixing of concrete shall be performed in accordance with Sections 1905.8.1 through 1905.8.3.

1905.8.1 General. Concrete shall be mixed until there is a uniform distribution of materials and shall be discharged completely before the mixer is recharged.

1905.8.2 Ready-mixed concrete. Ready-mixed concrete shall be mixed and delivered in accordance with the requirements of ASTM C 94 or ASTM C 685. Concrete plants shall be certified by the National Ready Mixed Concrete Association (NRMCA) and shall comply with the rules of the department. Concrete producers shall have their plants inspected quarterly and have their scales and trucks certified. In fulfilling this certification requirement, the concrete producer may present certification by either a New York City government agency, or by the New York State Department of Transportation subject to the approval of the commissioner. Concrete ready-mix truck drivers shall be certified by the NRMCA and shall comply with the rules of the department.

If required by the registered design professional of record, batch tickets shall accompany every load of concrete delivered to a site. The batch ticket shall contain the information given below:

1. Plant name and location;
2. Contract number and project;
3. Mix designation as to type and strength;
4. Each material in the load along with quantities of each by weight; and
5. The total amount of mix proportion water approved, quantity of water added at the plant and in transit, and the remaining water that can be added on site.

1905.8.3 Job-mixed concrete. Job-mixed concrete shall comply with ACI 318, Section 5.8.3.

1905.9 Conveying. The method and equipment for conveying concrete to the place of deposit shall comply with Sections 1905.9.1 and 1905.9.2.

1905.9.1 Method of conveyance. Concrete shall be conveyed from the mixer to the place of final deposit by methods that will prevent separation or loss of materials that may alter the properties of the concrete delivered. Cylinders shall be made at the truck to determine the quality of concrete delivered to the site. Cylinders shall be made at the point of placement to determine the quality of concrete in-place.

1905.9.2 Conveying equipment. The conveying equipment shall be capable of providing a supply of concrete at the site of placement without separation of ingredients and without interruptions sufficient to permit the loss of plasticity between successive increments.

1905.10 Depositing. The depositing of concrete shall comply with the provisions of Sections 1905.10.1 through 1905.10.8.

1905.10.1 Segregation. Concrete shall be deposited as nearly as practicable to its final position to avoid segregation due to rehandling or flowing.

1905.10.2 Placement timing. Concreting operations shall be carried on at such a rate that the concrete is at all times plastic and flows readily into spaces between reinforcement.

1905.10.3 Unacceptable concrete. Concrete that has partially hardened or been contaminated by foreign materials shall not be deposited in the structure.

1905.10.4 Retempering. Retempered concrete or concrete that has been remixed after initial set shall not be used unless approved by the registered design professional.

1905.10.5 Continuous operation. After concreting has started, it shall be carried on as a continuous operation until placing of a panel or section, as defined by its boundaries or predetermined joints, is completed, except as permitted or prohibited by Section 1906.8.

1905.10.6 Placement in vertical lifts. The top surfaces of vertically formed lifts shall be generally level.

1905.10.7 Construction joints. When construction joints are required, they shall be made in accordance with Section 1906.8.

1905.10.8 Consolidation. Concrete shall be thoroughly consolidated by suitable means during placement and shall be thoroughly worked around reinforcement and embedded fixtures and into corners of the forms.

1905.11 Curing. The curing of concrete shall be in accordance with Sections 1905.11.1 through 1905.11.3.

1905.11.1 Regular. Concrete (other than high early strength) shall be maintained above 50°F (10°C) and in a moist condition for at least the first seven days after placement, except when cured in accordance with Section 1905.11.3.

1905.11.2 High-early-strength. High-early-strength concrete shall be maintained above 50°F (10°C) and in a moist condition for at least the first three days, except when cured in accordance with Section 1905.11.3.

1905.11.3 Accelerated curing. Accelerated curing of concrete shall comply with ACI 318, Section 5.11.3.

1905.12 Cold weather requirements. Concrete that is to be placed during freezing or near-freezing weather shall comply with the following:

1. Adequate equipment shall be provided for heating concrete materials and protecting concrete during freezing or near-freezing weather.
2. Concrete materials and reinforcement, forms, fillers and ground with which concrete is to in contact shall be free from frost.
3. Frozen materials or materials containing ice shall not be used.

1905.13 Hot weather requirements. During hot weather, proper attention shall be given to ingredients, production methods, handling, placing, protection and curing to prevent excessive concrete temperatures or water evaporation that could impair the required strength or serviceability of the member or structure.

SECTION BC 1906 FORMWORK, EMBEDDED PIPES AND CONSTRUCTION JOINTS

1906.1 General requirements. The design, fabrication and erection of forms shall comply with the requirements of section 1906.1.1 through 1906.1.6.

1906.1.1 Safe support of loads. Formwork, including all related braces, shoring, framing, and auxiliary construction, shall be proportioned, erected, supported, braced, and maintained so that it will safely support all vertical and lateral loads that might be applied until such loads can be supported by the permanent construction.

1906.1.2 Vertical and lateral loads. Vertical and lateral loads shall be carried to the ground by the formwork system, by the new construction after it has attained adequate strength for that purpose, or by existing structures. Forms and their supports shall be designed so as not to damage previously placed structures.

1906.1.3 Bracing. Forms shall be properly braced or tied together so as to maintain position and shape, and shall conform to the sizes and shapes of members as shown on the design drawings.

1906.1.4 Ramps, runways and platforms. Ramps, runways, and platforms shall meet the requirements of Section 3315.

1906.1.5 Design. Design of formwork shall comply with ACI 318, Section 6.1.5.

1906.1.6 Forms for prestressed and post-tensioned concrete. Forms for prestressed and post-tensioned concrete members shall be designed and constructed to permit movement of the member without damage during application of the pre-stressing force.

1906.2 Inspection. Formwork, including shores, reshores, braces and other supports, shall be inspected prior to placement of reinforcing steel to verify that the sizes of the concrete members that are being formed conform to the construction documents and form design drawings. Such inspections shall be performed by a qualified person designated by the contractor. Subsequently, inspections shall be performed by such person periodically during the placement of concrete. During and after

concreting, the elevations, camber, and vertical alignment of formwork systems shall be inspected using tell-tale devices. A record of all such inspections shall be kept at the site available to the commissioner. The names of the persons responsible for such inspections and the foreman in charge of the formwork shall be posted in the field office.

1906.3 Design of concrete formwork. Wherever the shore height exceeds 14 feet (4267 mm) or the total load on the forms exceeds 150 pounds per square foot (732 kg/m²), or wherever power buggies or two-stage shores are used, the forms, including shoring foundation, shall be designed by a registered design professional and shall be constructed in conformance with such design. A copy of the design drawings and any construction drawings and specifications shall be kept on the job site available to the commissioner.

1906.3.1 Vertical loads. Vertical loads shall include the total dead and live loads. Dead load shall include the weight of the formwork plus the weight of the reinforcement and fresh concrete. Live load shall allow for the weight of the workers and equipment, with allowance for impact, but in no case shall be less than 20 pounds per square foot (98 kg/m²).

1906.3.2 Lateral concrete pressure. Design of forms, ties and bracing shall satisfy the minimum lateral pressures of fresh concrete specified in Table 1906.3.2.

1906.3.3 External lateral loads. Braces and shores shall be designed to resist all external lateral loads, including, but not limited to, wind, cable tensions, inclined supports, dumping of concrete, and starting and stopping of equipment. In no case shall the assumed value of lateral load due to wind, dumping of concrete, and equipment acting in any direction at each floorline be less than 100 plf edge or 2 percent of total dead load of the floor, whichever is greater. Except for foundation walls that are poured against a rigid

**TABLE 1906.3.2
MINIMUM LATERAL PRESSURES TO BE ASSUMED FOR FRESH CONCRETE WEIGHING 150 POUNDS PER CUBIC FOOT**

TYPE OF WORK	MINIMUM LATER PRESSURE ASSUMED (psf)	LIMITATIONS
Columns: Ordinary work with normal internal vibration	$p = 150 + \frac{9000R}{T}$	Maximum 3,000 psf or 150h, whichever is less
Walls: Rate of placement at 7 ft. per hr. or less	$p = 150 + \frac{9000R}{T}$	Maximum 2,000 psf or 150h, whichever is less
Walls: Rate of placement at greater than 7 ft. per hr.	$p = 150 + \frac{43,400}{T} + \frac{2800R}{T}$	Maximum 2,000 psf or 150h, whichever is less
Slabs	$p = 150h$	None

For SI: 1 inch = 25.4 mm, 1 foot per second = 0.305 m/s, 1 pound per cubic foot = 16.02 kg/m³, 1 pound per square foot = 4.882 kg/m², °C = (°F-32)/1.8.

