

## CHAPTER 19

# CONCRETE

*Italics are used for text within Sections 1903 through 1905 of this code to indicate provisions that differ from ACI 318.*

### SECTION 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 1905 of this code. Except for the provisions of Sections 1904 and 1907, 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 Construction documents.** The *construction documents* for structural concrete construction shall include:

1. The specified compressive strength of concrete at the stated ages or stages of construction for which each concrete element is designed.
2. The specified strength or grade of reinforcement.
3. The size and location of structural elements, reinforcement and anchors.
4. Provision for dimensional changes resulting from creep, shrinkage and temperature.
5. The 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 post-tensioning tendons.
11. For structures assigned to *Seismic Design Category* D, E or F, a statement if slab on grade is designed as a structural diaphragm.

**1901.4 Special inspection.** The *special inspection* of concrete elements of buildings and structures and concreting operations shall be as required by Chapter 17.

### SECTION 1902 DEFINITIONS

**1902.1 General.** The words and terms defined in ACI 318 shall, for the purposes of this chapter and as used elsewhere

in this code for concrete construction, have the meanings shown in ACI 318 as modified by Section 1905.1.1.

### SECTION 1903 SPECIFICATIONS FOR TESTS AND MATERIALS

**1903.1 General.** Materials used to produce concrete, concrete itself and testing thereof shall comply with the applicable standards listed in ACI 318. *Where required, special inspections and tests shall be in accordance with Chapter 17.*

**1903.2 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.*

**1903.3 Flat wall insulating concrete form (ICF) systems.** *Insulating concrete form material used for forming flat concrete walls shall conform to ASTM E 2634.*

### SECTION 1904 DURABILITY REQUIREMENTS

**1904.1 Exposure categories and classes.** Concrete shall be assigned to exposure classes in accordance with the durability requirements of ACI 318 based on:

1. Exposure to freezing and thawing in a moist condition or deicer chemicals;
2. Exposure to sulfates in water or soil;
3. Exposure to water where the concrete is intended to have low permeability; and
4. Exposure to chlorides from deicing chemicals, salt, saltwater, brackish water, seawater or spray from these sources, where the concrete has steel reinforcement.

**1904.2 Concrete properties.** Concrete mixtures shall conform to the most restrictive maximum water-cementitious materials ratios, maximum cementitious admixtures, minimum air-entrainment and minimum specified concrete compressive strength requirements of ACI 318 based on the exposure classes assigned in Section 1904.1.

