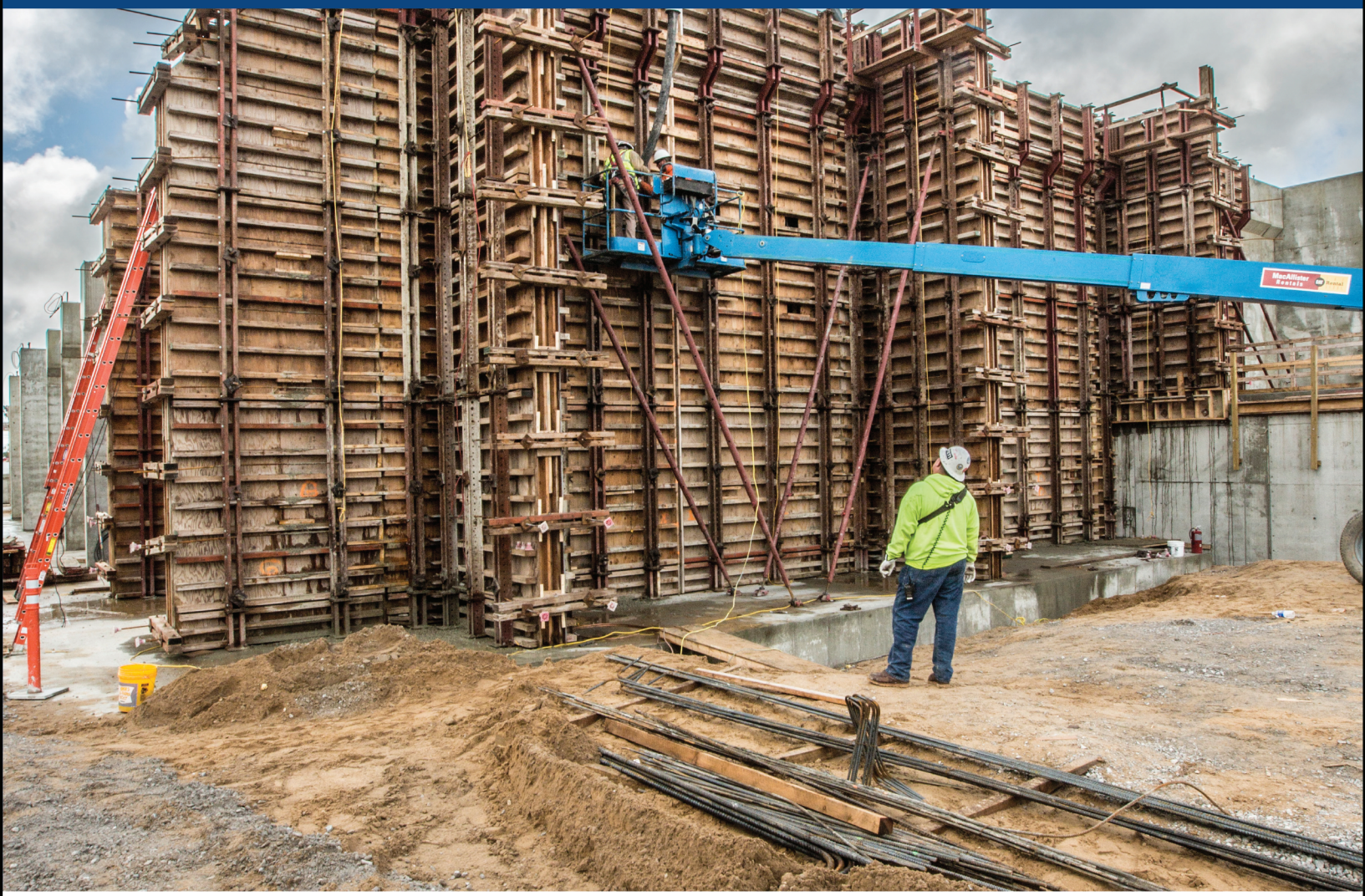


An ACI Manual

Field Reference Manual

ACI 301-20 Specifications for Concrete Construction with Selected ACI References



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FIELD REFERENCE MANUAL

Specifications for Concrete Construction

ACI 301-20

with selected ACI references

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ACI 301-20

Specifications for Concrete Construction

An ACI Standard

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This is a Reference Specification that the Architect/Engineer can apply to projects involving concrete construction by citing it in the Project Specification. A mandatory requirements checklist and an optional requirements checklist are provided to assist the Architect/Engineer in supplementing the provisions of this Specification as required or needed by designating or specifying individual project requirements.