- a. Allowances for change in lateral pressure shall be made for concrete weighing other than 150 pcf; for concrete containing pozzolanic additions or cements other than Type I, for concrete having slumps greater than 6 inches, or for concrete consolidated by revibration or external vibration of forms.
- b. Where retarding admixtures are employed under hot weather conditions an effective value of temperature less than that of the concrete in the forms shall be used in the above formula.
- c. If retarding admixtures are used in cold weather, the lateral pressure may be assumed as that exerted by a fluid weighing 150 pcf.

where:

R = rate of placement, feet per hour.

T = temperature of concrete in the forms, °F.

h = height of fresh concrete above point considered, feet.

backing, wall forms shall be designed for a minimum lateral load of 10 pounds per square foot (49 kg/m²), and bracing for wall forms shall be designed for a lateral load of at least 100 plf of wall, applied at the top. The lateral load acting on walls greater than 14 feet (4267 mm) high shall be determined by analysis of conditions applicable to the site and building.

1906.3.4 Special loads. The formwork shall be designed for any special conditions of construction likely to occur, such as unsymmetrical placement of concrete, impact of machine-delivered concrete, uplift and concentrated loads.

1906.3.5 Shoring and bracing. Shoring and bracing shall comply with Sections 1906.3.5.1 through 1906.3.5.4.

1906.3.5.1 Approval. When patented or commercial devices that are not susceptible to design are used for shoring, bracing, or splicing, they shall be approved by the commissioner.

1906.3.5.2 Splices. Splices shall develop the full strength of the spliced members.

1906.3.5.3 Bracing. Where shore height exceeds 10 feet (3048 mm), or when necessary to provide structural stability, diagonal bracing shall be provided. Struts, anchored into masonry or to panel joints of adjacent braced bays may be used to prevent buckling of individual members not supported by the diagonal bracing, but bracing an entire tier of shores with struts without diagonal bracing shall be prohibited unless the system can be demonstrated to be braced by other rigid construction.

1906.3.5.4 Unbraced length of shores. The unbraced length of shores shall not exceed the maximum length determined in accordance with the requirements of this code for the structural material used.

1906.3.6 Foundations. Foundations for shores more than 10 feet (3048 mm) high and supported on the ground shall be designed by a registered design professional.

1906.3.7 Settlement. Formwork shall be so constructed that vertical adjustments can be made to compensate for take-up and settlements. Wedges, jacks or other positive means shall be provided for this purpose.

1906.3.8 Structural ramps, runways and platforms. Structural runways, ramps and platforms shall comply with Section 3315 in addition to the requirements of Section 1906.3.

1906.4 Construction. Construction of concrete formwork shall comply with the requirements of Sections 1906.4.1 through 1906.4.4.

1906.4.1 Field-constructed lap splices. Field-constructed lap splices, other than approved devices, shall not be used more often than for every other shore under slabs or for every third shore under beams and shall develop the full strength of the members. Such spliced shores shall be uniformly distributed throughout the work. Splices shall not be located near the midheight of the shores unless lateral support is provided, nor midway between points of lateral support.

1906.4.2 Vertical shores. Vertical shores for multifloor forms shall be set plumb and in alignment with lower tiers so that loads from upper tiers are transferred directly to the lower tiers, or adequate transfer members shall be provided. Provision shall be made to transfer the lateral loads to the ground or to completed construction of adequate strength. Vertical shores shall be so erected that they cannot tilt, and shall have firm bearing. Inclined shores and the bearing ends of all shores shall be braced against slipping or sliding. The bearing surfaces shall be cut square and have a tight fit at splices.

1906.4.3 Runways. Runways for moving equipment shall be provided with struts or legs as required and shall be supported directly on the formwork or structural member and not on the reinforcement.

1906.4.4 Unsafe conditions. Any unsafe condition or necessary adjustment revealed by inspection shall be remedied immediately. If, during construction, any weakness develops and the formwork shows any undue settlement or distortion, the work shall be stopped, the affected construction removed if permanently damaged, and the formwork strengthened.

1906.5 Removal of forms and shoring. The removal of forms and shoring shall comply with the requirements of Sections 1906.5.1 through 1906.5.6.

1906.5.1 Removal schedule. Before starting construction, the contractor shall develop a procedure and schedule for removal of shores and installation of reshores and for calculating the loads transferred to the structure during the process.

1906.5.1.1 Data and analysis. The structural analysis and concrete strength data used in planning and implementing form removal and reshoring shall be furnished by the registered design professional responsible for the removal schedule to the commissioner when so requested.

1906.5.1.2 Support and removal. No construction loads shall be supported on, nor any shoring removed from, any part of the structure under construction except when that portion of the structure in combination with the remaining forming and shoring system has sufficient strength to support safely its weight and the loads placed thereon.

1906.5.1.3 Concrete strength. Sufficient strength shall be demonstrated by structural analysis of the proposed loads, the strength of the forming and shoring system, and concrete strength data. Concrete strength data shall be based on tests of field-cured cylinders or, when approved by the commissioner, on other procedures for evaluating concrete strength.

1906.5.2 Construction loads. No construction loads exceeding the combination of superimposed dead load plus specified live load shall be supported on any unshored portion of the structure under construction, unless analysis indicates adequate strength to support such additional loads.

1906.5.3 Prestressed members. Form supports for prestressed concrete members shall not be removed until suffi-

cient prestressing has been applied to prestressed members to carry their dead load and anticipated construction loads.

1906.5.4 Manner of removal. Forms shall be removed in such a manner as to assure the complete safety of the structure and workers.

1906.5.5 Shores support. Where the structure as a whole is supported on shores, beam and girder sides, columns and similar vertical forms may be removed after the concrete is sufficiently hard to withstand damage from the removal. In no case shall the supporting forms or shoring be removed until the members have acquired sufficient strength to support safely their weight and the load thereon.

1906.5.6 Control tests and alternate methods. The results of control tests, including concrete cylinder specimens prepared in accordance with ANSI/ASTM C 31, 2003a, cast-in-place cores, or other device that will produce test specimens representative of the condition of the concrete in place, of suitable size and proportions, and approved by the registered design professional of record shall be evidence that the concrete has attained sufficient strength or the strength as may be specified on the drawings. The contractor may submit alternate methods of stripping, reshoring, and strength control for approval by the registered design professional of record, subject to review by the commissioner.

1906.6 Reshoring. Reshoring shall be provided to support the construction where forms and shores are stripped before the concrete has attained sufficient strength to support the superimposed loads due to construction above. Reshoring shall comply with Sections 1906.6.1 through 1906.6.7.

1906.6.1 Reshores limitations. Reshores shall comply with the requirements of Sections 1906.6.1.1 through 1906.6.1.7.

1906.6.1.1 Secureness of reshores. Reshores of wood or metal shall be screw adjusted or jacked and locked and wedged to make them secure. Reshores shall not be jacked or screwed so tight that they preload the floor below or remove the normal deflection of the slab above.

1906.6.1.2 Reshores in proximity to facades. Reshores within 10 feet (3048 mm) of the facade of a building shall be secured to prevent them from falling off the building.

1906.6.1.3 Wedges. Wedges shall not be used within 10 feet (3048 mm) of the facade or at such other locations as determined by the commissioner.

1906.6.1.4 Stresses. In no case shall shores be so located as to alter the pattern of stresses determined in the original structural analysis or to induce tensile stresses where reinforcing bars are not provided.