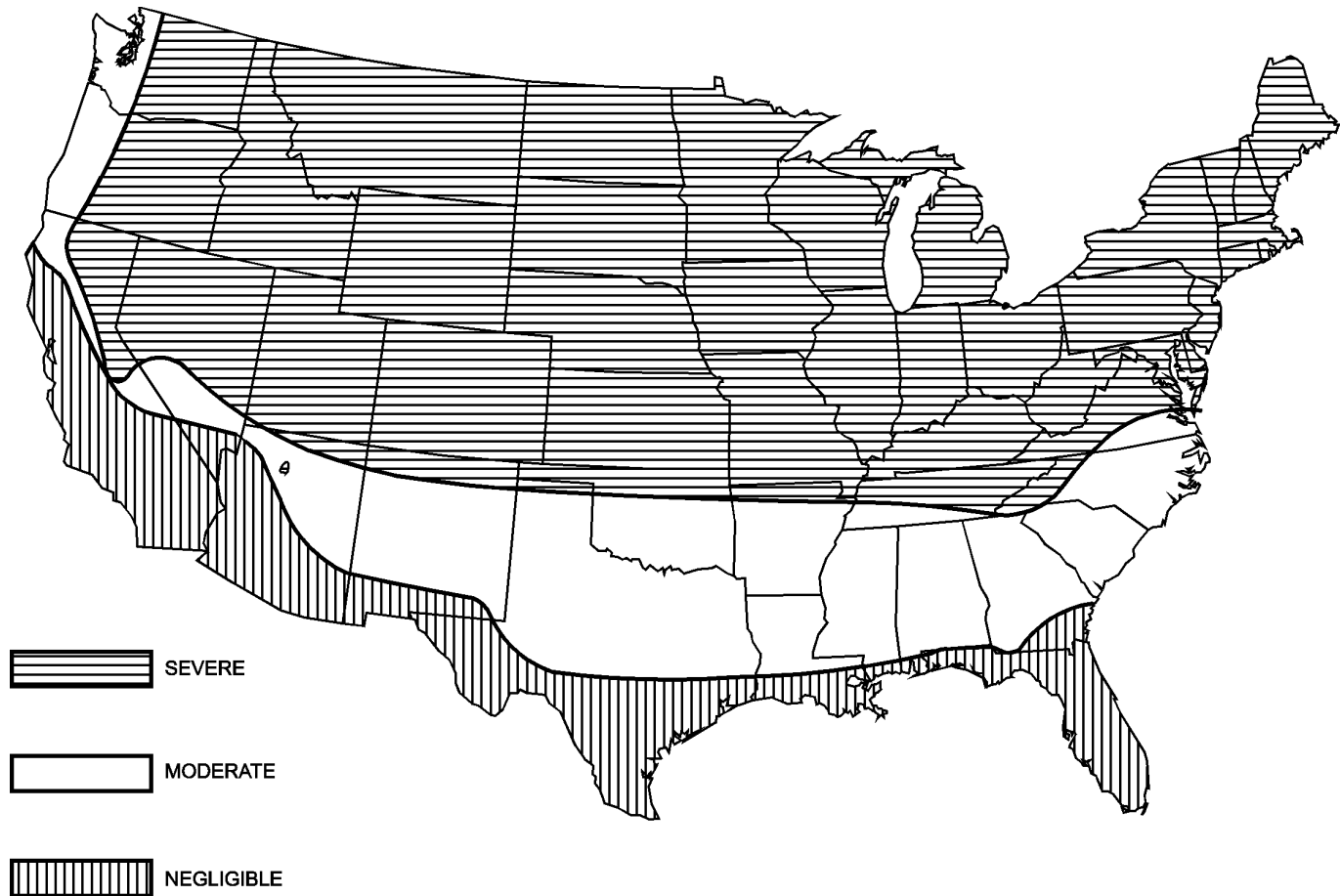
**Exception:** *For occupancies and appurtenances thereto in Group R occupancies that are in buildings less than four stories above grade plane, normal-weight aggregate concrete is permitted to comply with the requirements of Table 1904.2 based on the weathering classification (freezing and thawing) determined from Figure 1904.2 in lieu of the durability requirements of ACI 318.*

**TABLE 1904.2  
MINIMUM SPECIFIED COMPRESSIVE STRENGTH ( $f'_c$ )**

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

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 Section 1904.2.
- b. Concrete shall be air entrained in accordance with ACI 318.
- c. Structural plain concrete basement walls are exempt from the requirements for exposure conditions of Section 1904.2.
- d. For garage floor slabs where a steel trowel finish is used, the total air content required by ACI 318 is permitted to be reduced to not less than 3 percent, provided the minimum specified compressive strength of the concrete is increased to 4,000 psi.



**FIGURE 1904.2  
WEATHERING PROBABILITY MAP FOR CONCRETE<sup>a, b, c</sup>**

- a. Lines defining areas are approximate only. Local areas can be more or less severe than indicated by the region classification.
- b. A “severe” classification is where weather conditions encourage or require the use of deicing chemicals or where there is potential for a continuous presence of moisture during frequent cycles of freezing and thawing. A “moderate” classification is where weather conditions occasionally expose concrete in the presence of moisture to freezing and thawing, but where deicing chemicals are not generally used. A “negligible” classification is where weather conditions rarely expose concrete in the presence of moisture to freezing and thawing.
- c. Alaska and Hawaii are classified as severe and negligible, respectively.

## SECTION 1905 MODIFICATIONS TO ACI 318

**1905.1 General.** The text of ACI 318 shall be modified as indicated in Sections 1905.1.1 through 1905.1.10.

**1905.1.1 ACI 318, Section 2.2.** Modify existing definitions and add the following definitions to ACI 318, Section 2.2.

