

CHAPTER 19

CONCRETE

780 CMR 1901.0 CONCRETE DESIGN STANDARDS

1901.1 Reinforced and prestressed concrete: Structural members of reinforced concrete, including prestressed concrete, shall be designed and constructed in accordance with the provisions of 780 CMR19 and ACI 318 listed in *Appendix A*, hereafter referred to in 780 CMR 19 as ACI 318.

1901.2 Plain concrete: Structural members of plain concrete shall be designed and constructed in accordance with the provisions of 780 CMR 19 and ACI 318.1 listed in *Appendix A*. Concrete that is either unreinforced or contains less reinforcement than the minimum specified for reinforced concrete by ACI 318 shall be classified as plain concrete. Plain concrete shall not be used for structural members where special design considerations are required for blast forces, unless specifically approved.

780 CMR 1902.0 DEFINITIONS

1902.1 General: The following words and terms shall, for the purposes of 780 CMR 19 and as used elsewhere in 780 CMR 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 mixing to modify the properties of the concrete.

Cementitious material: A material specified in 780 CMR 1906.0 which has cementing value when used in concrete either by itself, such as portland cement or blended hydraulic cements, or when used in combination with portland cement or blended hydraulic cement, such as fly ash, raw or calcined natural pozzolans or ground-granulated blast-furnace slag.

Concrete: A mixture of portland cement or any other hydraulic cement, fine and course aggregates and water, with or without admixtures, of such proportions and manipulation as to meet specific requirements.

Concrete, reinforced: Concrete with no less reinforcement than required by 780 CMR, prestressed or nonprestressed, and designed on the assumption that the two materials act together in resisting forces (see 780 CMR 1901.1).

Member

Primary: Any member of the structural frame of a building or structure used as a column or grillage beam, or to support masonry walls and partitions, including trusses, isolated lintels spanning an opening of eight feet (2438 mm) or more, and any other member required to brace a column or a truss.

Secondary: Any member of the structural framework other than a primary member, including fill-in beams of floor systems.

780 CMR 1903.0 SEISMIC REQUIREMENTS FOR REINFORCED CONCRETE

1903.1 General: The design and construction of reinforced concrete components that resist seismic forces shall conform to the requirements of 780 CMR 1903.0 and ACI 318 except as modified by 780 CMR 1903.1.1.

1903.1.1 Modifications to ACI 318: The sections of ACI 318 shall be modified as indicated in 780 CMR 1903.1.1 items 1 through 13.

1. Modify Section 8.1.2 to read: "except where load combinations of 780 CMR 1616, including seismic forces, are used, design of nonprestressed reinforced concrete members using *Appendix A*, Alternate Design Method, is permitted."

2. Replace ACI 318 Section 9.2.3 with 780 CMR 1616.

3. Add the following definitions to Section 21.1 of ACI 318:

"Confined region: That portion of a reinforced concrete component in which the concrete is confined by closely spaced special transverse reinforcement restraining the concrete in directions perpendicular to the applied stress."

"Joint: That portion of a column bounded by the highest and lowest surfaces of the other members framing into it."

"Special transverse reinforcement: Reinforcement composed of spirals, closed stirrups, or hoops and supplementary cross ties provided to restrain the concrete and qualify the portion of the component, where used, as a confined region."

4. Replace ACI 318 Sections 21.2.1.3 and 21.2.1.4 with the requirements of 780 CMR 1903.3 through 1903.6.

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5. Modify Section 21.2.1.5 to read: "A reinforced concrete structural system not satisfying the requirements of 780 CMR 19, including those composed of precast elements, is allowed if it is demonstrated by experimental evidence and analysis that the proposed system will have strength and toughness equal to or exceeding that provided by a comparable monolithic reinforced concrete structure satisfying 780 CMR 19."

6. Add the following to the end of Section 21.2.5.1: "Post-tensioning tendons are allowed in flexural members of frames provided the average prestress (f_{pc}) calculated for an area equal to the member's shortest cross-sectional dimension multiplied by the perpendicular dimension, does not exceed 350 psi."

7. Add a new Section 21.3.2.5 to read: "For members in which prestressing tendons are used together with ASTM A706 or A615 (Grades 40 or 60) reinforcement to resist earthquake-induced forces, prestressing tendons shall not provide more than one-quarter of the strength for both positive moments and negative moments at the joint face. Anchorages for tendons shall 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% of the minimum specified strength of the tendon. Tendons shall extend through exterior joints and be anchored at the exterior face of the joint or beyond."

8. Modify Section 21.3.3.4 to read: "Where hoops are not required, stirrups with 135-degree or greater hooks with six bar diameter but not less than three-inch extensions shall be located throughout the length of the member and spaced not more than one-half the distance from the extreme compression fiber to the centroid of tension reinforcement (d)."

9. Add a new Section 21.4.4.7 to read: "At any section where the nominal strength (fP_n) of the column is less than the sum of the shear (V_c) computed in accordance with Section 21.4.5.1 for all of the beams framing into the column above the level under consideration, special transverse reinforcement shall be provided. For beams framing into opposite sides of the column, the moment components are allowed to be assumed to be of opposite sign. For determination of the nominal strength (P_n) of the column, these moments are allowed to be assumed to result from the deformation of the frame in any one principal axis."

10. Add to the end of Section 21.6.1: "A cast-in-place topping on a precast floor system is allowed to serve as a diaphragm provided that the cast-in-place topping is proportioned and detailed to

resist the design shear forces. Where untopped precast elements are used as diaphragms, the strength reduction factor (ϕ) for connections between elements shall be 0.5 except that for connection elements that form a continuous tie across and through the untopped element, extending across the diaphragm, the strength reduction factor (ϕ) shall be 0.7."

11. Modify Section 21.6.3 to read: "The design shear force (V_u) shall be obtained from the lateral load analysis in accordance with the factored loads and combinations of loads specified in 780 CMR 1616.0."

12. Renumber existing Sections 21.6.6 through 21.6.8 to Sections 21.6.7 through 21.6.9, respectively, and add a new Section 21.6.6 to read:

21.6.6 Coupling beams: A coupling beam (beam which interconnects two shear walls in their own plane) with clear-span-to-effective-depth ratio (l_n/d) of less than four and with factored shear force (V_u) exceeding shall be provided with shear reinforcement as specified in Sections 21.6.6.1 through 21.6.6.3.

21.6.6.1 Factored shear force (V_u) shall be resisted by two intersecting groups of symmetrical diagonally placed bars extending across the full length of the member and adequately anchored within the shear walls. Each group shall consist of a minimum of four bars providing an area (A_{vd}) not less than that calculated by the following formula:

$$A_{vd} = \frac{V_u}{2f_y \sin \alpha}$$

where: α is the angle between the diagonal reinforcement and the longitudinal axis of the member.

21.6.6.2 Contribution of the diagonal reinforcement to nominal flexural strength of the coupling beam shall be included.

21.6.6.3 Each group of diagonally placed bars shall be enclosed in special transverse reinforcement conforming to Sections 21.4.4.1 through 21.4.4.3. For the purpose of computing A_g in accordance with Equations 10-5 and 21-3, minimum cover as specified in Section 7.7 shall be assumed over each group of diagonally placed reinforcing bars."