1906.6.1.5 Angle to surface. Reshores shall be perpendicular to the surface that they are supporting.

1906.6.1.6 Adjusting devices. Adjusting devices shall not be used if heavily rusted, bent, dented, rewelded or having broken weldments or other defects.

1906.6.1.7 Metal shoring and accessory parts. Metal shoring and accessory parts shall be fully operative when in use.

1906.6.2 Site safety provisions. Reshoring shall comply with all of the requirements of Chapter 33 regarding safeguards during construction and the requirements of Sections 1906.6.2.1 through 1906.6.2.3.

1906.6.2.1 Emergency. Extra shores or material and equipment that might be needed in an emergency shall be furnished.

1906.6.2.2 Stripping. Care shall be taken while stripping is underway to insure that material does not fall off the building.

1906.6.2.3 Building materials. Building materials shall be properly piled and tied or contained.

1906.6.3 Bracing. Lateral bracing shall be provided during reshoring operations, and reshores shall be located as close as practical to the same position on each floor to provide continuous support from floor to floor.

1906.6.4 Reshoring beam and girder construction. Where reshoring of beam and girder construction is required, the forms shall not be removed from more than one girder at a time, and the girder shall be reshored before any other supports are removed. After the supporting girders are reshored, the form shall be removed from one beam with its adjacent slabs and the beam shall be reshored before any other supports are removed. Slabs spanning 10 feet (3048 mm) or more shall be reshored along the centerline of the span.

1906.6.5 Reshoring flat slabs. Where reshoring of flat-slab construction is required, the formwork cannot be stripped until the concrete has acquired sufficient strength to safely support its weight and the load thereon, or temporary reshores are provided supporting the slab at intervals of no more than 8 feet (2438 mm) on center to be replaced by reshores prior to placing concrete on the floor above. Reshores must be installed and remain in place until the concrete reaches full or sufficient strength to sustain the superimposed loads to which the concrete will be subjected.

1906.6.6 Stripping operation. Waste debris as a result of stripping operations shall be immediately contained and removed at reasonable intervals. Stripping operations on concrete structures shall not be performed more than three stories below the story being formed.

1906.6.7 Prestressed construction. Solid safety shields shall be provided at end anchorages of prestressing beds, or where necessary, for protection against breakage of prestressing strands, cables, or other assemblies during prestressing or casting operations.

1906.7 Conduits and pipes embedded in concrete. Conduits, pipes and sleeves of any material not harmful to concrete and within the limitations of ACI 318, Section 6.3, are permitted to be embedded in concrete with approval of the registered design professional of record.

1906.8 Construction joints. Construction joints shall comply with the provisions of Sections 1906.8.1 through 1906.8.6.

1906.8.1 Surface cleaning. The surface of concrete construction joints shall be cleaned and laitance removed.

1906.8.2 Joint treatment. Immediately before new concrete is placed, construction joints shall be wetted and standing water removed.

1906.8.3 Location for force transfer. Construction joints shall be so made and located as not to impair the strength of the structure. Provision shall be made for the transfer of shear and other forces through construction joints in accordance with ACI 318, Section 11.7.9.

1906.8.4 Location in slabs, beams and girders. Construction joints in floors shall be located within the middle third of spans of slabs, beams and girders. Joints in girders shall be offset a minimum distance of two times the width of intersecting beams.

1906.8.5 Vertical support. Beams, girders or slabs supported by columns or walls shall not be cast or erected until concrete in the vertical support members is no longer plastic.

1906.8.6 Monolithic placement. Beams, girders, haunches, drop panels and capitals shall be placed monolithically as part of a slab system, unless otherwise shown in the design drawings or specifications.

SECTION BC 1907 DETAILS OF REINFORCEMENT

1907.1 Hooks. Standard hooks on reinforcing bars used in concrete construction shall comply with ACI 318, Section 7.1.

1907.2 Minimum bend diameters. Minimum reinforcement bend diameters utilized in concrete construction shall comply with ACI 318, Section 7.2.

1907.3 Bending. The bending of reinforcement shall comply with Sections 1907.3.1 and 1907.3.2.

1907.3.1 Cold bending. Reinforcement shall be bent cold, unless otherwise permitted by the registered design professional of record.

1907.3.2 Embedded reinforcement. Reinforcement partially embedded in concrete shall not be field bent, except as shown on the construction documents or permitted by the registered design professional of record.

1907.4 Surface conditions of reinforcement. The surface conditions of reinforcement shall comply with the provisions of Sections 1907.4.1 through 1907.4.3.

1907.4.1 Coatings. At the time concrete is placed, reinforcement shall be free from mud, oil or other nonmetallic coatings that decrease bond. Epoxy coatings of steel reinforcement in accordance with ACI 318, Sections 3.5.3.7 and 3.5.3.8, are permitted.

1907.4.2 Rust or mill scale. Except for prestressing steel, steel reinforcement with rust, mill scale or a combination of both, shall be permitted, provided the minimum dimensions, including height of deformations and weight of a hand-wire-brushed test specimen, comply with applicable ASTM specifications specified in Section 1903.5.

1907.4.3 Prestressing steel. Prestressing steel shall be clean and free of oil, dirt, scale, pitting and excessive rust. A light coating of rust is permitted.

1907.5 Placing reinforcement. The placement of concrete reinforcement shall comply with the provisions of Sections 1907.5.1 through 1907.5.4.

1907.5.1 Support. Reinforcement, including tendons, and posttensioning ducts shall be accurately placed and adequately supported before concrete is placed, and shall be secured against displacement within tolerances permitted in Section 1907.5.2. Where approved by the registered design professional of record, embedded items (such as dowels or inserts) that either protrude from precast concrete members or remain exposed for inspection are permitted to be embedded while the concrete is in a plastic state, provided the following conditions are met:

1. Embedded items are maintained in the correct position while the concrete remains plastic.
2. The concrete is properly consolidated around the embedded item. Embedded items are not required to be hooked or tied to reinforcement within the concrete.

1907.5.2 Tolerances. Unless otherwise specified by the registered design professional of record, reinforcement, including tendons, and posttensioning ducts shall be placed within the tolerances specified in Sections 1907.5.2.1 and 1907.5.2.2.

1907.5.2.1 Depth and cover. Tolerance for depth, d , and minimum concrete cover in flexural members, walls and compression members shall be as shown in Table 1907.5.2.1, except that tolerance for the clear distance to formed soffits shall be minus $1/4$ inch (6.4 mm) and tolerance for cover shall not exceed minus one-third the minimum concrete cover required in the design drawings or specifications.

TABLE 1907.5.2.1
TOLERANCES

DEPTH (d) (inches)	TOLERANCE ON d (inch)	TOLERANCE ON MINIMUM CONCRETE COVER
$d \leq 8$	$\pm 3/8$	$- 3/8$
$d > 8$	$\pm 1/2$	$- 1/2$

For SI: 1 inch = 25.4 mm.

1907.5.2.2 Bends and ends. Tolerance for longitudinal location of bends and ends of reinforcement shall be ± 2 inches (± 51 mm) except the tolerance shall be $\pm 1/2$ inch (± 12.7 mm) at the discontinuous ends of brackets and corbels, and ± 1 inch (25 mm) at the discontinuous ends of other members. The tolerance for minimum concrete cover of Section 1907.5.2.1 shall also apply at discontinuous ends of members.

1907.5.3 Welded wire fabric. Welded wire fabric with wire size not greater than W5 or D5 used in slabs not exceeding 10 feet (3048 mm) in span is permitted to be curved from a point near the top of the slab over the support to a point near

the bottom of the slab at midspan, provided such reinforcement is either continuous over, or securely anchored at support.

1907.5.4 Welding. Welding of crossing bars shall not be permitted for assembly of reinforcement unless authorized by the registered design professional of record.

1907.6 Spacing limits for reinforcement. The clear distance between reinforcing bars, bundled bars, tendons and ducts shall comply with ACI 318, Section 7.6.

1907.7 Concrete protection for reinforcement. The minimum concrete cover for reinforcement shall comply with Sections 1907.7.1 through 1907.7.7.