**DESIGN DISPLACEMENT.** Total lateral displacement expected for the design-basis earthquake, *as specified by Section 12.8.6 of ASCE 7.*

**DETAILED PLAIN CONCRETE STRUCTURAL WALL.** *A wall complying with the requirements of Chapter 22, including 22.6.7.*

**ORDINARY PRECAST STRUCTURAL WALL.** *A precast wall complying with the requirements of Chapters 1 through 18.*

**ORDINARY REINFORCED CONCRETE STRUCTURAL WALL.** *A cast-in-place wall complying with the requirements of Chapters 1 through 18.*

**ORDINARY STRUCTURAL PLAIN CONCRETE WALL.** *A wall complying with the requirements of Chapter 22, excluding 22.6.7.*

**SPECIAL STRUCTURAL WALL.** *A cast-in-place or precast wall complying with the requirements of 21.1.3 through 21.1.7, 21.9 and 21.10, as applicable, in addition to the requirements for ordinary reinforced concrete structural walls or ordinary precast structural walls, as applicable. Where ASCE 7 refers to a "special reinforced concrete structural wall," it shall be deemed to mean a "special structural wall."*

**WALL PIER.** *A wall segment with a horizontal length-to-thickness ratio of at least 2.5, but not exceeding 6, whose clear height is at least two times its horizontal length.*

**1905.1.2 ACI 318, Section 21.1.1.** Modify ACI 318 Sections 21.1.1.3 and 21.1.1.7 to read as follows:

*21.1.1.3 - Structures assigned to Seismic Design Category A shall satisfy requirements of Chapters 1 to 19 and 22; Chapter 21 does not apply. Structures assigned to Seismic Design Category B, C, D, E or F also shall satisfy 21.1.1.4 through 21.1.1.8, as applicable. Except for structural elements of plain concrete complying with Section 1905.1.8 of the Building Code, structural elements of plain concrete are prohibited in structures assigned to Seismic Design Category C, D, E or F.*

*21.1.1.7 - Structural systems designated as part of the seismic force-resisting system shall be restricted to those permitted by ASCE 7. Except for Seismic Design Category A, for which Chapter 21 does not apply, the following provisions shall be satisfied for each structural system designated as part of the seismic force-resisting system, regardless of the Seismic Design Category:*

- (a) Ordinary moment frames shall satisfy 21.2.
- (b) Ordinary reinforced concrete structural walls and ordinary precast structural walls need not satisfy any provisions in Chapter 21.

- (c) Intermediate moment frames shall satisfy 21.3.
- (d) Intermediate precast structural walls shall satisfy 21.4.
- (e) Special moment frames shall satisfy 21.5 through 21.8.
- (f) Special structural walls shall satisfy 21.9.
- (g) Special structural walls constructed using precast concrete shall satisfy 21.10.

All special moment frames and special structural walls shall also satisfy 21.1.3 through 21.1.7.

**1905.1.3 ACI 318, Section 21.4.** Modify ACI 318, Section 21.4, by renumbering Section 21.4.3 to become 21.4.4 and adding new Sections 21.4.3, 21.4.5, 21.4.6 and 21.4.7 to read as follows:

*21.4.3 - Connections that are designed to yield shall be capable of maintaining 80 percent of their design strength at the deformation induced by the design displacement or shall use Type 2 mechanical splices.*

*21.4.4 - Elements of the connection that are not designed to yield shall develop at least 1.5  $S_y$ .*

*21.4.5 - Wall piers in Seismic Design Category D, E or F shall comply with Section 1905.1.4 of the Building Code.*

*21.4.6 - Wall piers not designed as part of a moment frame in buildings assigned to Seismic Design Category C shall have transverse reinforcement designed to resist the shear forces determined from 21.3.3. Spacing of transverse reinforcement shall not exceed 8 inches (203 mm). Transverse reinforcement shall be extended beyond the pier clear height for at least 12 inches (305 mm).*

### Exceptions:

1. Wall piers that satisfy 21.13.
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 stiffnesses of all the wall piers.

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

**1905.1.4 ACI 318, Section 21.9.** Modify ACI 318, Section 21.9, by deleting Section 21.9.8 and replacing with the following:

*21.9.8 - Wall piers and wall segments.*

*21.9.8.1 - Wall piers not designed as a part of a special moment frame shall have transverse reinforcement designed to satisfy the requirements in 21.9.8.2.*

### Exceptions:

1. Wall piers that satisfy 21.13.
2. Wall piers along a wall line within a story where other shear wall segments provide lateral support to the wall piers and such seg-

ments have a total stiffness of at least six times the sum of the stiffnesses of all the wall piers.