13. Modify the title of Section 21.8 to read: "Requirements for Intermediate Moment Frames"

1903.2 Headed bolts and headed stud anchors in concrete: Headed bolts and headed stud anchors shall be solidly cast in concrete. The factored loads on embedded headed bolts and headed stud anchors shall not exceed the design strengths determined by 780 CMR 1903.2.2.

1903.2.1 Load factor multipliers: In addition to the load factors in 780 CMR 1616.1, a multiplier of 2 shall be used if *special inspection* is not

1903.2.2 Strength of anchors: The strength of headed bolts and headed stud anchors solidly cast in concrete shall be taken as the average of ten tests for each concrete strength and anchor size or calculated in accordance with 780 CMR 1903.2.2.1 through 1903.2.2.3. The loadbearing area of headed anchors shall be at least 1½ times the shank area for anchors of not more than 60,000 psi yield strength.

1903.2.2.1 Strength in tension: The strength of anchors in tension shall be the minimum of P_s or fP_c where:

and

$$fP_c = f\lambda (2.8A_s + 4A_t)$$

where:

A_b = Area (in square inches) of bolt or stud. Must be used with the corresponding steel properties to determine the weakest part of the assembly in tension. In shear, the insert leg is not required to be checked.

A_s = The sloping area (in square inches) of an assumed failure surface. For a single anchor or anchors in a group where the distance between anchors is equal to or greater than twice their embedment length, the surface is assumed to be that of a truncated cone radiating at a 45-degree slope from the loadbearing edge of the anchor to the surface (i.e., $A_t = 0$).

For anchors in a group where the distance between anchors is less than twice their embedment length, the failure surface is assumed to be that of a truncated pyramid radiating at a 45-degree slope from the loadbearing edge of the anchor group to the surface. Additionally, for thin sections with anchor groups, the failure surface shall assumed to follow the extension of this slope through to the far side rather than truncate as in A_t , (i.e., $A_t = 0$), and the failure mode resulting in the lower value of fP_c shall control.

A_t = The area (in square inches) of the flat bottom of the truncated pyramid of an assumed

provided, or a multiplier of 1.3 shall be used if *special inspection* is provided. Where anchors are embedded in the tension zone of a member, the load factors in 780 CMR 1616.1 shall have a multiplier of 3 if *special inspection* is not provided or of 2 if it is provided.

concrete failure surface. Where anchors in a group are closer than twice their embedment length, the failure surface pyramid is assumed to truncate at the anchor loadbearing edge rather than form separate cones.

f'_c = Specified compressive strength of concrete (psi), which shall not be taken greater than 6,000 psi.

f'_s = Ultimate tensile strength (in psi) of the bolt, stud or insert leg wires, which shall not be taken greater than 60,000 psi. For A307 bolts or A108 studs, f'_s shall be permitted to be assumed to be 60,000 psi.

P_u = Tensile strength required due to factored loads (pounds).

V_u = Shear strength required due to factored loads (pounds).

λ = One for normal-weight concrete, 0.75 for all lightweight concrete, and 0.85 for sand-lightweight concrete.

f = Strength reduction factor shall be taken as 0.65, except f is permitted to be taken as 0.85 where the anchor is attached to or hooked around reinforcing steel or otherwise terminated so as to transfer effectively forces to reinforcing steel that is designed to distribute forces and avert sudden local failure.

Where the edge distance is less than embedment length, reduce fP_c proportionately. For multiple edge distances less than the embedment length, use multiple reductions.

1903.2.2.2 Strength in shear: The strength of anchors in shear shall be the minimum of V_s or fV_c where:

and where loaded toward an edge greater than ten diameters away:

$$fV_c = f800A_b \lambda$$

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or where loaded toward an edge less than ten diameters away:

where:

d_e = Edge distance from the anchor axis to the free edge.

For groups of anchors, the concrete design shear strength shall be taken as the smallest of:

1. The strength of the weakest anchor times the number of anchors;
2. The strength of the row of anchors nearest the free edge in the direction of shear times the number of rows; or
3. The strength of the row farthest from the free edge in the direction of shear.

For shear loading toward an edge less than ten diameters away, or tension or shear not toward an edge less than four diameters away, reinforcing sufficient to carry the *load* shall be provided to prevent failure of the concrete in tension. In no case shall the edge distance be less than 3_ diameters for shear loading toward an edge, or 1_ diameters for tension or shear not toward an edge.

1903.2.2.3 Combined tension and shear:

Where tension and shear act simultaneously, both of the following shall be met:

and

1903.2.3 Special provisions for anchor bolts in tops of columns: Anchor bolts at the tops of columns shall be enclosed with not less than two #4 ties located within four inches from the top of the column. Bolts in the tops of columns shall be embedded not less than nine bolt diameters.

1903.3 Moment frames: Moment frames shall comply with 780 CMR 1903.3.1, or 1903.3.2.

1903.3.1 Intermediate moment frames: Intermediate moment frames shall comply with the requirements of Section 21.8 of ACI 318, except as follows:

1903.3.1.1 Transverse reinforcement for frame members subjected principally to bending, where the factored axial compressive force on the members do not exceed $(A_g f'_c / 10)$, shall comply with Section 21.3.3 of ACI 318.

1903.3.1.2 Transverse reinforcement for frame members subjected to bending and axial load, where the factored axial compressive force on the members exceeds $(A_g f'_c / 10)$, shall comply with Section 21.4.4 of ACI 318.

1903.3.1.3 Transverse reinforcement as specified in Section 21.4.4 of ACI 318 shall be provided within joints of frames, for the full height of the joints, except that it may be omitted over the depth of the shallowest beam where beams frame into all four sides of columns.

1903.3.1.4 Moment frames composed of two way slabs without beams shall not be used to resist lateral seismic forces. Delete Section 21.8.6 of ACI 318.

1903.3.2 Special moment frames: Special moment frames shall comply with the requirements of Sections 21.2 through 21.5 of ACI 318 as modified in 780 CMR 1903.1.1, and with the requirements of 780 CMR 1903.3.1 for intermediate moment frames.

1903.4 Seismic Performance Category C: Buildings assigned to Seismic Performance Category C shall conform to all of the requirements of ACI 318 as listed in *Appendix A* and to 780 CMR 1903.4.1, 1903.4.2 and 1903.4.3.

1903.4.1 Moment frames: All moment frames that are part of the seismic-resisting system shall be intermediate moment frames conforming to

780 CMR 1903.3.1, or special moment frames conforming to 780 CMR 1903.3.2.

1903.4.2 Discontinuous members: Columns supporting reactions from discontinuous stiff members, such as walls, shall be provided with special transverse reinforcement at the spacing (s_o) as defined in Section 21.9.5.1 of ACI 318 over their full height beneath the level at which the discontinuity occurs. This special transverse reinforcement shall be extended above and below the column as required by Section 21.4.4.5 of ACI 318.

1903.4.3 Shear walls: The design shear strength of shear walls shall be calculated as the maximum shear obtained from design load combinations which include twice the earthquake effect calculated in accordance with the provisions of 780 CMR.