1907.7.1 Cast-in-place concrete (nonprestressed). Minimum concrete cover shall be provided for reinforcement in nonprestressed, cast-in-place concrete construction in accordance with Table 1907.7.1, but shall not be less than required by Sections 1907.7.5 and 1907.7.7.

**TABLE 1907.7.1
MINIMUM CONCRETE COVER**

CONCRETE EXPOSURE	MINIMUM COVER (inches)
1. Concrete cast against and permanently exposed to earth	3
2. Concrete exposed to earth or weather No. 6 through No. 18 bar No. 5 bar, W31 or D31 wire, and smaller	2 1 1/2
3. Concrete not exposed to weather or in contact with ground Slabs, walls, joists: No. 14 and No. 18 bars No. 11 bar and smaller Beams, columns: Primary reinforcement, ties, stirrups, spirals Shells, folded plate members: No. 6 bar and larger No. 5 bar, W31 or D31 wire, and smaller	1 1/2 3/4 1 1/2 3/4 1 1/2

For SI: 1 inch = 25.4 mm.

1907.7.2 Cast-in-place concrete (prestressed). The minimum concrete cover for prestressed and nonprestressed reinforcement, ducts and end fittings in cast-in-place prestressed concrete shall comply with ACI 318, Section 7.7.2.

1907.7.3 Precast concrete (manufactured under plant control conditions). The minimum concrete cover for prestressed and nonprestressed reinforcement, ducts and end fittings in precast concrete manufactured under plant control conditions shall comply with ACI 318, Section 7.7.3.

1907.7.4 Bundled bars. The minimum concrete cover for bundled bars shall comply with ACI 318, Section 7.7.4.

1907.7.5 Corrosive environments. In corrosive environments or other severe exposure conditions, prestressed and nonprestressed reinforcement shall be provided with additional protection in accordance with ACI 318, Section 7.7.5.

1907.7.6 Future extensions. Exposed reinforcement, inserts and plates intended for bonding with future extensions shall be protected from corrosion.

1907.7.7 Fire protection. When this code requires a thickness of cover for fire protection greater than the minimum concrete cover specified in Section 1907.7, such greater thickness shall be used.

1907.8 Special reinforcement details for columns. Offset bent longitudinal bars in columns and load transfer in structural steel cores of composite compression members shall comply with the provisions of ACI 318, Section 7.8.

1907.9 Connections. Connections between concrete framing members shall comply with the provisions of ACI 318, Section 7.9.

1907.10 Lateral reinforcement for compression members. Lateral reinforcement for compression members shall comply with the provisions of ACI 318, Section 7.10.

1907.11 Lateral reinforcement for flexural members. Lateral reinforcement for compression reinforcement in flexural members shall comply with the provisions of ACI 318, Section 7.11.

1907.12 Shrinkage and temperature reinforcement. Reinforcement for shrinkage and temperature stresses in concrete members shall comply with the provisions of ACI 318, Section 7.12.

1907.13 Requirements for structural integrity. The detailing of reinforcement and connections between concrete members shall comply with the provisions of ACI 318, Section 7.13.

**SECTION BC 1908
MODIFICATIONS TO ACI 318**

1908.1 General. The text of ACI 318 shall be modified as indicated in Sections 1908.1.1 through 1908.1.7.

1908.1.1 ACI 318, Section 21.1. Modify existing definitions and add the following definitions to ACI 318, Section 21.1.

DESIGN DISPLACEMENT. Total lateral displacement expected for the design-basis earthquake, as specified by Section 9.5.5.7 of ASCE 7 or 1617.5.4 of this code.

STORY DRIFT RATIO. The design displacement over a story divided by the story height.

WALL PIER. A wall segment with a horizontal length-to-thickness ratio of at least 2.5, but not exceeding six, whose clear height is at least two times its horizontal length.

1908.1.2 ACI 318, Section 21.2.1. Modify Sections 21.2.1.2, 21.2.1.3 and 21.2.1.4 to read as follows:

21.2.1.2 For structures assigned to Seismic Design Category B, provisions of Chapters 1 through 18 and 22 shall apply except as modified by the provisions of this chapter. Where the seismic design loads are computed using provisions for intermediate or special concrete systems, the requirements of Chapter 21 for intermediate or special systems, as applicable, shall be satisfied.

21.2.1.3 For structures assigned to Seismic Design Category C, intermediate or special moment frames, or ordinary or special reinforced concrete structural walls shall

be used to resist seismic forces induced by earthquake motions. Where the design seismic loads are computed using provisions for special concrete systems, the requirements of Chapter 21 for special systems, as applicable, shall be satisfied.

21.2.1.4 For structures assigned to Seismic Design Category D, E or F, special moment frames, special reinforced concrete structural walls, diaphragms and trusses and foundations complying with Sections 21.2 through 21.10 shall be used to resist forces induced by earthquake motions when special systems are required. Intermediate moment frames and ordinary reinforced concrete walls, where allowed, shall comply with Chapter 21. Frame members not proportioned to resist earthquake forces shall comply with Section 21.11.

1908.1.3 ACI 318, Section 21.2.5. Modify ACI 318, Section 21.2.5, by renumbering as Section 21.2.5.1 and adding new Sections 21.2.5.2, 21.2.5.3 and 21.2.5.4 to read as follows:

21.2.5 Reinforcement in members resisting earthquake-induced forces.

21.2.5.1 Except as permitted in Sections 21.2.5.2 through 21.2.5.4, reinforcement resisting earthquake-induced flexural and axial forces in frame members and in structural wall boundary elements shall comply with ASTM A 706, ASTM 615, Grades 40 and 60 reinforcement, shall be permitted in these members if (a) the actual yield strength based on mill tests does not exceed the specified yield strength by more than 18,000 psi (retests shall not exceed this value by more than an additional 3,000 psi), and (b) the ratio of the actual ultimate tensile strength to the actual tensile yield strength is not less than 1.25.

21.2.5.2 Prestressing steel shall be permitted in flexural members of frames, provided the average prestress, f_{ps} , calculated for an area equal to the member's shortest cross-sectional dimension multiplied by the perpendicular dimension shall be the lesser of 700 psi (4.83MPa) or $f'_c/6$ at locations of nonlinear action where prestressing steel is used in members of frames.

21.2.5.3 Unless the seismic-force-resisting frame is qualified for use through structural testing as required by the ACI Provisional Standard ITG/T1.1, for members in which prestressing steel is used together with mild reinforcement to resist earthquake-induced forces, prestressing steel shall not provide more than one-quarter of the strength for either positive or negative moments at the nonlinear action location and shall be anchored at the exterior face of the joint or beyond.

21.2.5.4 Anchorages for tendons must be demonstrated to perform satisfactorily for seismic loadings. Anchorage assemblies shall withstand, without failure, a minimum of 50 cycles of loading ranging between 40 and 85 percent of the minimum specified tensile strength of the prestressing steel.

1908.1.4 ACI 318, Section 21.7. Modify ACI 318, Section 21.7, by adding a new Section 21.7.10 to read as follows:

21.7.10 Wall piers and wall segments.

21.7.10.1 Wall piers not designed as a part of a special moment frame shall have transverse reinforcement designed to satisfy the requirements in Section 21.7.10.2.

Exceptions:

1. Wall piers that satisfy Section 21.11.
2. Wall piers along a wall line within a story where other shear wall segments provide lateral support to the wall piers, and such segments have a total stiffness of at least six times the sum of the stiffness of all the wall piers.

21.7.10.2 Transverse reinforcement shall be designed to resist the shear forces determined from Sections 21.3.4.2 and 21.4.5.1. Where the axial compressive force, including earthquake effects, is less than $Agf'_c/20$, transverse reinforcement in wall piers is permitted to have standard hooks at each end in lieu of hoops. Spacing of transverse reinforcement shall not exceed 6 inches (152 mm). Transverse reinforcement shall be extended beyond the pier clear height for at least the development length of the largest longitudinal reinforcement in the wall pier.

21.7.10.3 Wall segments with a horizontal length-to-thickness ratio less than 2.5 shall be designed as columns.

1908.1.5 ACI 318, Section 21.10.1.1. Modify ACI 318, Section 21.10.1.1, to read as follows:

21.10.1.1 Foundations resisting earthquake-induced forces or transferring earthquake-induced forces between a structure and the ground shall comply with the requirements of Section 21.10 and other applicable provisions of ACI 318 unless modified by Chapter 18 of this code.

