CHAPTER 19

CONCRETE
(including 2017 errata)

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

User note: Code change proposals to this chapter will be considered by the IBC – Structural Code Development Committee during the 2016 (Group B) Code Development Cycle. See explanation on page iv.

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 Anchoring to concrete. Anchoring to concrete shall be in accordance with ACI 318 as amended in Section 1905, and applies to cast-in (headed bolts, headed studs and hooked J- or L-bolts), post-installed expansion (torque-controlled and displacement-controlled), undercut and adhesive anchors.

1901.4 Composite structural steel and concrete structures. Systems of structural steel acting compositely with reinforced concrete shall be designed in accordance with Section 2206 of this code.

1901.5 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 posttensioning 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.

1901.6 Special inspections and tests. *Special inspections* and tests 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.

Exception: *The following standards as referenced in Chapter 35 shall be permitted to be used.*

1. *ASTM C150*
2. *ASTM C595*
3. *ASTM C1157*

1903.2 Special inspections. *Where required, special inspections and tests shall be in accordance with Chapter 17.*

1903.3 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.*

1903.4 Flat wall insulating concrete form (ICF) systems. *Insulating concrete form material used for forming flat concrete walls shall conform to ASTM E2634.*

SECTION 1904
DURABILITY REQUIREMENTS

1904.1 Structural concrete. Structural concrete shall conform to the durability requirements of ACI 318.

Exception: *For Group R-2 and R-3 occupancies not more than three stories above grade plane, the specified compressive strength, f'_c, for concrete in basement walls, foundation walls, exterior walls and other vertical surfaces*

exposed to the weather shall be not less than 3,000 psi (20.7 MPa).

1904.2 Nonstructural concrete. The registered design professional shall assign nonstructural concrete a freeze-thaw exposure class, as defined in ACI 318, based on the anticipated exposure of nonstructural concrete. Nonstructural concrete shall have a minimum specified compressive strength, f'c, of 2,500 psi (17.2 MPa) for Class F0; 3,000 psi (20.7 MPa) for Class F1; and 3,500 psi (24.1 MPa) for Classes F2 and F3. Nonstructural concrete shall be air entrained in accordance with ACI 318.

Code Alternate CA1904.2: Five-sack 2000 psi (13.8 MPa) and five 1/2-sack 2500 psi (17.2 MPa) concrete mixes shall be deemed to comply with the requirements for 3000 psi (20.7 MPa) concrete in Sections 1904.1 and 1904.2. Air-entrainment is not required for durability purposes. Mixes shall be proportioned to produce a 5-inch or less slump, with a maximum allowable tolerance of 1-inch plus.

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 ((~~1905.1.8~~)) 1905.1.10.

1905.1.1 ACI 318, Section 2.3. Modify existing definitions and add the following definitions to ACI 318, Section 2.3.

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 14, including 14.6.2.

ORDINARY PRECAST STRUCTURAL WALL. A precast wall complying with the requirements of Chapters 1 through 13, 15, 16 and 19 through 26.

ORDINARY REINFORCED CONCRETE STRUCTURAL WALL. A *cast-in-place* wall complying with the requirements of Chapters 1 through 13, 15, 16 and 19 through 26.

ORDINARY STRUCTURAL PLAIN CONCRETE WALL. A wall complying with the requirements of Chapter 14, *excluding 14.6.2*.

SPECIAL STRUCTURAL WALL. A cast-in-place or precast wall complying with the requirements of 18.2.4 through 18.2.8, 18.10 and 18.11, 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."*

1905.1.2 ACI 318, Section 18.2.1. Modify ACI 318 Sections 18.2.1.2 and 18.2.1.6 to read as follows:

18.2.1.2 – Structures assigned to Seismic Design Category A shall satisfy requirements of Chapters 1 through 17 and 19 through 26*; Chapter 18 does not apply*. Structures assigned to *Seismic Design Category* B, C, D, E or F also shall satisfy 18.2.1.3 through 18.2.1.7, as applicable. *Except for structural elements of plain concrete complying with Section 1905.1.7 of the International Building Code, structural elements of plain concrete are prohibited in structures assigned to Seismic Design Category C, D, E or F.*

18.2.1.6 – 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 18 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 18.3.

(b) Ordinary reinforced concrete structural walls *and ordinary precast structural walls* need not satisfy any provisions in Chapter 18.

(c) Intermediate moment frames shall satisfy 18.4.

(d) Intermediate precast *structural* walls shall satisfy 18.5.

(e) Special moment frames shall satisfy 18.6 through 18.9.

(f) Special structural walls shall satisfy 18.10.

(g) Special structural walls constructed using precast concrete shall satisfy 18.11.

All special moment frames and special structural walls shall also satisfy 18.2.4 through 18.2.8.

1905.1.3 ACI 318, Section 18.5. Modify ACI 318, Section 18.5, by adding new Section 18.5.2.2 and renumbering existing Sections 18.5.2.2 and 18.5.2.3 to become 18.5.2.3 and 18.5.2.4, respectively.