1903.4.4 Shear walls in Dual Systems: Shear walls acting in combination with a moment frame in a Dual System shall conform to sections 21.2 through 21.6 in ACI 318 as modified by 780 CMR 1903.1.1.

1903.5 Seismic Performance Category D: Buildings assigned to Seismic Performance Category D shall conform to all of the requirements for Seismic Performance Category C, and to the requirements of 780 CMR 1903.5.1 through 1903.5.3.

1903.5.1 Moment frames: All moment frames that are part of the seismic-resisting system, regardless of height, shall be special moment frames conforming to 780 CMR 1903.3.2.

1903.5.2 Seismic-resisting system: All materials and components in the seismic-resisting system shall conform to Sections 21.2 through 21.6 in ACI 318, as modified by 780 CMR 1903.1.1.

1903.5.3 Frame members not proportioned to resist earthquake forces: All frame components which are not part of the seismic-resisting system shall conform to 780 CMR 1612.4.4.3.3 and to Section 21.7.1.1 or 21.7.1.2, and Section 21.7.2 of ACI 318.

780 CMR 1904.0 SEISMIC REQUIREMENTS FOR PLAIN CONCRETE

1904.1 General: The design and construction of plain concrete components that resist seismic forces shall conform to the requirements of ACI 318.1 listed in *Appendix A* except as modified by 780 CMR 1904.0.

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1904.2 Seismic Performance Category C: Structural members of plain concrete in buildings assigned to Seismic Performance Category C shall conform to the requirements of ACI 318.1 listed in *Appendix A* and the additional provisions and limitations of 780 CMR 1904.0.

1904.2.1 Footings: Plain concrete footings supporting walls shall be provided with not less than two continuous longitudinal reinforcing bars. Bars shall not be smaller than #4, and shall have a total area of not less than 0.002 times the gross cross-sectional area of the footing. Continuity of reinforcement shall be provided at corners and intersections.

1904.2.2 Pedestals: Plain concrete pedestals shall not be used to resist lateral forces due to earthquake.

1904.2.3 Walls: *Basement* and foundation walls shall be reinforced as specified in ACI 318.1 listed in *Appendix A*. Other walls shall be reinforced vertically and horizontally as required by 780 CMR 1904.2.3.1 and 1904.2.3.2.

1904.2.3.1 Vertical reinforcement: Vertical reinforcement consisting of at least one #4 bar shall be provided continuously from support to support at each corner, at each side of each opening and at ends of walls or panels.

1904.2.3.2 Horizontal reinforcement: Horizontal reinforcement consisting of at least one #4 bar shall be provided as follows:

1. At the top and bottom of each wall opening, extending not less than 24 inches (610 mm) beyond the sides of the opening; and
2. Continuously at structurally connected roofs and floors, at the top of walls, at the bottom of the wall or in the top of the foundation where the foundation is doweled to the wall, and at a maximum vertical spacing of ten feet (3048 mm).

Reinforcement at the top and bottom of wall openings shall be continuous to qualify as reinforcement required by 780 CMR 1904.2.3.2 item 2.

1904.3 Seismic Performance Category D: Structural members of plain concrete are not permitted in buildings assigned to Seismic Performance Category D.

Exceptions:

1. For occupancies in Use Group R-3 in buildings of wood frame construction, plain concrete footings without longitudinal

reinforcement supporting walls, and plain concrete column footings are permitted.

2. In all other buildings, plain concrete footings supporting walls shall be permitted provided that such footings are reinforced longitudinally as specified in 780 CMR 1904.2.1.

3. For occupancies in Use Group R-3, plain concrete foundation or *basement* walls having a thickness of not less than 7½ inches (191 mm) and retaining four feet (1219 mm) or less of unbalanced fill shall be permitted.

780 CMR 1905.0 MINIMUM SLAB THICKNESS

1905.1 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; 152 µm) polyethylene *vapor retarder* with joints lapped not less than six 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 Use 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 Use Group R-3;
3. For buildings of other use groups 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; or
5. Where approved based upon local site conditions.

780 CMR 1906.0 MATERIALS

1906.1 General: Materials used to produce concrete and admixtures for concrete shall comply with the requirements of 780 CMR 1906.0 and ACI 318.

1906.2 Cements: Cement shall conform to ASTM C150 listed in *Appendix A*, or to such other cements as listed in ACI 318.

1906.3 Aggregates: Concrete aggregates shall conform to ASTM C33 or to ASTM C330 listed in *Appendix A*.

1906.3.1 Special tests: Aggregates failing to meet the specifications listed in 780 CMR 1906.3 shall not be used unless approved and shown by special

test or actual service to produce concrete of adequate strength and durability.

1906.3.2 Nominal size: Nominal maximum size of coarse aggregate shall not be larger than:

1. $1/5$ of the narrowest dimension between sides of forms;

Exception: These limitations shall not apply where information is submitted by the engineer and is approved showing that the workability and methods of consolidation are such that concrete will be placed without honeycomb or voids.

1906.4 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 reinforcement.

1906.4.1 Chloride ions: Mixing water for prestressed concrete or for concrete that will contain aluminum embedments, including that portion of mixing water contributed in the form of free moisture on aggregates, shall not contain deleterious amounts of chloride ion (see 780 CMR 1907.1.4).

1906.4.2 Potability: Nonpotable water shall not be used in concrete unless the specific requirements of ACI 318 allowing the use of nonpotable water are satisfied.

1906.5 Metal reinforcement: Reinforcement and welding of reinforcement to be placed in concrete construction shall conform to the requirements of 780 CMR 1906.5

1906.5.1 Reinforcement Type: Reinforcement shall be of the deformed type, except for plain reinforcement used for spirals or tendons and reinforcement consisting of structural steel, steel pipe or steel tubing as specified in ACI 318. Reinforcement shall conform to the applicable ASTM standards listed in ACI 318.

1906.5.2 Welding: Reinforcing bars to be welded shall be indicated on the drawings, and the welding procedure to be used shall be specified. ASTM reinforcing bar specifications, except for ASTM A706 listed in *Appendix A*, shall be supplemented to require a report of material properties necessary to conform to welding procedures specified in AWS D1.4 listed in *Appendix A*.

1906.5.3 Tests: Where unidentified reinforcement is approved for use, not less than three tension and three bending tests shall be made on representative specimens of the reinforcement from each shipment and grade of reinforcing steel proposed for use in the work.

2. $1/4$ of the depth of slabs; nor
3. $3/4$ of the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing tendons or ducts.

1906.6 Admixtures: Admixtures used in concrete shall comply with 780 CMR 1906.6.1 through 1906.6.4.

1906.6.1 Chloride: Calcium chloride or admixtures containing chloride from other than impurities from admixture ingredients shall not be used in prestressed concrete, in concrete containing embedded aluminum, in concrete cast against stay-in-place galvanized metal forms, or in concrete to be exposed to severe or very severe sulfate-containing solutions as defined in ACI 318 (see 780 CMR 1907.1.3 and 1907.1.4).

1906.6.2 Standards: Air-entraining admixtures shall conform to ASTM C260 listed in *Appendix A*. Water-reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and retarding admixtures, and water-reducing and accelerating admixtures shall conform to ASTM C494 listed in *Appendix A*.