1908.1.6 ACI 318, Section 21.11. Modify ACI Sections 21.11.1 and 21.11.2.2 and add Sections 21.11.5 through 21.11.7 as follows:

21.11.1 Frame members assumed not to contribute to lateral resistance shall be detailed according to Section 21.11.2 or 21.11.3 depending on the magnitude of moments induced in those members when subjected to the design displacement. If effects of design displacements are not explicitly checked, it shall be permitted to apply the requirements of Section 21.11.3. Slab-column connections shall comply with Sections 21.11.5 through 21.11.7. Conformance to Section 21.11 satisfies the deformation compatibility requirements of Section 9.5.2.2.4.3 of ASCE 7.

21.11.2.2 Members with factored gravity axial forces exceeding $(Ag f'_c/10)$ shall satisfy Sections 21.4.3, 21.4.4.1(c), 21.4.4.3 and 21.4.5. The maximum longitudinal spacing of ties shall be, $S_{o,}$ for the full column height. The spacing, $S_{o,}$ shall not be more than six diame-

ters of the smallest longitudinal bar enclosed or 6 inches (152 mm), whichever is smaller. *Lap splices of longitudinal reinforcement in such members need not satisfy Section 21.4.3.2 in structures where the seismic force-resisting system does not include special moment frames.*

21.11.5 Reinforcement to resist punching shear shall be provided in accordance with Sections 21.11.5.1 and 21.11.5.2 at slab column connections where story drift ratio exceeds $[0.035 - 0.05 (V_u/\Phi V_c)]$ except that Sections 21.11.5.1 and 21.11.5.2 need not be satisfied where $V_u/\Phi V_c$ is less than 0.2 or where the story drift ratio is less than 0.005. V_u equals the factored punching shear from gravity load excluding shear stress from unbalanced moment. V_u is calculated for the load combination $1.2D + 1.0L + 0.2S$. The load factor on L is permitted to be reduced to 0.5 in accordance with Section 9.2.1(a). In no case shall shear reinforcement be less than that required in Section 11.12 for loads without consideration of seismic effects.

21.11.5.1 — The slab shear reinforcement shall provide V_s not less than $3.5v_f'c$.

21.11.5.2 — Slab shear reinforcement shall extend not less than five times the slab thickness from the face of column.

21.11.6 — Bottom bars or wires within the column strip shall conform to Section 13.3.8.5 except that splices shall be Class B.

21.11.7—Within the effective slab width defined in Section 13.5.3.2, the ratio of nonprestressed bottom reinforcement to gross concrete area shall not be less than 0.004. Where bottom reinforcement is not required to be continuous, such reinforcement shall extend a minimum of five times the slab thickness plus one development length beyond the face of the column or terminated at the slab edge with a standard hook.

1908.1.7 ACI 318, Section 21.13.2. Modify ACI 318, Section 21.13.2, to read as follows:

21.13.2 In connections between wall panels, or between wall panels and the foundation, *yielding shall be restricted to reinforcement.*

1908.2 General. The text of ACI 318 shall be modified as indicated in Sections 1908.2.1 through 1908.2.4.

1908.2.1 ACI 318, Section 10.15. Modify ACI 318 by adding Section 10.15.4 to read as follows:

10.15.4 When the specified compressive strength of concrete in a column is greater than 1.4 times that specified for a floor system, the following additional requirements shall be adhered to:

1. All of the design provisions of Section 10.15 (unmodified) are adhered to.
2. The concrete construction is supervised and inspected continuously by a full-time professional engineer responsible for the concrete placement special inspection. Such professional engineer

shall not delegate this responsibility to any subordinates.

1908.2.2 ACI 318, Section 16.3. Modify ACI 318 by adding Section 16.3.3 to read as follows:

16.3.3 - Lifting devices shall have a capacity sufficient to support four times the appropriate portion of the member's dead weight. The inclination of the lifting force shall be considered.

1908.2.3 ACI 318, Section 21.12.3. Modify ACI 318, Section 21.12.3 to read as follows:

21.12.3 Design shear strength of beams and columns resisting earthquake effect shall not be less than either 1 or 2:

1. The sum of the shear associated with development of nominal moment strengths of the member at each restrained end of the clear span and the shear calculated for factored gravity loads;
2. The maximum shear obtained from design load combinations that include earthquake effect E , with E assumed to be twice that prescribed by this code for earthquake-resistant design.

1908.2.4 ACI 318, Section 21.12.6.8. Modify ACI 318, Section 21.12.6.8 to read as follows:

21.12.6.8 At the critical sections for columns defined in 11.12.1.2, two-way shear caused by factored gravity loads shall not exceed $0.4\phi V_c$, where V_c shall be calculated as defined in 11.12.2.1. for nonprestressed slabs and in 11.12.2.2. for prestressed slabs. For slabs with shear reinforcing, it shall be permitted to waive this requirement if the contribution of the earthquake-induced factored two way shear stress transferred by eccentricity of shear in accordance with 11.12.6.1 and 11.12.6.2 at the point of maximum stress does not exceed one-half of the stress ϕV_n permitted by 11.12.6.2.

SECTION BC 1909 STRUCTURAL PLAIN CONCRETE

1909.1 Scope. The design and construction of structural plain concrete, both cast-in-place and precast, shall comply with the minimum requirements of Section 1909 and ACI 318, Chapter 22.

1909.1.1 Special structures. For special structures, such as arches, underground utility structures, gravity walls and shielding walls, the provisions of Section 1909 shall govern where applicable.

1909.2 Limitations. The use of structural plain concrete columns and structural plain concrete footings on piles is not permitted. In addition to the limitations set forth in Section 1910 of this chapter, the use of structural plain concrete shall otherwise be limited to:

1. Members that are continuously supported by soil, such as walls and footings, or by other structural members capable of providing continuous vertical support.

2. Members for which arch action provides compression under all conditions of loading.
3. Walls and pedestals.

➔ **1909.3 Joints.** Contraction or isolation joints shall be provided to divide structural plain concrete members into flexurally discontinuous elements in accordance with ACI 318, Section 22.3.

1909.4 Design. Structural plain concrete walls, footings and pedestals shall be designed for adequate strength in accordance with ACI 318, Sections 22.4 through 22.8.

➔ **Exception:** For Group R-3 occupancies and buildings of other occupancies less than two stories in height of light-frame construction, the required edge thickness of ACI 318 is permitted to be reduced to 6 inches (152 mm), provided that the footing does not extend more than 4 inches (102 mm) on either side of the supported wall.

1909.5 Precast members. The design, fabrication, transportation and erection of precast, structural plain concrete elements shall be in accordance with ACI 318, Section 22.9.

1909.6 Walls. In addition to the requirements of this section, structural plain concrete walls shall comply with the applicable requirements of ACI 318, Chapter 22.

1909.6.1 Basement walls. The thickness of exterior basement walls and foundation walls shall be not less than 7½ inches (191 mm). Structural plain concrete exterior basement walls shall be exempt from the requirements for special exposure conditions of Section 1904.2.2.

1909.6.2 Other walls. Except as provided in Section 1909.6.1, the thickness of bearing walls shall be not less than ¼ the unsupported height or length, whichever is shorter, but not less than 5½ inches (140 mm).

1909.6.3 Openings in walls. Not less than two No. 5 bars shall be provided around window and door openings. Such bars shall extend at least 24 inches (610 mm) beyond the corners of openings.

SECTION BC 1910 SEISMIC DESIGN PROVISIONS

➔ **1910.1 General.** The design and construction of concrete components that resist seismic forces shall conform to the requirements of this section and to ACI 318 as modified by Section 1908.

1910.2 Classification of shear walls. Structural concrete shear walls that resist seismic forces shall be classified in accordance with Sections 1910.2.1 through 1910.2.4.

1910.2.1 Ordinary plain concrete shear walls. Ordinary plain concrete shear walls are walls conforming to the requirements of Chapter 22 of ACI 318.