21.9.8.2 - Transverse reinforcement with seismic hooks at both ends shall be designed to resist the shear forces determined from 21.6.5.1. Spacing of transverse reinforcement shall not exceed 6 inches (152 mm). Transverse reinforcement shall be extended beyond the pier clear height for at least 12 inches (305 mm).

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

**1905.1.5 ACI 318, Section 21.10.** Modify ACI 318, Section 21.10.2, to read as follows:

21.10.2 - Special structural walls constructed using precast concrete shall satisfy all the requirements of 21.9 for cast-in-place special structural walls in addition to Sections 21.4.2 through 21.4.4.

**1905.1.6 ACI 318, Section 21.12.1.1.** Modify ACI 318, Section 21.12.1.1, to read as follows:

21.12.1.1 - Foundations resisting earthquake-induced forces or transferring earthquake-induced forces between a structure and ground shall comply with the requirements of Section 21.12 and other applicable provisions of ACI 318 unless modified by Chapter 18 of the Building Code.

**1905.1.7 ACI 318, Section 22.6.** Modify ACI 318, Section 22.6, by adding new Section 22.6.7 to read as follows:

22.6.7 - Detailed plain concrete structural walls.

22.6.7.1 - Detailed plain concrete structural walls are walls conforming to the requirements of ordinary structural plain concrete walls and 22.6.7.2.

22.6.7.2 - Reinforcement shall be provided as follows:

(a) Vertical reinforcement of at least 0.20 square inch (129 mm<sup>2</sup>) 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 22.6.6.5.

(b) Horizontal reinforcement at least 0.20 square inch (129 mm<sup>2</sup>) 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.

**1905.1.8 ACI 318, Section 22.10.** Delete ACI 318, Section 22.10, and replace with the following:

22.10 - Plain concrete in structures assigned to Seismic Design Category C, D, E or F.

22.10.1 - Structures assigned to Seismic Design Category C, D, E or F shall not have elements of structural plain concrete, except as follows:

(a) Structural plain concrete basement, foundation or other walls below the base are permitted in detached one- and two-family dwellings three stories or less in height constructed with stud-bearing walls. In dwellings assigned to Seismic Design Category D or E, the height of the wall shall not exceed 8 feet (2438 mm), the thickness shall not be less than 7½ inches (190 mm), and the wall shall retain no more than 4 feet (1219 mm) of unbalanced fill. Walls shall have reinforcement in accordance with 22.6.6.5.

(b) 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.

(c) Plain concrete footings supporting walls are permitted, provided the footings have at least 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 that exceed 8 inches (203 mm) in thickness, a minimum of one bar shall be provided at the top and bottom of the footing. Continuity of reinforcement shall be provided at corners and intersections.

**Exceptions:**

1. In Seismic Design Categories A, B and C, detached one- and two-family dwellings three stories or less in height constructed with stud-bearing walls, are permitted to have plain concrete footings without longitudinal reinforcement.
2. For foundation systems consisting of a plain concrete footing and a plain concrete stemwall, a minimum of one bar shall be provided at the top of the stemwall and at the bottom of the footing.
3. Where a slab on ground is cast monolithically with the footing, one No. 5 bar is permitted to be located at either the top of the slab or bottom of the footing.

**1905.1.9 ACI 318-08, Section D.3.3.** Modify ACI 318-08 Sections D.3.3.4 through D.3.3.6 and add Section D.3.3.7 to read as follows:

*D.3.3.4 - Anchors shall be designed to be governed by the steel strength of a ductile steel element as determined in accordance with D.5.1 and D.6.1, unless either D.3.3.5 or D.3.3.6 is satisfied.*