1906.6.3 Pozzolans: Fly ash or other pozzolans used as admixtures shall conform to ASTM C618 listed in *Appendix A*.

1906.6.4 Blast-furnace slag: Ground-granulated blast-furnace slag used as an admixture shall conform to ASTM C989 listed in *Appendix A*.

1906.7 Tests of materials: Tests of concrete and the materials used in concrete shall be in accordance with ACI 318.

780 CMR 1907.0 DURABILITY REQUIREMENTS

1907.1 Durability requirements: Where concrete is exposed to special conditions as described in 780 CMR 1907.1.1 through 1907.1.5, the requirements set forth in 780 CMR 1907.1.1 through 1907.1.5 shall be met.

1907.1.1 Freezing and thawing and deicer chemicals: Normal weight and lightweight concrete exposed to freezing and thawing or deicer chemicals shall be air entrained with the air content indicated in Table 1907.1.1. Tolerance on air content as delivered shall be $\pm 1.5\%$. For a specified compressive strength (f'_c) greater than 5,000 psi (34475 kPa), the required air content indicated in Table 1907.1.1 shall be reduced by

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1%. Where finely divided materials of fly ash or natural pozzolans are used as mineral admixtures (see 780 CMR 1906.6.3) in air-entrained portland cement concrete, air content tests shall be made in accordance with ASTM C231 listed in *Appendix A*, to assure compliance with the air content requirements of Table 1907.1.1. The frequency of air content tests shall be the same as that for strength tests required by 780 CMR 1908.3.1.

**Table 1907.1.1
TOTAL AIR CONTENT FOR FROST-
RESISTANT CONCRETE**

Nominal maximum aggregate size ^b (inches)	Air content, percent	
	severe ^a exposure	Moderate ^a exposure
1/2	7 1/2	6
3/4	7	5 1/2
1	6	5
1 1/2	6	4 1/2
2 ^c	5 1/2	4 1/2
3 ^c	5	4
	4 1/2	3 1/2

Note a. The severe and moderate exposures referenced in this table are not based upon the weathering regions shown in figure 1907.1.2. For the purposes of 780 CMR 1907, severe and moderate exposures shall be defined as follows:

Severe exposure occurs when 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.

Moderate exposure occurs when 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.

Note b. See ASTM C33 listed in *Appendix A* for oversize tolerances for various nominal maximum size designations.

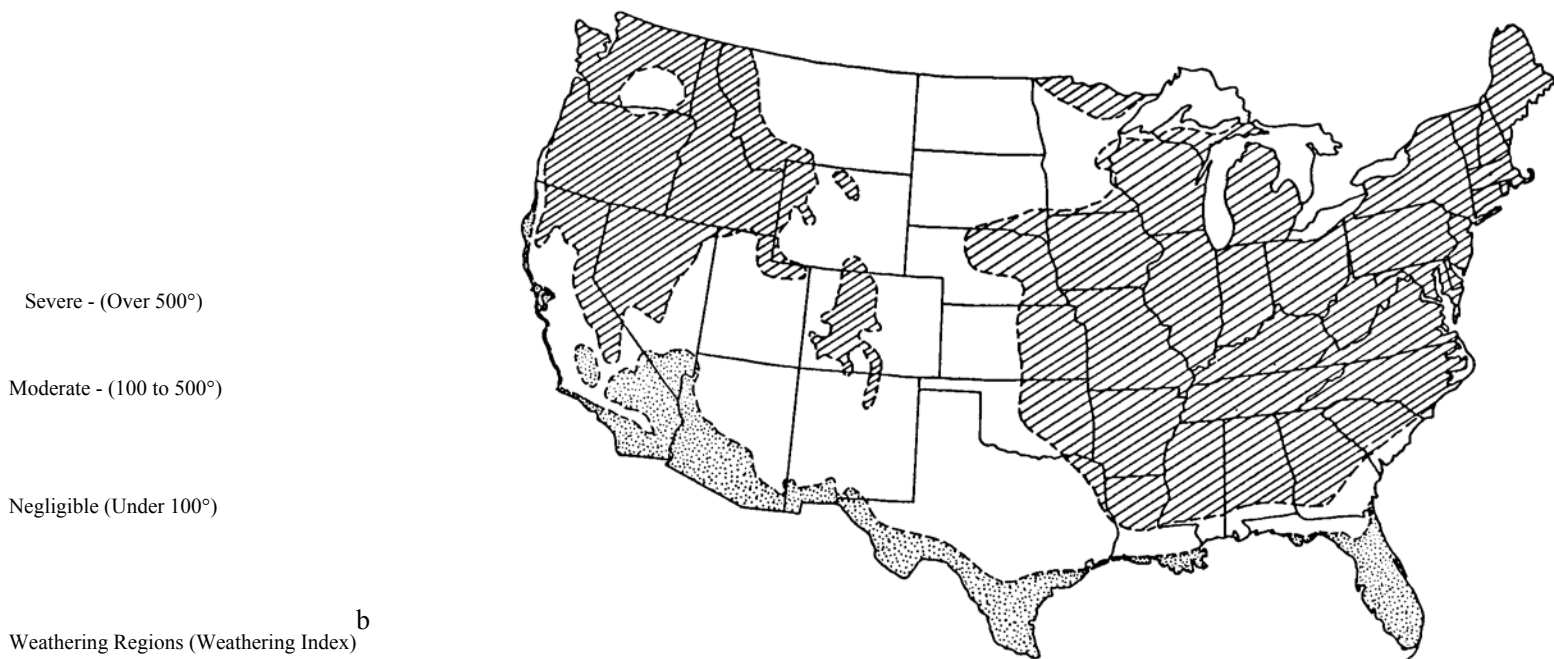
Note c. These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than

1 1/2 inches is removed by handpicking or sieving and air content is determined on the minus-1 1/2-inch fraction of mix. (Tolerance on air content as delivered applies to this value.) Air content of the total mix is computed from the value determined on the minus-1 1/2-inch fraction.

1907.1.2 Water-cementitious material ratio and strength:

For occupancies and appurtenances thereto in Use Group R-3, and occupancies in Use Group R-2 that are in buildings less than four stories in *height*, normal-weight aggregate concrete that is subject to weathering (freezing and thawing), as determined from Figure 1907.1.2, or deicer chemicals shall comply with the requirements of Table 1907.1.2(1). In all other buildings, concrete that is intended to have a low permeability to water, or concrete that will be subject to freezing and thawing in a moist condition or that will be exposed to deicing salts, brackish water, sea water or spray from these sources, shall conform to the requirements of Table 1907.1.2(2). Additionally, concrete that will be exposed to deicing chemicals shall conform to the limitations of 780 CMR 1907.1.2.2.

**Figure 1907.1.2
Weathering Probability Map for Concrete^a**



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Note a. Lines defining areas are approximate only. Local conditions can be more or less severe than indicated by the region classification.

Note b. Data needed to determine the weathering index for any locality can be found or estimated from the *Tables of Local Climatological Data*, published by the National Oceanic & Atmospheric Administration, U.S. Department of Commerce.