1910.2.2 Detailed plain concrete shear walls. Detailed plain concrete shear walls are walls conforming to the requirements for ordinary plain concrete shear walls and shall have reinforcement as follows: Vertical reinforcement of at least 0.20 square inch (129 mm²) in cross-sectional area shall be provided continuously from support to support

at each corner, at each side of each opening and at the ends of walls. The continuous vertical bar required beside an opening is permitted to substitute for one of the two No. 5 bars required by Section 22.6.6.5 of ACI 318. Horizontal reinforcement at least 0.20 square inch (129 mm²) in cross-sectional area shall be provided:

1. Continuously at structurally connected roof and floor levels and at the top of walls;
2. At the bottom of load-bearing walls or in the top of foundations where doweled to the wall; and
3. At a maximum spacing of 120 inches (3048 mm).

Reinforcement at the top and bottom of openings, where used in determining the maximum spacing specified in Item 3 above, shall be continuous in the wall.

1910.2.3 Ordinary reinforced concrete shear walls. Ordinary reinforced concrete shear walls are walls conforming to the requirements of ACI 318 for ordinary reinforced concrete structural walls.

1910.2.4 Special reinforced concrete shear walls. Special reinforced concrete shear walls are walls conforming to the requirements of ACI 318 for special reinforced concrete structural walls or special precast structural walls.

1910.3 Seismic Design Category B. Structures assigned to Seismic Design Category B, as determined in accordance with Section 1616, shall conform to the requirements for Seismic Design Category A and to the additional requirements for Seismic Design Category B of this section.

1910.3.1 Ordinary moment frames. In flexural members of ordinary moment frames forming part of the seismic-force-resisting system, at least two main flexural reinforcing bars shall be provided continuously top and bottom throughout the beams, through or developed within exterior columns or boundary elements.

1910.3.1.1 Shear. Columns of ordinary moment frames having a clear height-to-maximum-plan-dimension ratio of five or less shall be designed for shear in accordance with Section 21.12.3 of ACI 318.

1910.4 Seismic Design Category C. Structures assigned to Seismic Design Category C, as determined in accordance with Section 1616, shall conform to the requirements for Seismic Design Category B and to the additional requirements for Seismic Design Category C of this section.

1910.4.1 Seismic-force-resisting systems. Moment frames used to resist seismic forces shall be intermediate moment frames or special moment frames. Shear walls used to resist seismic forces shall be ordinary reinforced concrete shear walls or special reinforced concrete shear walls. Ordinary reinforced concrete shear walls constructed of precast concrete elements shall comply with the additional requirements of Section 21.13 of ACI 318 for intermediate precast concrete structural walls, as modified by Section 1908.1.7.

1910.4.2 Discontinuous members. Columns supporting reactions from discontinuous stiff members, such as walls, shall be designed for the special load combinations in Section 1605.4 and shall be provided with transverse reinforcement at the spacing, *S*, as defined in Section 21.12.5.2 of

ACI 318 over their full height beneath the level at which the discontinuity occurs. This transverse reinforcement shall be extended above and below the column as required in Section 21.4.4.5 of ACI 318.

1910.4.3 Plain concrete. Structural plain concrete members in structures assigned to Seismic Design Category C shall conform to ACI 318 and with Sections 1910.4.3.1 through 1910.4.3.3.

1910.4.3.1 Walls. Structural plain concrete walls are not permitted in structures assigned to Seismic Design Category C.

Exception: Structural plain concrete basement, foundation or other walls below the base are permitted in detached one- and two-family dwellings constructed with stud-bearing walls. Such walls shall have reinforcement in accordance with Section 22.6.6.5 of ACI 318.

1910.4.3.2 Footings. Isolated footings of plain concrete supporting pedestals or columns are permitted provided the projection of the footing beyond the face of the supported member does not exceed the footing thickness.

Exception: In detached one- and two-family dwellings three stories or less in height, the projection of the footing beyond the face of the supported member is permitted to exceed the footing thickness.

1910.4.3.2.1 Reinforcing bars. Plain concrete footings supporting walls shall be provided with not less than two continuous longitudinal reinforcing bars. Bars shall not be smaller than No. 4 and shall have a total area of not less than 0.002 times the gross cross-sectional area of the footing. For footings which exceed 8 inches (203 mm) in thickness, a minimum of one bar shall be provided at the top and bottom of the footing. For foundation systems consisting of a plain concrete footing and a plain concrete stem wall, a minimum of one bar shall be provided at the top of the stem wall and at the bottom of the footing. Continuity of reinforcement shall be provided at corners and intersections.

Exceptions:

1. In detached one- and two-family dwellings three stories or less in height and constructed with stud-bearing walls, plain concrete footings supporting walls are permitted without longitudinal reinforcement.
2. Where a slab-on-ground is cast monolithically with the footing, one No. 5 bar is permitted to be located at either the top or bottom of the footing.

1910.4.3.3 Pedestals. Plain concrete pedestals shall not be used to resist lateral seismic forces.

1910.5 Seismic Design Category D. Structures assigned to Seismic Design Category D, as determined in accordance with Section 1616, shall conform to the requirements for Seismic

Design Category C and to the additional requirements of this section.

1910.5.1 Seismic-force-resisting systems. Moment frames used to resist seismic forces shall be special moment frames. Shear walls used to resist seismic forces shall be special reinforced concrete shear walls.

1910.5.2 Frame members not proportioned to resist forces induced by earthquake motions. Frame components assumed not to contribute to lateral force resistance shall conform to ACI 318, Section 21.11, as modified by Section 1908.1.6 of this chapter.

SECTION BC 1911 MINIMUM SLAB PROVISIONS

1911.1 General. The thickness of concrete floor slabs supported directly on the ground shall not be less than 3½ inches (89 mm). A 6-mil (0.006 inch; 0.152 mm) polyethylene vapor retarder with joints lapped not less than 6 inches (152 mm) shall be placed between the base course or subgrade and the concrete floor slab, or other acceptable equivalent methods or materials shall be used to retard vapor transmission through the floor slab.

Exception: A vapor retarder is not required:

1. For detached structures accessory to occupancies in Group R-3, such as garages, utility buildings or other unheated facilities.
2. For unheated storage rooms having an area of less than 70 square feet (6.5 m²) and carports attached to occupancies in Group R-3.
3. For buildings of other occupancies where migration of moisture through the slab from below will not be detrimental to the intended occupancy of the building.
4. For drive ways, walks, patios and other flat work that will not be enclosed at a later date.
5. Where approved based on local site conditions.

SECTION BC 1912 ANCHORAGE TO CONCRETE—ALLOWABLE STRESS DESIGN

1912.1 Scope. The provisions of this section shall govern the allowable stress design of headed bolts and headed stud anchors cast in normal-weight concrete for purposes of transmitting structural loads from one connected element to the other. These provisions do not apply to anchors installed in hardened concrete or where load combinations include earthquake loads or effects. The bearing area of headed anchors shall be not less than one and one-half times the shank area. Where strength design is used, or where load combinations include earthquake loads or effects, the design strength of anchors shall be determined in accordance with Section 1913. Bolts shall conform to ASTM A 307 or an acceptable equivalent.

1912.2 Allowable service load. The allowable service load for headed anchors in shear or tension shall be as indicated in Table 1912.2. Where anchors are subject to combined shear and tension, the following relationship shall be satisfied:

$$(P_s/P_t)^{5/3} + (V_s/V_t)^{5/3} \leq 1 \quad \text{(Equation 19-1)}$$

where:

- P_s = Applied tension service load, pounds (newtons).
- P_t = Allowable tension service load from Table 1912.2, pounds (newtons).
- V_s = Applied shear service load, pounds (newtons).
- V_t = Allowable shear service load from Table 1912.2, pounds (newtons).

1912.3 Required edge distance and spacing. The allowable service loads in tension and shear specified in Table 1912.2 are for the edge distance and spacing specified. The edge distance and spacing are permitted to be reduced to 50 percent of the values specified with an equal reduction in allowable service load. Where edge distance and spacing are reduced less than 50 percent, the allowable service load shall be determined by linear interpolation.