18.5.2.2 – 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.

18.5.2.3 – For elements of the connection that are not designed to yield the required strength shall be based on 1.5 S_y of the yielding portion of the connection.

18.5.2.4 – In structures assigned to SDC D, E or F, wall *piers* shall be designed in accordance with 18.10.8 or 18.14 in ACI 318.

1905.1.4 ACI 318, Section 18.11. Modify ACI 318, Section 18.11.2.1, to read as follows:

18.11.2.1 – Special structural walls constructed using precast concrete shall satisfy all the requirements of 18.10 *for cast-in-place special structural walls* in addition to 18.5.2.

1905.1.5 ACI 318, Section 18.13.1.1. Modify ACI 318, Section 18.13.1.1, to read as follows:

18.13.1.1 – Foundations resisting earthquake-induced forces or transferring earthquake-induced forces between a structure and ground shall comply with the requirements of 18.13 and other applicable provisions of ACI 318 *unless modified by Chapter 18 of the International Building Code.*

1905.1.6 ACI 318, Section 14.6. Modify ACI 318, Section 14.6, by adding new Section 14.6.2 to read as follows:

14.6.2 – Detailed plain concrete structural walls.

14.6.2.1 – Detailed plain concrete structural walls are walls conforming to the requirements of ordinary structural plain concrete walls and 14.6.2.2.

14.6.2.2 – Reinforcement shall be provided as follows:

(a) Vertical reinforcement of at least 0.20 square inch (129 mm^2) 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 14.6.1.

(b) Horizontal reinforcement at least 0.20 square inch (129 mm^2) 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.

1905.1.7 ACI 318, Section 14.1.4. Delete ACI 318, Section 14.1.4, and replace with the following:

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

14.1.4.1 – 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 as defined in ASCE 7 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 be not less than $7\frac{1}{2}$ 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 14.6.1.

(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.*

1905.1.8 ACI 318, Section 17.2.3. Modify ACI 318 Sections 17.2.3.4.2, 17.2.3.4.3(d) and 17.2.3.5.2 to read as follows:

17.2.3.4.2 – Where the tensile component of the strength-level earthquake force applied to anchors exceeds 20 percent of the total factored anchor tensile force associated with the same load combination, anchors and their attachments shall be designed in accordance with 17.2.3.4.3. The anchor design tensile strength shall be determined in accordance with 17.2.3.4.4.

***Exception:** 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 shall be deemed to satisfy Section 17.2.3.4.3(d).*

17.2.3.4.3(d) – The anchor or group of anchors shall be designed for the maximum tension obtained from design load combinations that include ***E***, with ***E*** increased by Ω_0. The anchor design tensile strength shall *be calculated from 17.2.3.4.4*.

17.2.3.5.2 – Where the shear component of the strength-level earthquake force applied to anchors exceeds 20 percent of the total factored anchor shear force associated with the same load combination, anchors and their attachments shall be designed in accordance with 17.2.3.5.3. The anchor design shear strength for resisting earthquake forces shall be determined in accordance with 17.5.

Exceptions:

1. *For the calculation of the in-plane shear strength of anchor bolts attaching wood sill plates of bearing or nonbearing walls of light-frame wood structures to foundations or foundation stem walls, the in-plane shear strength in accordance with 17.5.2 and 17.5.3 need not be computed and 17.2.3.5.3 shall be deemed to be satisfied provided all of the following are met:*
   - *1.1. The allowable in-plane shear strength of the anchor is determined in accordance with ANSI/AWC NDS Table 11E for lateral design values parallel to grain.*
   - *1.2. The maximum anchor nominal diameter is $^5/_8$ inch (16 mm).*
   - *1.3. Anchor bolts are embedded into concrete a minimum of 7 inches (178 mm).*
   - *1.4. Anchor bolts are located a minimum of $1^3/_4$ inches (45 mm) from the edge of the concrete parallel to the length of the wood sill plate.*
   - *1.5. 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.*
   - *1.6. The sill plate is 2-inch (51 mm) or 3-inch (76 mm) nominal thickness.*
2. *For the calculation of the in-plane shear strength of anchor bolts attaching cold-formed steel track of bearing or nonbearing walls of light-frame construction to foundations or foundation stem walls, the in-plane shear strength in accordance with 17.5.2 and 17.5.3 need not be computed and 17.2.3.5.3 shall be deemed to be satisfied provided all of the following are met:*
   - *2.1. The maximum anchor nominal diameter is $^5/_8$ inch (16 mm).*
   - *2.2. Anchors are embedded into concrete a minimum of 7 inches (178 mm).*
   - *2.3. Anchors are located a minimum of $1^3/_4$ inches (45 mm) from the edge of the concrete parallel to the length of the track.*
   - *2.4. Anchors are located a minimum of 15 anchor diameters from the edge of the concrete perpendicular to the length of the track.*
   - *2.5. The track is 33 to 68 mil (0.84 mm to 1.73 mm) 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.
3. *In light-frame construction bearing or nonbearing walls, shear strength of concrete anchors less than or equal to 1 inch [25 mm] in diameter attaching sill plate or track to foundation or foundation stem wall need not satisfy 17.2.3.5.3(a) through (c) when the design strength of the anchors is determined in accordance with 17.5.2.1(c).*