Table 1907.1.2(1)
MINIMUM SPECIFIED COMPRESSIVE
STRENGTH (f'_c)^c

Type of location of concrete construction	Minimum specified compressive strength (f'_c at 28 days, psi)		
	Negligible exposure	Moderate exposure	Severe exposure
Basement walls and foundations not exposed to the weather	2,500	2,500	2,500 ^a
Basement slabs and interior slabs on grade, except garage floor slabs	2,500	2,500	2,500 ^a
Basement walls, foundation walls, exterior walls and other vertical concrete surfaces exposed to the weather	2,500	3,000 ^b	3,000 ^b
Driveways, curbs, walks, patios, porches, carport slabs, steps and other flat-work exposed to the weather, and garage floor slabs	2,500	3,000 ^b	3,500 ^b

Note a. Concrete in these locations which can be subjected to freezing and thawing during construction shall be of air-entrained concrete in accordance with Table 1907.1.1.

Note b. Concrete shall be air entrained in accordance with Table 1907.1.1.

Note c. 1 psi = 6.895 kPa.

Table 1907.1.2(2)
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) ^a
Concrete intended to have low permeability when exposed to water	0.50	4,000
Concrete exposed to freezing and thawing in a moist condition	0.45	4,500
For corrosion protection for reinforced concrete exposed to deicing salts, brackish water, sea-water or spray from these sources	0.40	5,000

Note a. 1 psi = 6.895 kPa.

1907.1.2.1 Calculation of water-cementitious material ratio: To determine compliance with the maximum water-cementitious material ratio requirement of Table 1907.1.2(2), the weight

of cementitious material shall include weights of any of the following if contained in the concrete mixture: cement conforming to the requirements of ASTM C150 or C595; fly ash or other pozzolan conforming to the requirements of ASTM C618; and ground-granulated blast-furnace slag conforming to the requirements of ASTM C989 listed in *Appendix A*.

1907.1.2.2 Limitations on use of certain cementitious materials: For concrete exposed to deicing chemicals, the maximum weight of fly ash or other pozzolan, or ground granulated blast-furnace slag that is included in the calculation of water-cementitious material ratio, shall not exceed the percentages of the total weight of cementitious material specified in 780 CMR 1907.1.2.2.1 through 1907.1.2.2.3.

1907.1.2.2.1 Concrete containing fly ash or pozzolan: The combined weight of fly ash and other pozzolan conforming to ASTM C618 listed in *Appendix A* shall not exceed 25% of the total weight of cementitious materials. Fly ash or other pozzolan used to manufacture Type IP or IPM blended hydraulic cement conforming to ASTM C595 listed in *Appendix A* shall be included with fly ash or other pozzolan added as an admixture.

1907.1.2.2.2 Concrete containing ground-granulated blast-furnace slag: The weight of ground-granulated blast-furnace slag conforming to ASTM C989 listed in *Appendix A* shall not exceed 50% of the total weight of cementitious materials. Slag used to manufacture Type IS or ISM blended hydraulic cement conforming to ASTM C595 listed in *Appendix A* shall be included with slag added as an admixture.

1907.1.2.2.3 Concrete containing fly ash or pozzolan and slag: If fly ash or other pozzolan and slag are used in concrete, portland cement conforming to ASTM C150 listed in *Appendix A* shall constitute not less than 50% of the total weight of cementitious materials. Fly ash or other pozzolan shall constitute not more than 25% of the total weight of cementitious materials. See 780 CMR 1907.1.2.2.1.

1907.1.3 Protection from sulfate: Concrete that will be exposed to sulfate-containing solutions or soils shall conform to the requirements for such exposure in ACI 318.

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1907.1.4 Corrosion resistance: For corrosion resistance, the maximum water-soluble chloride

ion concentrations in concrete shall not exceed the limitations established in ACI 318.

1907.1.5 Protection from salt: Where reinforced concrete will be exposed to deicing chemicals, salts, brackish water, sea water or spray from these sources, the requirements of Table 1907.1.2(2) for the water-cementitious material ratio, or the concrete strength and minimum concrete cover requirements of 780 CMR 1910.6, shall be satisfied.

	concrete	Absolute ratio by weight	US gallon per 94 pound bag of cement	Absolute ratio by weight	US gallon per 94 pound bag of cement
2,500	5	0.67	7.6	0.54	6.1
3,000	5½	0.58	6.6	0.46	5.2
3,500	6	0.51	5.8	0.40	4.5

780 CMR 1908.0 CONCRETE QUALITY, MIXING AND PLACING

Note a. 1 psi = 6.895 kPa; 1 gallon = .00379 m³; 1 pound = 0.454 kg.

1908.1 General: Concrete shall be proportioned to provide an average compressive strength as prescribed by ACI 318, and to satisfy the durability criteria of 780 CMR 1907.0. Concrete shall be produced to minimize frequency of strengths below f'_c as prescribed in 780 CMR 1908.3.2. The specified compressive strength (f'_c) for concrete designed and constructed in accordance with this chapter shall not be less than 2,500 psi (17238 kPa).

1908.2.2 Limitation on use: Table 1908.2.1 shall be used only for concrete to be made with cements conforming to the strength requirements for Type I, IA, II, IIA, III, IIIA or V of ASTM C 150 listed in *Appendix A* or Type IS, IS-A, IS(MS), IS-A(MS), I(SM), I(SM)-A, IP, IP-A, I(PM), I(PM)-A, IP(MS), IP-A(MS) or P of ASTM C595 listed in *Appendix A* and shall not be applied to concrete containing lightweight aggregates or admixtures other than those for entraining air.

Unless otherwise specified, f'_c shall be based on 28-day strength. If other than 28 days is used in the design, the length of time to reach f'_c shall be indicated on the *construction documents*.

1908.2.3 Durability requirements: Concrete proportioned by the water-cementitious material ratio limitations prescribed in Table 1908.2.1 shall also conform to the durability requirements of 780 CMR 1907.0 and to compressive strength test criteria of 780 CMR 1908.3.

1908.2 Selection of concrete proportions: Concrete proportions shall be determined in accordance with ACI 318 and as modified in 780 CMR 1908.

1908.3 Evaluation for acceptance of concrete: For evaluation and acceptance of concrete, the procedures established in 780 CMR 1908.3.1 through 1908.3.4 shall be followed.

1908.2.1 Proportioning by water-cementitious material ratio: If data based on field experience or trial mixture as required by ACI 318 are not available, concrete proportions shall be based on the water-cementitious material ratio limitations shown in Table 1908.2.1, subject to approval. The specified compressive strengths in Table 1908.2.1 are 28-day strengths for cements conforming to the strength limitations of ASTM C150 listed in ACI 318, Type I, IA, II or IIA and seven-day strengths for Types III and IIIA. For strengths above 3,500 psi (24133 kPa), concrete proportioned by the water-cementitious material ratio shall be established by the methods listed in ACI 318.