1912.4 Reserved.

1912.5 Increase for special inspection. Where special inspection is provided for the installation of anchors, a 100-percent increase in the allowable tension values of Table 1912.2 is permitted. No increase in shear value is permitted.

SECTION BC 1913 ANCHORAGE TO CONCRETE—STRENGTH DESIGN

1913.1 Scope. The provisions of this section shall govern the strength design of anchors installed in concrete for purposes of

transmitting structural loads from one connected element to the other. Headed bolts, headed studs and hooked (J- or L-) bolts cast in concrete and expansion anchors and undercut anchors installed in hardened concrete shall be designed in accordance with Appendix D of ACI 318, provided they are within the scope of Appendix D.

Exception: Where the basic concrete breakout strength in tension of a single anchor, N_b , is determined in accordance with Equation (D-7), the concrete breakout strength requirements of Section D.4.2.2 shall be considered satisfied by the design procedures of Sections D.5.2 and D.6.2 for anchors exceeding 2 inches (51 mm) in diameter or 25 inches (635 mm) tensile embedment depth.

1913.1.1 Anchors outside scope of Appendix D. The strength design of anchors that are not within the scope of Appendix D of ACI 318, as modified by this code, shall be in accordance with a procedure subject to the approval of the commissioner.

SECTION BC 1914 SHOTCRETE

1914.1 General. Shotcrete is mortar or concrete that is pneumatically projected at high velocity onto a surface. Except as specified in this section, shotcrete shall conform to the requirements of this chapter for plain or reinforced concrete.

1914.2 Proportions and materials. Shotcrete proportions shall be selected that allow suitable placement procedures using the delivery equipment selected and shall result in finished in-place hardened shotcrete meeting the strength requirements of this code.

1914.3 Aggregate. Coarse aggregate, if used, shall not exceed $3/4$ inch (19.1 mm).

**TABLE 1912.2
ALLOWABLE SERVICE LOAD ON EMBEDDED BOLTS (pounds)**

BOLT DIAMETER (inches)	MINIMUM EMBEDMENT (inches)	EDGE DISTANCE (inches)	SPACING (inches)	MINIMUM CONCRETE STRENGTH (psi)					
				$f'_c = 2,500$		$f'_c = 3,000$		$f'_c = 4,000$	
				Tension	Shear	Tension	Shear	Tension	Shear
$1/4$	$2 1/2$	$1 1/2$	3	200	500	200	500	200	500
$3/8$	3	$2 1/4$	$4 1/2$	500	1,100	500	1,100	500	1,100
$1/2$	4	3	6	950	1,250	950	1,250	950	1,250
		5	5	1,450	1,600	1,500	1,650	1,550	1,750
$5/8$	$4 1/2$	$3 3/4$	$7 1/2$	1,500	2,750	1,500	2,750	1,500	2,750
	$4 1/2$	$6 1/4$	$7 1/2$	2,125	2,950	2,200	3,000	2,400	3,050
$3/4$	5	$4 1/2$	9	2,250	3,250	2,250	3,560	2,250	3,560
	5	$7 1/2$	9	2,825	4,275	2,950	4,300	3,200	4,400
$7/8$	6	$5 1/4$	$10 1/2$	2,550	3,700	2,550	4,050	2,550	4,050
1	7	6	12	3,050	4,125	3,250	4,500	3,650	5,300
$1 1/8$	8	$6 3/4$	$13 1/2$	3,400	4,750	3,400	4,750	3,400	4,750
$1 1/4$	9	$7 1/2$	15	4,000	5,800	4,000	5,800	4,000	5,800

For SI: 1 inch = 25.4 mm, 1 pound per square inch = 0.00689 MPa, 1 pound = 4.45 N.

1914.4 Reinforcement. Reinforcement used in shotcrete construction shall comply with the provisions of Sections 1914.4.1 through 1914.4.4.

1914.4.1 Size. The maximum size of reinforcement shall be No. 5 bars unless it is demonstrated by preconstruction tests that adequate encasement of larger bars will be achieved.

1914.4.2 Clearance. When No. 5 or smaller bars are used, there shall be a minimum clearance between parallel reinforcement bars of $2\frac{1}{2}$ inches (64 mm). When bars larger than No. 5 are permitted, there shall be a minimum clearance between parallel bars equal to six diameters of the bars used. When two curtains of steel are provided, the curtain nearer the nozzle shall have a minimum spacing equal to 12 bar diameters and the remaining curtain shall have a minimum spacing of six bar diameters.

Exception: Subject to the approval of the commissioner, required clearances shall be reduced where it is demonstrated by preconstruction tests that adequate encasement of the bars used in the design will be achieved.

1914.4.3 Splices. Lap splices of reinforcing bars shall utilize the noncontact lap splice method with a minimum clearance of 2 inches (51 mm) between bars. The use of contact lap splices necessary for support of the reinforcing is permitted when approved by the commissioner, based on satisfactory preconstruction tests that show that adequate encasement of the bars will be achieved, and provided that the splice is oriented so that a plane through the center of the spliced bars is perpendicular to the surface of the shotcrete.

1914.4.4 Spirally tied columns. Shotcrete shall not be applied to spirally tied columns.

1914.5 Preconstruction tests. When required by the commissioner, a test panel shall be shot, cured, cored or sawn, examined and tested prior to commencement of the project. The sample panel shall be representative of the project and simulate job conditions as closely as possible. The panel thickness and reinforcing shall reproduce the thickest and most congested area specified in the structural design. It shall be shot at the same angle, using the same nozzleman and with the same concrete mix design that will be used on the project. The equipment used in preconstruction testing shall be the same equipment used in the work requiring such testing, unless substitute equipment is approved by the commissioner.

1914.6 Rebound. Any rebound or accumulated loose aggregate shall be removed from the surfaces to be covered prior to placing the initial or any succeeding layers of shotcrete. Rebound shall not be used as aggregate.

1914.7 Joints. Except where permitted herein, unfinished work shall not be allowed to stand for more than 30 minutes unless edges are sloped to a thin edge. For structural elements that will be under compression and for construction joints shown on the approved construction documents, square joints are permitted. Before placing additional material adjacent to previously applied work, sloping and square edges shall be cleaned and wetted.

1914.8 Damage. In-place shotcrete that exhibits sags, sloughs, segregation, honeycombing, sand pockets or other obvious

defects shall be removed and replaced. Shotcrete above sags and sloughs shall be removed and replaced while still plastic.

1914.9 Curing. During the curing periods specified herein, shotcrete shall be maintained above 40°F (4°C) and in moist condition.

1914.9.1 Initial curing. Shotcrete shall be kept continuously moist for 24 hours after shotcreting is complete or shall be sealed with an approved curing compound.

1914.9.2 Final curing. Final curing shall continue for seven days after shotcreting, or for three days if high-early-strength cement is used, or until the specified strength is obtained. Final curing shall consist of the initial curing process or the shotcrete shall be covered with an approved moisture-retaining cover.

1914.9.3 Natural curing. Natural curing shall not be used in lieu of that specified in this section unless the relative humidity remains at or above 85 percent, and is authorized by the registered design professional of record and approved by the commissioner.

1914.10 Strength tests. Strength tests for shotcrete shall be made by an approved agency on specimens that are representative of the work and that have been water soaked for at least 24 hours prior to testing. When the maximum-size aggregate is larger than $\frac{3}{8}$ inch (9.5 mm), specimens shall consist of not less than three 3-inch-diameter (76 mm) cores or 3-inch (76 mm) cubes. When the maximum-size aggregate is $\frac{3}{8}$ inch (9.5 mm) or smaller, specimens shall consist of not less than 2-inch-diameter (51 mm) cores or 2-inch (51 mm) cubes.

1914.10.1 Sampling. Specimens shall be taken from the in-place work or from test panels, and shall be taken at least once each shift, but not less than one for each 50 cubic yards (38.2 m³) of shotcrete.