The first five sections of this Specification cover general requirements for concrete construction. These sections cover materials and proportioning of concrete; reinforcement and prestressing steel; production, placing, finishing, and curing of concrete; formwork performance criteria and construction; treatment of joints; embedded items; repair of surface defects; and finishing of formed and unformed surfaces. Provisions governing testing, evaluation, and acceptance of concrete as well as acceptance of the structures are included. The remaining sections are devoted to architectural concrete, lightweight concrete, mass concrete, post-tensioned concrete, shrinkage-compensating concrete for interior slabs, industrial floor slabs, tilt-up construction, precast structural concrete, and precast architectural concrete.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certification or equivalent.

Keywords: architectural concrete; cold weather; compressive strength; consolidation; curing; durability; finish; formwork; grouting; hot weather; industrial floors; inspection; joints; lightweight concrete; mass concrete; mixture proportions; placing; post-tensioned concrete; precast concrete; prestressing steel; repair; reshoring; shoring; shrinkage-compensating concrete; slabs-on-ground; steel reinforcement; testing; tilt-up; tolerance; welded wire reinforcement.

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SECTION 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 This Specification covers construction of cast-in-place concrete, architectural concrete, lightweight concrete, mass concrete, post-tensioned concrete, shrinkage-compensating concrete for interior slabs, industrial floor slabs cast on ground, tilt-up construction, precast structural concrete, and precast architectural concrete.

1.1.2 Unless otherwise specified, Sections 1 through 5 apply to Work where this Specification is referenced. Work covered by Sections 6 through 14 apply only if that Work is designated in Contract Documents.

1.1.3 This Specification is incorporated by Contract Documents and provides requirements for Contractor.

1.1.4 This Specification governs for construction within its scope. If there are differences between requirements of this Specification and project-specific Contract Documents, project-specific Contract Documents govern.

1.1.5 Use shotcrete as designated in Contract Documents.

1.1.6 *Work not specified*—The following Work is not in the scope of this Specification:

(a) Manufactured concrete products specified by ASTM standards
(b) Environmental concrete structures
(c) Heavyweight shielding concrete
(d) Paving concrete
(e) Terrazzo
(f) Insulating concrete
(g) Refractory concrete
(h) Nuclear containment structures
(i) Concrete piles; drilled piers; and caissons assigned to Seismic Design Categories A, B, and C
(j) Fire safety
(k) Slipformed concrete walls
(l) Residential post-tensioned slabs-on-ground

1.1.7 This Specification governs if there is a conflict with referenced materials and testing standards.

1.1.8 Contractor is permitted to submit written alternatives to any provision in this Specification for consideration.

1.1.9 Ignore provisions of this Specification that are not applicable to Work.

1.1.10 *Units*—Values in this Specification are stated in inch-pound units. A companion specification in SI units is available.

1.1.11 Unless otherwise stated, the inch-pound system of units is applicable to ASTM combined standards referenced in this Specification.

1.1.12 The Notes to Specifier are not part of this Specification.

1.2—Interpretation

1.2.1 Unless otherwise explicitly stated, this Specification shall be interpreted using the following principles:

1.2.1.1 Interpret this Specification consistent with the plain meaning of the words and terms used.

1.2.1.2 Definitions provided in this Specification govern over the definitions of the same or similar words or terms found elsewhere.

1.2.1.3 Headings are part of this Specification and are intended to identify the scope of the provisions or sections that follow. If there is a difference in meaning or implication between the text of a provision and a heading, the meaning of the text governs.

1.2.1.4 Notes to a table are part of this Specification. The meaning of the provision text governs in the event of a difference in meaning or implication between the provision text and a note to a table.