1908.3.1 Frequency of testing: Testing shall be conducted as required by the following:

1. 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 150 cubic yards (115 m³) of concrete, nor less than once for each 5,000 square feet (465 m²) of surface area for slabs or walls.
2. On a given project, if the total volume of concrete is such that the frequency of testing required by 780 CMR 1908.3.1, item 1, provides 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.
3. Where total quantity of a given class of concrete is less than 50 cubic yards (38 m³), strength tests are not required when approved and evidence of satisfactory strength is provided. Satisfactory evidence shall include, but not be limited to, certification from the

**Table 1908.2.1
MAXIMUM WATER-CEMENTITIOUS MATERIAL RATIOS AND MINIMUM CEMENT CONTENTS**

Specified compressive strength ^a (psi)	Minimum sacks of cement per cubic yard of	Maximum permissible water-cementitious material ratios ^a	
		Nonair-entrained concrete	Air-entrained concrete

concrete supplier that the concrete to be provided will be proportioned to achieve the specified compressive strength based on "field experience" or "trial batches" in accordance with ACI 318. In the absence of satisfactory evidence, concrete shall be proportioned in accordance with Table 1908.2.1.

4. A strength test shall be the average of the strengths of two cylinders made from the same

2. Cylinders for strength tests shall be molded and laboratory cured in accordance with ASTM C31 listed in *Appendix A*, and tested in accordance with ASTM C39 listed in *Appendix A*.

3. Strength level of an individual class of concrete shall be considered satisfactory if both of the following requirements are met:

3.1. Average of all sets of three consecutive strength tests equals or exceeds f'_c ; and

3.2. All individual strength tests (average of two cylinders) shall not fall below f'_c by more than 500 psi (3448 kPa).

4. If either of the requirements of 780 CMR 1908.3.2, item 3, is not met, steps shall be taken to increase the average of subsequent strength test results. The requirements of 780 CMR 1908.3.4 shall apply if the requirement in 780 CMR 1908.3.2, item 3.2, is not met.

1908.3.3 Field-cured specimens: Where the code official requires strength tests of cylinders cured under field conditions to check adequacy of curing and protection of concrete in the structure, the field-cured specimens shall conform to the following criteria:

1. Field-cured cylinders shall be cured under field conditions in accordance with ASTM C31 listed in *Appendix A*.

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

3. Procedures for protecting and curing concrete shall be improved where the strength of field-cured cylinders at the test age designated for determination of f'_c is less than 85% of that of companion laboratory-cured cylinders. The 85% criterion is not required where the field-cured strength exceeds f'_c by more than 500 psi (3448 kPa).

1908.3.4 Investigation of low-strength test results: If the investigation of concrete indicates low-strength conditions, the following procedures shall apply:

1. If any strength test (see 780 CMR 1908.3.1, item 4) of laboratory-cured cylinders falls below the specified value of f'_c by more than 500 psi (3448 kPa) (see 780 CMR 1908.3.2,

sample of concrete and tested at 28 days or at the test age designated for determination of f'_c

1908.3.2 Laboratory-cured specimens: Laboratory-cured specimens shall conform to the following criteria:

1. Samples for strength tests shall be taken in accordance with ASTM C172 listed in *Appendix A*.

item 3.2) or if tests of field-cured cylinders indicate deficiencies in protection and curing (see 780 CMR 1908.3.3, item 3), steps shall be taken to assure that the loadbearing capacity of the structure is not jeopardized.

2. If the likelihood of low-strength concrete is confirmed and computations indicate that the loadbearing capacity will be significantly reduced, tests of cores drilled from the area in question shall be made in accordance with ACI 318.

3. Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is not less than 85% of f'_c and if a single core is not less than 75% of f'_c . Where necessary to check testing accuracy, locations represented by erratic core strengths shall be retested.

4. If the criteria of 780 CMR 1908.3.4, item 3, are not met, and if structural adequacy remains in doubt, load tests shall be ordered at the discretion of the engineer or the code official as outlined in Chapter 20 of ACI 318 for the questionable portion of the structure, or other appropriate action taken.

1908.4 Preparation of equipment and place of deposit: Preparation before concrete placement shall include the following criteria:

1. All equipment for mixing and transporting concrete shall be clean.

2. All 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 coating.

6. Water shall be removed from the place of deposit before concrete is placed, unless a extreme is to be used or unless otherwise approved by the code official.

7. All laitance and other unsound material shall be removed before additional concrete is placed against hardened concrete.

1908.5 Mixing: All concrete shall be mixed until there is a uniform distribution of materials, and shall be discharged completely before the mixer is recharged.

1908.5.1 Ready-mixed concrete: Ready-mixed concrete shall be mixed and delivered in accordance with ASTM C94 or ASTM C685 listed in *Appendix A*.

1908.5.2 Job-mixed concrete: Job-mixed concrete shall be mixed in accordance with ACI 318.

1908.6 Conveying: Concrete shall be conveyed from the mixer to the place of final deposit by methods that will prevent separation or loss of materials. Conveying equipment shall be capable of providing a supply of concrete at the site of

1908.7.2 Unacceptable concrete: Concrete that has partially hardened or has been contaminated by foreign materials shall not be deposited in the structure.

1908.7.3 Retempering: Retempered concrete or concrete that has been remixed after initial set shall not be used unless approved by the *registered design professional*.

1908.7.4 Continuous concreting: Once started, concreting shall be carried on as a continuous operation until the placement of a panel or section, as defined by panel or section boundaries or predetermined joints, is completed except as provided for in 780 CMR 1909.4.

1908.7.5 Placement in walls: Top surfaces of vertically formed lifts shall be generally level.

1908.7.6 Construction joints: Where construction joints are required, such joints shall be made in accordance with 780 CMR 1909.4.

1908.7.7 Consolidation: All concrete shall be thoroughly consolidated by suitable means during placement and shall be thoroughly worked around reinforcement and embedded fixtures and into corners of forms.

1908.8 Curing: 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 780 CMR 1908.8.2.

1908.8.1 High-early-strength concrete: High-early-strength concrete shall be maintained above 50°F (10°C) and in a moist condition for at least the first three days after placement, except when cured in accordance with 780 CMR 1908.8.2.

1908.8.2 Accelerated curing: If curing is to be accelerated, such curing shall be done in accordance with ACI 318.

placement without separation of ingredients and without interruptions sufficient to permit loss of plasticity between successive increments.

1908.7 Depositing: Concrete shall be deposited as nearly as practicable in its final position to avoid segregation caused by rehandling or flowing.

1908.7.1 Placement timing: Concrete placement shall be carried on at such a rate that the concrete is at all times plastic and flows readily into spaces between reinforcement.

1908.9 Cold-weather requirements: Adequate equipment shall be provided for heating concrete materials and protecting concrete during freezing or near-freezing weather.

1908.9.1 Frost: All concrete materials and all reinforcement, forms, fillers and ground with which concrete is to come in contact shall be free from frost.

1908.9.2 Ice: Frozen materials or materials containing ice shall not be used.

1908.10 Hot-weather requirements: During hot weather, attention shall be given to ingredients, production methods, handling, placing, protection and curing to prevent excessive concrete temperatures or water evaporation that would impair required strength or serviceability of the member or structure.

780 CMR 1909.0 FORMWORK, EMBEDDED PIPES AND CONSTRUCTION JOINTS

1909.1 Design of formwork: The design, fabrication and erection of forms shall result in a final structure that conforms to shapes, lines and dimensions of the members as required by the *construction documents*.