**Exceptions:**

1. Anchors designed to resist wall out-of-plane forces with design strengths equal to or greater than the force determined in accordance with ASCE 7 Equation 12.11-1 or 12.14-10 need not satisfy Section D.3.3.4.
2. D.3.3.4 need not apply and the design shear strength in accordance with D.6.2.1(c) need not be computed for anchor bolts attaching wood sill plates of bearing or nonbearing walls of light-frame wood structures to foundations or foundation stem walls provided all of the following are satisfied:
  - 2.1. The allowable in-plane shear strength of the anchor is determined in accordance with AF&PA NDS Table 11E for lateral design values parallel to grain.
  - 2.2. The maximum anchor nominal diameter is  $\frac{5}{8}$  inch (16 mm).
  - 2.3. Anchor bolts are embedded into concrete a minimum of 7 inches (178 mm).
  - 2.4. Anchor bolts are located a minimum of  $1\frac{3}{4}$  inches (45 mm) from the edge of the concrete parallel to the length of the wood sill plate.
  - 2.5. Anchor bolts are located a minimum of 15 anchor diameters from the edge of the concrete perpendicular to the length of the wood sill plate.
  - 2.6. The sill plate is of 2-inch or 3-inch nominal thickness.
3. Section D.3.3.4 need not apply and the design shear strength in accordance with Section D.6.2.1(c) need not be computed for anchor bolts attaching cold-formed steel track of bearing or nonbearing walls of light-frame construction to foundations or foundation stem walls provided all of the following are satisfied:
  - 3.1. The maximum anchor nominal diameter is  $\frac{5}{8}$  inch (16 mm).
  - 3.2. Anchors are embedded into concrete a minimum of 7 inches (178 mm).

3.3. Anchors are located a minimum of  $1\frac{3}{4}$  inches (45 mm) from the edge of the concrete parallel to the length of the track.

3.4. Anchors are located a minimum of 15 anchor diameters from the edge of the concrete perpendicular to the length of the track.

3.5. The track is 33 to 68 mil designation thickness.

Allowable in-plane shear strength of exempt anchors, parallel to the edge of concrete shall be permitted to be determined in accordance with AISI S100 Section E3.3.1.

4. In light-frame construction, design of anchors in concrete shall be permitted to satisfy D.3.3.7.

*D.3.3.5 - Instead of D.3.3.4, the attachment that the anchor is connecting to the structure shall be designed so that the attachment will undergo ductile yielding at a force level corresponding to anchor forces no greater than the design strength of anchors specified in D.3.3.3.*

**Exceptions:**

1. Anchors in concrete designed to support non-structural components in accordance with ASCE 7 Section 13.4.2 need not satisfy Section D.3.3.5.
2. Anchors designed to resist wall out-of-plane forces with design strengths equal to or greater than the force determined in accordance with ASCE 7 Equation 12.11-1 or 12.14-10 need not satisfy Section D.3.3.5.

*D.3.3.6 - As an alternative to D.3.3.4 and D.3.3.5, it shall be permitted to take the design strength of the anchors as 0.4 times the design strength determined in accordance with D.3.3.3.*

*D.3.3.7 - In light-frame construction, bearing or non-bearing walls, shear strength of concrete anchors less than or equal to 1 inch (25 mm) in diameter of sill plate or track to foundation or foundation stem wall need not satisfy D.3.3.6 when the design strength of the anchors is determined in accordance with D.6.2.1(c).*

**1905.1.10 ACI 318, Section D.4.2.2.** Delete ACI 318, Section D.4.2.2, and replace with the following:

*D.4.2.2 - The concrete breakout strength requirements for anchors in tension shall be considered satisfied by the design procedure of D.5.2 provided Equation D-7 is not used for anchor embedments exceeding 25 inches. The concrete breakout strength requirements for anchors in shear with diameters not exceeding 2 inches shall be considered satisfied by the design procedure of D.6.2. For anchors in shear with diameters exceeding 2 inches, shear anchor reinforcement shall be provided in accordance with the procedures of D.6.2.9.*

**SECTION 1906  
STRUCTURAL PLAIN CONCRETE**

**1906.1 Scope.** The design and construction of structural plain concrete, both cast-in-place and precast, shall comply with the minimum requirements of ACI 318, as modified in Section 1905.

**Exception:** For Group R-3 occupancies and buildings of other occupancies less than two stories above grade plane of light-frame construction, the required footing 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.

**SECTION 1907  
MINIMUM SLAB PROVISIONS**

**1907.1 General.** The thickness of concrete floor slabs supported directly on the ground shall not be less than 3 1/2 inches (89 mm). A 6-mil (0.006 inch; 0.15 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 approved 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 m<sup>2</sup>) 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 driveways, walks, patios and other flatwork which will not be enclosed at a later date.
5. Where *approved* based on local site conditions.