1.2.1.5 If a provision of this Specification involves two or more items, conditions, requirements, or events connected by the conjunctions "and" or "or," interpret the conjunction as follows:

(a) "and" indicates that all the connected items, conditions, requirements, or events apply.
(b) "or" indicates that the connected items, conditions, requirements, or events apply singularly.

1.2.1.6 The use of the verbs "may" or "will" indicates that the specification provision is for information to Contractor.

1.2.1.7 The phrases "as indicated in Contract Documents" and "as designated in Contract Documents" mean the specifier included provision requirements in Contract Documents.

1.2.1.8 The phrase "unless otherwise specified" means the specifier may have included an alternative to the default requirement in Contract Documents.

1.2.1.9 The phrase "if specified" means the specifier may have included a requirement in Contract Documents for which there is no default requirement in this Specification.

1.3—Definitions

acceptable or **accepted**—determined to be satisfactory by Architect/Engineer based on requirements of Contract Documents.

acceptance—acknowledgment by Architect/Engineer that submittal or completed Work is acceptable.

ACI Concrete Field Testing Technician Grade I—a person who has demonstrated knowledge and ability to perform and record the results of ASTM standard tests on freshly mixed concrete and to make and cure test specimens; knowledge and ability shall be demonstrated by passing prescribed written and performance examinations and having credentials that are current with the American Concrete Institute.

Architect/Engineer—Architect, Engineer, architectural firm, design or engineering firm, or architectural and engineering firm issuing Contract Documents, or administering the Work under Contract Documents, or both.

backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect, or support its own weight or existing construction loads.

cast-in-place concrete—concrete that is deposited and allowed to harden in the place where it is required to be in the completed structure.

check test—test performed to verify result of previous test result of freshly-mixed concrete.

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Contract Documents—a set of documents that form the basis of an agreement between Owner and Contractor; these documents can contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

Contractor—the person, firm, or entity under contract for construction of Work.

defective work—construction or material that does not comply with Contract Documents.

design reference sample—sample of architectural concrete for color, finish, and texture that is submitted for initial verification of design intent.

drawings—graphic presentation that details requirements for Work.

duct—a conduit in a concrete member to accommodate the prestressing steel of a post-tensioning tendon and provide an annular space for protective coating.

encapsulated tendon—a tendon that is enclosed completely in a watertight covering from end to end, including anchorages, sheathing with coating, and caps over the strand tails.

equivalent diameter of bundle—the diameter of a circle having an area equal to the sum of the bar areas in a bundle of reinforcing bars.

expansive cement—a cement that, when mixed with water, produces a paste that, after setting, increases in volume and is used to compensate for volume decrease due to shrinkage or to induce tensile stress in reinforcement.

exposed to view—portion of structure that can be observed by the public during normal use.

high-early-strength concrete—concrete that, through the use of additional cement, high-early-strength cement, admixtures, or other acceptable methods, has accelerated early-age strength development.

jack clearance—minimum space required to safely install, operate, and remove a hydraulic jack through its full range of movement in stressing of a tendon.

licensed design engineer—an individual retained by the Contractor who is licensed to practice engineering as defined by the statutory requirements of the professional licensing laws of the state or jurisdiction in which the project is to be constructed.

movement joint—an interface between adjacent portions of Work that allows movement in one or more direction.

nonencapsulated tendon—a tendon that has bare metallic anchorages and sheathing that is continuous between anchorages but not connected to the anchorages.

normalweight concrete—concrete containing aggregate that conforms to ASTM C33/C33M and that typically has a density between 135 and 160 lb/ft^3.