1905.1.9 ACI 318, Section ((~~5.1.1~~)) 19.2.1.2. Modify ACI 318, Section ((~~5.1.1~~)) 19.2.1.2, to read as follows:

((~~5.1.1 – Concrete shall be proportioned to provide an average compressive strength, f'_e, as prescribed in 5.3.2 and shall satisfy the durability criteria of Chapter 4. Concrete shall be produced to minimize the frequency of strength tests below f'_e, as prescribed in 5.6.3.3. For concrete designed and constructed in accordance with the Code, f'_e shall not be less than 2500 psi.~~))

19.2.1.2 The specified compressive strength shall be used for proportioning of concrete mixtures in Section 26.4.3 and for testing and acceptance of concrete in Section 26.12.3.

Exception: Concrete is permitted to be designed and constructed in accordance with Section ((~~1905.1.2~~)) 1905.1.10.

1905.1.10 ACI 318, Section ((~~5.2~~)) 26.4.3. Modify ACI 318, Section ((~~5.2~~)) 26.4.3 by adding new Section ((~~5.2.4~~)) 26.4.3.2 as follows:

Concrete proportioning in accordance with Table 1905.1.10 is permitted to be used for concrete to be made with cements meeting strength requirements for Type I, II, or III of ASTM C 150. Table 1905.1.10 shall not be used to proportion concrete containing lightweight aggregates. If approved by the building official, Table 1905.1.10 is permitted to be used with air-entraining admixtures (conforming to ASTM C260) and/or normal-range water-reducing admixtures (conforming to ASTM C494-11 Standard Specification for Chemical Admixtures for Concrete, Types A, D or E; or C618-12 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete). For strengths greater than 4000 psi (27.7 MPa), proportions shall be established on the basis of field experience and trial mixtures according to ACI Section

((~~5.3~~)) 26.4.3.1(b) or by proportioning without field mixtures or trial mixtures according to ACI Section ((~~5.4~~)) 26.4.4.1(b). When approved by the building official, concrete proportions shall be determined in accordance with the provisions of ACI 318, Section ((~~5.3 or 5.4~~)) 26.4.3.1(b) or 26.4.4.1(b).

TABLE 1905.1.10
MINIMUM PERMISSIBLE CEMENT CONTENT FOR CONCRETE
(Strength Data from Trial Batches or Field Experience are not Available)

SPECIFIED 28-DAY COMPRESSIVE STRENGTH IN psi ($f'_{c\,c}$)	MINIMUM PERMISSIBLE CEMENT CONTENT IN lb/cu yd	MINIMUM PERMISSIBLE CEMENT CONTENT IN STD. 94-lb SACKS/cu yd
2000	423	4 1/2[1]
2500	470	5[1]
3000	517	5 1/2
4000[2]	611	6 1/2

1. Where special inspection is not required under Section 1705, the minimum permissible cement content shall be increased by 1/2 sack per cubic yard of concrete.
2. For strengths above 4000 psi, see Section 1905.1.10.

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^2) 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 that will not be enclosed at a later date.
5. Where *approved* based on local site conditions.

SECTION 1908
SHOTCRETE

1908.1 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.

1908.2 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.

1908.3 Aggregate. Coarse aggregate, if used, shall not exceed $^3/_4$ inch (19.1 mm).

1908.4 Reinforcement. Reinforcement used in shotcrete construction shall comply with the provisions of Sections 1908.4.1 through 1908.4.4.

1908.4.1 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.

1908.4.2 Clearance. When No. 5 or smaller bars are used, there shall be a minimum clearance between parallel reinforcement bars of $2^1/_2$ 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.

1908.4.3 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.

1908.4.4 Spirally tied columns. Shotcrete shall not be applied to spirally tied columns.

1908.5 Preconstruction tests. Where preconstruction tests are required by Section 1908.4, 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*. Reports of preconstruction tests shall be submitted to the *building official* as specified in Section 1704.5.

1908.6 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.

1908.7 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.

1908.8 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.

1908.9 Curing. During the curing periods specified herein, shotcrete shall be maintained above 40°F (4°C) and in moist condition.

1908.9.1 Initial curing. Shotcrete shall be kept continuously moist for 24 hours after shotcreting is complete or shall be sealed with an *approved* curing compound.

1908.9.2 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.

1908.9.3 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*.

1908.10 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 $^3/_8$ 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 $^3/_8$ 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.

1908.10.1 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^3) of shotcrete.

1908.10.2 Panel criteria. When the maximum-size aggregate is larger than $^3/_8$ 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 $^3/_8$ 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 nozzlemen doing the work. The conditions under which the panels are cured shall be the same as the work.

1908.10.3 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.