1909.1.1 Form strength: Forms shall be substantial and shall be sufficiently tight to prevent leakage of concrete.

1909.1.2 Form bracing: Forms shall be properly braced or tied together to maintain position and shape.

1909.1.3 Form placement: Forms and their supports shall be designed so as not to damage previously placed structures.

1909.2 Removal of forms and shores: Construction loads shall not be supported on, nor any shoring

removed from, any part of the structure under construction except where that portion of the structure, in combination with the remaining forming and shoring system, has sufficient strength to support safely its weight and *loads* placed thereon.

1909.2.1 Structural analysis: Sufficient strength shall be demonstrated by structural analysis considering proposed *loads*, strength of the forming and shoring system, and concrete strength data. Concrete strength data shall be based on tests of field-cured cylinders or, where approved, on other procedures to evaluate concrete strength. Structural analysis and concrete-strength test data shall be furnished to the code official when so required.

1909.2.2 Construction loads: Construction *loads* exceeding the combination of superimposed *dead load* plus specified *live load* shall not be

1909.3 Conduits and pipes embedded in concrete: Where conduits, pipes and sleeves of any material not harmful to concrete and within limitations of 780 CMR 1909 are embedded in concrete with the approval of the engineer, such embedments shall not be considered to replace structurally the displaced concrete, except as provided for in 780 CMR 1909.3.5.

1909.3.1 Aluminum conduit and pipe: Conduits and pipes of aluminum shall not be embedded in structural concrete unless effectively coated or covered to prevent aluminum concrete reaction or electrolytic action between aluminum and steel.

1909.3.2 Structural effect: Conduits, pipes and sleeves passing through a slab, wall or beam shall not impair significantly the strength of the construction.

1909.3.3 Columns: Conduits and pipes, including fittings, embedded within a column, shall not displace more than 4% of the area of the cross section on which strength is calculated or which is required for fire protection.

1909.3.4 Slabs, walls or beams: Except where *construction documents* for conduits and pipes are approved by the *registered design professional* and the code official, conduits and pipes embedded within a slab, wall or beam (other than those merely passing through) shall:

1. Not be larger in outside dimension than $\frac{1}{4}$ of the overall thickness of the slab, wall or beam in which such conduits and pipes are embedded.
2. Not be spaced closer than three diameters or widths on center.
3. Not impair significantly the strength of the construction.

supported on any unshored portion of the structure under construction, unless analysis indicates adequate strength to support such additional *loads*.

1909.2.3 Safety: Forms shall be removed in such a manner so as not to impair safety and serviceability of the structure. All concrete to be exposed by form removal shall have sufficient strength not to be damaged thereby.

1909.2.4 Prestressed members: Form supports for prestressed concrete members shall not be removed unless sufficient prestressing has been applied to enable prestressed members to carry their *dead load* and anticipated construction *loads*.

1909.3.5 Displaced concrete: Conduits, pipes and sleeves shall not be considered in compression as replacing structurally the displaced concrete unless such conduits, pipes and sleeves:

1. Are not exposed to rusting or other deterioration.
2. Are of uncoated or galvanized iron or steel not thinner than standard Schedule 40 steel pipe.
3. Have a nominal inside diameter not over two inches and are spaced not less than three diameters on center.

1909.3.6 Additional considerations: In addition to the other requirements of 780 CMR 1909.3, pipes that will contain liquid, gas or vapor which are embedded in structural concrete shall conform to the following conditions:

1. Pipes and fittings shall be designed to resist effects of the material, pressure and temperature to which the pipes and fittings will be subjected.
2. Liquid, gas or vapor except water not exceeding 90°F (32°C) or 50 psi (345 kPa) pressure, shall not be placed in the pipes until the concrete has attained design strength.
3. In solid slabs, piping that is not used for radiant heating or snow melting shall be placed between top and bottom reinforcement.
4. Concrete cover for pipes, conduit and fittings shall not be less than 1½ inches (38 mm) for concrete exposed to earth or weather conditions or ¾ inch (19 mm) for concrete not exposed to weather conditions or in contact with ground.
5. Reinforcement with an area of not less than 0.002 times the area of the concrete section shall be provided normal to piping.

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6. Piping and conduit shall be fabricated and installed so that cutting, bending or displacement of reinforcement from the proper location will not be required.

1909.4 Construction joints: Construction joints shall be created using the procedures set forth in 780 CMR 1909.4.1 through 1909.4.6.

1909.4.1 Surface cleaning: Surface of concrete construction joints shall be cleaned and laitance removed.

1909.4.2 Preparation of joint: Immediately before new concrete is placed, all construction joints shall be wetted and standing water shall be removed.

1909.4.3 Effect on strength: Construction joints shall be so made and located as not to impair the strength of the structure. Provisions shall be made for the transfer of shear and other forces through construction joints.

1909.4.4 Location of joints: Construction joints in floors shall be located within the middle third of the spans of slabs, beams and girders. Joints in girders shall be offset a minimum distance of two times the width of intersecting beams.

1909.4.5 Support conditions: Beams, girders or slabs supported by columns or walls shall not be cast or erected until concrete in the vertical support members is not in a plastic state.

1909.4.6 Monolithic pours: Beams, girders, haunches, drop panels and capitals shall be placed monolithically as part of a slab system, unless otherwise shown on the *construction documents*.

780 CMR 1910.0 DETAILS OF REINFORCEMENT

1910.1 General: Details of reinforcement shall comply with the requirements of 780 CMR 1910.0 and ACI 318. Where unidentified reinforcement is approved for use, such reinforcement shall be tested in accordance with the following:

Not less than three tension and three bending tests shall be made on representative specimens of the reinforcement from each shipment and grade of reinforcing steel proposed for use in the project.

1910.2 Bending reinforcement: All reinforcement shall be bent cold, unless otherwise permitted by the *registered design professional* and approved. Reinforcement partially embedded in concrete shall

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not be field bent, except as shown on the construction documents or as authorized by the *registered design professional* and approved.

1910.3 Surface conditions of reinforcement: At the time concrete is placed, metal reinforcement shall be free from mud, oil or other nonmetallic coatings that adversely affect bonding capability.

1910.3.1 Rust or mill scale: Metal reinforcement, except prestressing tendons, with rust or mill scale, or a combination of both, shall be considered satisfactory, provided that the minimum dimensions (including height of deformations) and the weight of a hand-wire-brushed test specimen are not less than the specification requirements of the applicable ASTM standard referenced by ACI 318.

1910.3.2 Prestressing tendons: Prestressing tendons shall be clean and free of oil, dirt, scale, pitting and excessive rust. A light oxide is permissible.

1910.4 Placing reinforcement: Reinforcement, prestressing tendons and ducts shall be accurately placed and supported before concrete is placed, and shall be secured against displacement within the tolerances permitted in 780 CMR 1910.4.1 through 1910.4.3.