1914.10.2 Panel criteria. When the maximum-size aggregate is larger than $\frac{3}{8}$ inch (9.5 mm), the test panels shall have minimum dimensions of 18 inches by 18 inches (457 mm by 457 mm). When the maximum size aggregate is $\frac{3}{8}$ inch (9.5 mm) or smaller, the test panels shall have minimum dimensions of 12 inches by 12 inches (305 mm by 305 mm). Panels shall be shot in the same position as the work, during the course of the work and by the nozzle men doing the work. The conditions under which the panels are cured shall be the same as the work.

1914.10.3 Acceptance criteria. The average compressive strength of three cores from the in-place work or a single test panel shall equal or exceed $0.85 f'_c$ with no single core less than $0.75 f'_c$. The average compressive strength of three cubes taken from the in-place work or a single test panel shall equal or exceed f'_c with no individual cube less than $0.88 f'_c$. To check accuracy, locations represented by erratic core or cube strengths shall be retested.

SECTION BC 1915 REINFORCED GYPSUM CONCRETE

1915.1 General. Reinforced gypsum concrete shall comply with the requirements of ASTM C 317 and ASTM C 956.

1915.2 Minimum thickness. The minimum thickness of reinforced gypsum concrete shall be 2 inches (51 mm) except the minimum required thickness shall be reduced to 1½ inches (38 mm), provided the following conditions are satisfied:

1. The overall thickness, including the formboard, is not less than 2 inches (51 mm).
2. The clear span of the gypsum concrete between supports does not exceed 33 inches (838 mm).
3. Diaphragm action is not required.
4. The design live load does not exceed 40 pounds per square foot (psf) (1915 Pa).

1915.3 Limitations of use. Reinforced gypsum concrete shall not be used where exposed directly to the weather or where subject to frequent or continuous wetting. Precast units shall be protected by coverings or coatings from the weather and from contact with moisture during shipment and during storage at the work site.

SECTION BC 1916 CONCRETE-FILLED PIPE COLUMNS

1916.1 General. Concrete-filled pipe columns shall be manufactured from standard, extra-strong or double-extra-strong steel pipe or tubing that is filled with concrete so placed and manipulated as to secure maximum density and to ensure complete filling of the pipe without voids.

1916.2 Design. The safe supporting capacity of concrete-filled pipe columns shall be computed in accordance with ACI 318 and AISC-LRFD or AISC 335 or as determined by a test approved by the commissioner.

1916.3 Connections. Caps, base plates and connections shall be in accordance with ACI 318 and AISC-LRFD or AISC 335 and shall be positively attached to the shell and anchored to the concrete core. Welding of brackets without mechanical anchorage shall be prohibited. Where the pipe is slotted to accommodate webs of brackets or other connections, the integrity of the shell shall be restored by welding to ensure hooping action of the composite section.

1916.4 Reinforcement. Steel reinforcement shall be in the form of rods, structural shapes or pipe embedded in the concrete core in accordance with ACI 318 and AISC-LRFD or AISC 335 with sufficient clearance to ensure the composite action of the section, but not nearer than 1 inch (25 mm) to the exterior steel shell. Structural shapes used as reinforcement shall be milled to ensure bearing on cap and base plates.

1916.5 Fire-resistance-rating protection. Pipe columns shall be of such size or so protected as to develop the required fire-resistance ratings specified in Table 601. Where an outer steel shell is used to enclose the fire-resistant covering, the shell shall not be included in the calculations for strength of the column section. The minimum diameter of pipe columns shall be 4 inches (102 mm) except that in structures of Type V construction not exceeding three stories or 40 feet (12 192 mm) in height, pipe columns used in the basement and as secondary steel members shall have a minimum diameter of 3 inches (76 mm).

1916.6 Approvals. Details of column connections and splices shall be shop fabricated in accordance with ACI 318 and AISC-LRFD or AISC 335. Shop-fabricated concrete-filled pipe columns shall be inspected by an approved agency pursuant to Chapter 17 of this code.

SECTION BC 1917 STRUCTURAL INTEGRITY REQUIREMENTS

1917.1 General. Reinforced concrete structures shall meet all the requirements of Sections 1917.1 through 1917.3. Concrete slabs on metal deck shall be governed by the provisions of Chapter 22. Reinforcement provided for gravity, seismic and wind forces or for other purposes may be regarded as forming part of, or the whole of, these requirements. Reinforcing provided for one requirement may be counted towards the other requirements.

1917.2 Continuity and ties. The structural integrity requirements of ACI 318, Section 7.13 shall apply. In addition, the following requirements shall be met.

1917.2.1 Slab reinforcement. At all floor and roof levels, slabs shall have a mat of bottom reinforcement in two perpendicular (or roughly perpendicular) directions. Reinforcement in this bottom mat shall be made continuous with lap, mechanical or welded tension splices.

1917.2.1.1 Bottom mat reinforcement. In each direction, the bottom mat reinforcement shall be not less than, the steel required for temperature reinforcement. The bottom mat reinforcement shall be anchored at discontinuous edges within the column strip, reentrant corners, elevation changes and anywhere else the continuity of the reinforcing is interrupted.

Exception: Flat plate middle strip bottom mat reinforcing perpendicular to discontinuous slab edges.

In addition, the main bottom mat reinforcement in one-way slabs shall be anchored at discontinuous edges.

1917.2.2 Peripheral ties. At each floor and roof level, reinforcement forming a continuous peripheral tie shall be provided. Peripheral ties shall be located within perimeter beams or walls, where they occur, or within 4 feet (1219 mm) of the edge of slab, where perimeter beams or walls do not occur. Continuous tie reinforcement shall be equal to half of the bottom reinforcement within the edge or edge strip for two-way slabs but not less than two bars.

1917.2.3 Horizontal ties. At each column, beam reinforcement or slab bottom reinforcement shall be provided at each level that can develop a tension force equal to the maximum of 1 or 2:

1. Three times the load entering the column at that level, using a load combination of 1.0 x *DL* (self weight of structure only).
2. One and a half times the load entering the column at that level using the load combinations of (1.2 *DL* + 1.6 *LL*) or 1.4 *DL*.

1917.2.3.1 Bottom reinforcing†. This beam or slab bottom reinforcement shall be distributed around the col-

umn perimeter and shall be extended on all sides of the column into the adjacent slab for at least one-third of the span length. Where reinforcing bars cannot be extended beyond the column (e.g., at slab edges and openings), they shall be hooked or otherwise developed within the column.

1917.2.4 Vertical ties. Each column and each wall carrying vertical load shall be vertically tied continuously from its lowest to highest level. The vertical ties composed of vertical column reinforcement shall be capable of resisting a tensile force equal to the maximum design dead and live load received by the column or wall from any one story within four floors below.

1917.3 Precast concrete general. Precast concrete structural elements shall be reinforced to meet all of the requirements of this section. However, reinforcement provided for gravity, seismic and wind forces and for other purposes may be regarded as forming part of, or the whole of, these requirements. Reinforcing provided for one requirement may be counted towards the other requirements.

1917.3.1 Continuity and ties. The structural integrity requirements of ACI 318, Section 16.5, shall apply. In precast and composite structures, ties within precast structural elements shall be continuous and shall be anchored to the supporting structure. In addition to Sections 1917.2.2 and 1917.2.4, the following requirements shall be met.

1917.3.1.1 End connections. End connections of all precast slabs, beams and girders shall have an axial tension capacity equal to the larger of the vertical shear capacity of the connection at either end, or at least 2 percent of the maximum factored vertical dead and live load in the precast compression element, whichever is larger, but not less than 20 kips or 2,500 pounds per linear foot of slab (36.48 kN/m). Where more than one element frames in one direction, none of the elements or connections shall have an axial tension capacity of less than 1 percent of the column load but not less than 20 kips.

1917.3.1.2 Side connections. Side connections of all precast elements shall have an axial tension capacity not less than the steel required for temperature reinforcement of the larger element at either side.

1917.3.1.3 Connection forces. For design of the connections, the transverse shear force and the axial tensile force need not be considered to act simultaneously.

1917.3.2 Joints. Joints in precast structures shall not rely on friction due to gravity to transfer load.

1917.3.3 Bearing. The net bearing area shall not be less than 2 inches (51 mm) wide and 3 inches (76 mm) long in the direction of the member.