**SECTION 1908  
ANCHORAGE TO CONCRETE—  
ALLOWABLE STRESS DESIGN**

**1908.1 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 1909. Bolts shall conform to ASTM A 307 or an *approved* equivalent.

**1908.2 Allowable service load.** The allowable service load for headed anchors in shear or tension shall be as indicated in Table 1908.2. 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 (N).

$P_t$  = Allowable tension service load from Table 1908.2, pounds (N).

$V_s$  = Applied shear service load, pounds (N).

$V_t$  = Allowable shear service load from Table 1908.2, pounds (N).

**TABLE 1908.2  
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
	4	5	6	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.

**1908.3 Required edge distance and spacing.** The allowable service loads in tension and shear specified in Table 1908.2 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.

**1908.4 Increase in allowable load.** Increase of the values in Table 1908.2 by one-third is permitted where the provisions of Section 1605.3.2 permit an increase in allowable stress for wind loading.

**1908.5 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 1908.2 is permitted. No increase in shear value is permitted.

## SECTION 1909 ANCHORAGE TO CONCRETE— STRENGTH DESIGN

**1909.1 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 as modified by Sections 1905.1.9 and 1905.1.10, provided they are within the scope of Appendix D.

The strength design of anchors that are not within the scope of Appendix D of ACI 318, and as amended in Sections 1905.1.9 and 1905.1.10, shall be in accordance with an *approved* procedure.

## SECTION 1910 SHOTCRETE

**1910.1 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.

**1910.2 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.

**1910.3 Aggregate.** Coarse aggregate, if used, shall not exceed  $\frac{3}{4}$  inch (19.1 mm).

**1910.4 Reinforcement.** Reinforcement used in shotcrete construction shall comply with the provisions of Sections 1910.4.1 through 1910.4.4.

**1910.4.1 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.

**1910.4.2 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 *building official*, 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.

**1910.4.3 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 *building official*, 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.

**1910.4.4 Spirally tied columns.** Shotcrete shall not be applied to spirally tied columns.

**1910.5 Preconstruction tests.** When required by the *building official*, 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 *building official*.

**1910.6 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.

**1910.7 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.

**1910.8 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.

## CONCRETE

**1910.9 Curing.** During the curing periods specified herein, shotcrete shall be maintained above 40°F (4°C) and in moist condition.

**1910.9.1 Initial curing.** Shotcrete shall be kept continuously moist for 24 hours after shotcreting is complete or shall be sealed with an *approved* curing compound.

**1910.9.2 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.

**1910.9.3 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* and *approved* by the *building official*.

**1910.10 Strength tests.** Strength tests for shotcrete shall be made by an *approved agency* on specimens that are representative of the work and which 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.

**1910.10.1 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 m<sup>3</sup>) of shotcrete.

**1910.10.2 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.

**1910.10.3 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 1911 REINFORCED GYPSUM CONCRETE

**1911.1 General.** Reinforced gypsum concrete shall comply with the requirements of ASTM C 317 and ASTM C 956.

**1911.2 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).

### SECTION 1912 CONCRETE-FILLED PIPE COLUMNS

**1912.1 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.

**1912.2 Design.** The safe supporting capacity of concrete-filled pipe columns shall be computed in accordance with the *approved* rules or as determined by a test.

**1912.3 Connections.** Caps, base plates and connections shall be of *approved* types 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.

**1912.4 Reinforcement.** To increase the safe load-supporting capacity of concrete-filled pipe columns, the steel reinforcement shall be in the form of rods, structural shapes or pipe embedded in the concrete core 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.

**1912.5 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 protective 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 above grade plane* or 40 feet (12 192 mm) in *building height*, pipe columns used in basements and as secondary steel members shall have a minimum diameter of 3 inches (76 mm).

**1912.6 Approvals.** Details of column connections and splices shall be shop fabricated by *approved* methods and shall be *approved* only after tests in accordance with the *approved* rules. Shop-fabricated concrete-filled pipe columns shall be inspected by the *building official* or by an *approved* representative of the manufacturer at the plant.