Exception: Embedded items (such as dowels or inserts) of precast concrete members that either protrude from concrete or remain exposed for inspection shall not be embedded while the concrete is in a plastic state unless authorized by the *registered design professional* and the following conditions are met:

1. Embedded items are not required to be hooked or tied to reinforcement.
2. Embedded items shall be maintained in the correct position while concrete remains plastic.
3. Embedded items shall be properly anchored to develop required factored *loads*.

1910.4.1 Reinforcement, prestressing tendons and prestressing ducts: Unless otherwise specified by the engineer, reinforcement, prestressing tendons and prestressing ducts shall be placed within the following tolerances:

1. The tolerance for depth (*d*) and the minimum concrete cover in flexural members, walls and compression members shall be as specified in Table 1910.4.1, except that the tolerance for the clear distance to formed soffits shall be minus ¼ inch (6 mm) and the tolerance for cover shall not exceed minus one-third of the minimum concrete cover required in the design drawings or specifications.
2. The tolerance for longitudinal location of bends and ends of reinforcement shall be ± 2

inches (51 mm) except at discontinuous ends of members where the tolerance shall be ½ inch (13 mm).

**Table 1910.4.1
TOLERANCES^a**

Depth (<i>d</i>)	Tolerance on <i>d</i>	Tolerance on <i>d</i> minimum concrete cover
<i>d</i> less than or equal to 8 inches	$\pm \frac{1}{8}$ inch	$-\frac{1}{8}$ inch
<i>d</i> greater than 8 inches	$\pm \frac{1}{2}$ inch	$-\frac{1}{2}$ inch

Note a. 1 inch = 25.4 mm

1910.4.2 Welded wire fabric: Where welded wire fabric (with wire size not greater than W5 or D5) used in slabs not exceeding ten feet (3048 mm) in span is curved from a point near the top of slab over the support to a point near the bottom of slab at midspan, such reinforcement shall be either continuous over, or securely anchored at, the support.

1910.4.3 Welding: Welding of crossing bars shall not be permitted for assembly of reinforcement unless authorized by the engineer.

1910.5 Spacing limitations for reinforcement: The clear distance between reinforcing bars, bundled bars, prestressing tendons and ducts shall be in accordance with the limitations of ACI 318.

1910.6 Concrete protection for reinforcement: Reinforcement shall be provided with the protection required by 780 CMR 1910.6.1 through 1910.6.5.

1910.6.1 Cast-in-place concrete: In cast-in-place concrete (nonprestressed), the minimum concrete cover for reinforcement shall be as indicated in Table 1910.6.1.

**Table 1910.6.1
MINIMUM COVER**

Structural element and condition	Minimum cover (inches) ^a
1. Concrete cast against and permanently exposed to earth	3
2. Concrete exposed to earth or weather: #6 through #18 bars #5 bar, W31 or D31 wire and smaller	2 1½
3. Concrete not exposed to weather or in contact with ground Slabs, walls, joists #14 and #18 bars #11 bar and smaller	1½ ¾
Beams, columns: Primary reinforcement, ties, stirrups, spirals	1½

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Shells, folded plate members:	3/4
#6 bar and larger	
#5 bar, W31 or D31 wire, and smaller	1/2

1910.6.2 Precast concrete: The minimum cover for reinforcement in precast concrete manufactured under plant control conditions and for prestressed concrete shall be in accordance with ACI 318.

1910.6.3 Corrosive environments: In corrosive environments or other severe conditions, the amount of concrete protection shall be suitably increased, and the density and nonporosity of protection concrete shall be considered, or other protection shall be provided.

1910.6.4 Future extensions: Exposed reinforcement, inserts and plates intended for bonding with future extensions shall be protected from corrosion.

1910.6.5 Fire protection: Where this code requires a thickness of cover for fire protection greater than the minimum concrete cover specified in 780 CMR 1910.6.1 or ACI 318, such greater thickness shall be used.

780 CMR 1911.0 SHOTCRETE

1911.1 General: Except as specified in 780 CMR 911.0, shotcrete shall conform to the requirements for plain concrete or reinforced concrete. Shotcrete is mortar or concrete which is pneumatically projected at a high velocity onto a surface.

1911.2 Proportioning: Shotcrete proportions shall be selected that allow suitable placement procedures using the delivery equipment selected, and that results in in-place hardened shotcrete conforming to the strength requirements of 780 CMR.

1911.3 Aggregate: Coarse aggregate, if used, shall not exceed 3/4 inch (19 mm) in size.

1911.4 Reinforcement: Reinforcement shall comply with 780 CMR 1911.4.1 through 1911.4.3.

1911.4.1 Size: The maximum size of reinforcement shall be No. 5 bars. The code official shall approve the use of larger bars where it is demonstrated that adequate encasement of the larger bars will be achieved.

1911.4.2 Spacing: The minimum clearance between parallel reinforcing bars shall be 2 1/2 inches (64 mm). Welded wire fabric shall have a minimum wire spacing of two inches (51 mm) by two inches (51 mm).

Note a. 1 inch = 25.4 mm.

1911.4.3 Splices: Lap splices of reinforcing bars shall be by the noncontact lap-splice method with at least two inches (51 mm) of clearance between bars. The code official shall permit the use of contact lap splices where necessary for the support of the reinforcing and provided that it is demonstrated that adequate encasement of the bars at the splice will be achieved.

1911.5 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 reused as aggregate.

1911.6 Joints: Except where permitted herein, unfinished work shall not be allowed to stand for more than 30 minutes unless all edges are sloped to a thin edge. For structural elements which 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.

1911.7 Damage: Shotcrete that exhibits sags, sloughs, segregation, honeycombing, sand pockets or other obvious defects, shall be removed and replaced.

1911.8 Curing: During the curing periods specified herein, shotcrete shall be maintained above 40°F (4°C) and in a moist condition.

1911.8.1 Initial curing: Shotcrete shall be kept continuously moist for 24 hours after shotcreting is completed or shall be sealed with an approved curing compound.

1911.8.2 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.

1911.8.3 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%, and is authorized by the *registered design professional*, and approved by the code official.

1911.9 Strength test: A strength test of shotcrete shall be made in accordance with the quality assurance provisions of ACI 506.2 listed in *Appendix A*.

**780 CMR 1912.0 CONCRETE-FILLED
PIPE COLUMNS**

1912.1 General: Concrete-filled pipe columns shall be manufactured from standard, extra-strong or

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: All 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 insure 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 insure the composite action of the section, but not nearer than one inch (25 mm) to the exterior steel shell. All structural shapes used as reinforcement shall be milled to insure bearing on cap and base plates.

1912.5 Fireresistance rating protection: Pipe columns shall be of such size or so *protected* as to develop the required fireresistance ratings specified

double-extra-strong steel pipe or tubing which is filled with concrete so placed and manipulated as to secure maximum density and to insure complete filling of the pipe without voids.

in Table 602. Where an outer steel shell is used to enclose the fireresistive covering, the shell shall not be included in the calculations for strength of the column section. The minimum diameter of pipe columns shall be four inches (102 mm) except that in structures of Type 5 construction not exceeding three stories or 40 feet (12192 mm) in *height*, pipe columns used in the basement and as secondary steel members shall have a minimum diameter of three inches (76 mm).

1912.6 Approvals: All 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 code official or by an approved representative of the manufacturer at the plant.

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