Owner—the corporation, association, partnership, individual, public body, or authority for whom Work is constructed.

placing drawing—drawing that gives size, location, and spacing of reinforcement, and other information required for site-cast concrete construction.

point of delivery—location where concrete is discharged from the vehicle used to transport concrete to the project site.

point of placement—location where concrete is placed in structure.

prestressing steel—high-strength steel element; for example, strand, bars, or wire, used to impart prestress forces to concrete.

quality assurance—actions taken by Owner or Owner's Representative to provide confidence that Work done and materials provided are in accordance with Contract Documents.

quality control—actions taken by Contractor to ensure that Work meets the requirements in Contract Documents.

reference specification—a standardized mandatory-language document prescribing materials, dimensions, and workmanship, incorporated by reference in Contract Documents.

referenced standards—standardized mandatory-language documents of a technical society, organization, or association, including codes of local or federal authorities, which are incorporated by reference in Contract Documents.

required—required in this Specification or in Contract Documents.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, thus requiring the new slab or structural member to deflect and support its own weight and existing construction loads.

sheathing—a material encasing prestressing reinforcement to prevent bonding of prestressing reinforcement with surrounding concrete, to provide corrosion protection, and to contain corrosion-inhibiting coating.

shop drawings—drawings that provide details for a particular portion of Work that are prepared by Contractor in accordance with Contract Documents and are reviewed by Architect/Engineer.

shore—vertical or inclined support members designed to support the weight of the formwork, concrete, and construction loads above.

strength test—standard test conducted for evaluation and acceptance of concrete determined as the average of the compressive strengths of at least two 6 x 12 in. cylinders or at least three 4 x 8 in. cylinders made from the same sample of concrete, taken in accordance with ASTM C172/C172M at the point of delivery, handled and standard cured in accordance with ASTM C31/C31M, and tested in accordance with ASTM C39/C39M at 28 days or at test age designated for f_c'.

structural concrete—plain or reinforced concrete in a member required to transfer gravity loads, lateral loads, or both, to the ground.

submit—provide to Architect/Engineer for review.

submittal—documents or materials provided to Architect/Engineer for review and acceptance.

surface defects—imperfections in concrete surfaces defined in Contract Documents requiring repair.

tendon—in pretensioned applications, the tendon is the prestressing steel; in post-tensioned applications, the tendon is a complete assembly consisting of anchorages, prestressing steel, and sheathing with coating for unbonded applications or ducts with grout for bonded applications.

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testing agency—person, firm, or entity under contract for providing testing services that will be used to determine conformance to Contract Documents.

waste slab—temporary slab to provide a casting surface for tilt-up panels.

water-cementitious materials ratio (*w*/*cm*)—ratio of mass of water, excluding that absorbed by aggregate, to the mass of cementitious materials in a mixture, stated as a decimal.

Work—the entire construction or separately identifiable parts required to be furnished under Contract Documents.

1.4—Referenced standards

1.4.1 Standards cited in this Specification are listed with serial designation including year of adoption or revision.

1.4.1.1 *American Concrete Institute standards*

ACI 117-10(15)—Specification for Tolerances for Concrete Construction and Materials and Commentary

ACI 216.1-14(19)—Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

ACI 423.7-14—Specification for Unbonded Single-Strand Tendon Materials

ACI ITG-7-09—Specification for Tolerances for Precast Concrete

1.4.1.2 *ASTM International standards*

ASTM A36/A36M-19—Standard Specification for Carbon Structural Steel

ASTM A47/A47M-99(2018)—Standard Specification for Ferritic Malleable Iron Castings

ASTM A108-18—Standard Specification for Steel Bar, Carbon and Alloy, Cold-Finished

ASTM A123/A123M-17—Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

ASTM A153/A153M-16a—Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware

ASTM A184/A184M-17—Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement

ASTM A193/A193M-19—Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications

ASTM A276/A276M-17—Standard Specification for Stainless Steel Bars and Shapes

ASTM A307-14—Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60000 PSI Tensile Strength

ASTM A325-14—Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength

ASTM A416/A416M-18—Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete

ASTM A421/A421M-15—Standard Specification for Stress-Relieved Steel Wire for Prestressed Concrete

ASTM A490-14a—Standard Specification for Structural Bolts, Steel, Heat Treated, 150 ksi Minimum Tensile Strength

ASTM A500/A500M-18—Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes

ASTM A563-15—Standard Specification for Carbon and Alloy Steel Nuts

ASTM A572/A572M-18—Standard Specification for High Strength Low-Alloy Columbium-Vanadium Structural Steel

ASTM A615/A615M-18e1—Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A666-15—Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar

ASTM A675/A675M-14(2019)—Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties

ASTM A706/A706M-16—Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement

ASTM A722/A722M-16—Standard Specification for High-Strength Steel Bars for Prestressing Concrete

ASTM A767/A767M-16—Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement

ASTM A775/A775M-17—Standard Specification for Epoxy-Coated Steel Reinforcing Bars

ASTM A779/A779M-16—Standard Specification for Steel Strand, Seven-Wire, Uncoated, Compacted, for Prestressed Concrete

ASTM A780/A780M-09(2015)—Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings

ASTM A820/A820M-16—Standard Specification for Steel Fibers for Fiber-Reinforced Concrete

ASTM A882/A882M-04a(2010)—Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand

ASTM A884/A884M-14—Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Reinforcement

ASTM A886/A886M-17—Standard Specification for Steel Strand, Indented, Seven-Wire, Stress-Relieved for Prestressed Concrete

ASTM A910/A910M-18—Standard Specification for Uncoated, Weldless, 2-Wire and 3-Wire Steel Strand for Prestressed Concrete

ASTM A934/A934M-16—Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars

ASTM A955/A955M-18b—Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement

ASTM A970/A970M-18—Standard Specification for Headed Steel Bars for Concrete Reinforcement

ASTM A992/A992M-11(2015)—Standard Specification for Structural Steel Shapes

ASTM A996/A996M-16—Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

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ASTM A1022/A1022M-16b—Standard Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement

ASTM A1035/A1035M-16b—Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement

ASTM A1044/A1044M-16a—Standard Specification for Steel Stud Assemblies for Shear Reinforcement of Concrete

ASTM A1055/A1055M-16—Standard Specification for Zinc and Epoxy Dual-Coated Steel Reinforcing Bars

ASTM A1060/A1060M-16b—Standard Specification for Zinc-Coated (Galvanized) Steel Welded Wire Reinforcement, Plain and Deformed, for Concrete

ASTM A1064/A1064M-18a—Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

ASTM C31/C31M-19—Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C33/C33M-18—Standard Specification for Concrete Aggregates

ASTM C39/C39M-18—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C42/C42M-18a—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C67-14—Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile

ASTM C94/C94M-18—Standard Specification for Ready-Mixed Concrete

ASTM C109/C109M-16—Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

ASTM C114-15—Standard Test Methods for Chemical Analysis of Hydraulic Cement

ASTM C126-15—Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units

ASTM C138/C138M-17a—Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

ASTM C143/C143M-15—Standard Test Method for Slump of Hydraulic-Cement Concrete

ASTM C144-11—Standard Specification for Aggregate for Masonry Mortar

ASTM C150/C150M-19a—Standard Specification for Portland Cement

ASTM C157/C157M-08(2014)e1—Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

ASTM C171-07—Standard Specification for Sheet Materials for Curing Concrete

ASTM C172/C172M-17—Standard Practice for Sampling Freshly Mixed Concrete

ASTM C173/C173M-16—Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C192/C192M-15—Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM C216-15—Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)

ASTM C231/C231M-17a—Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

ASTM C260/C260M-10a(2016)—Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C309-11—Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

ASTM C330/C330M-17a—Standard Specification for Lightweight Aggregates for Structural Concrete

ASTM C373-14a—Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products, Ceramic Tiles, and Glass Tiles

ASTM C387/C387M-15—Standard Specification for Packaged, Dry, Combined Materials for Concrete and High Strength Mortar

ASTM C404-11—Standard Specification for Aggregates for Masonry Grout

ASTM C469/C469M-14—Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

ASTM C494/C494M-17—Standard Specification for Chemical Admixtures for Concrete

ASTM C567/C567M-14—Standard Test Method for Determining Density of Structural Lightweight Concrete

ASTM C578-15—Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation

ASTM C591-15—Standard Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation

ASTM C595/C595M-18—Standard Specification for Blended Hydraulic Cements

ASTM C597-09—Standard Test Method for Pulse Velocity through Concrete

ASTM C618-19—Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C642-13—Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

ASTM C650-04(2014)—Standard Test Method for Resistance of Ceramic Tile to Chemical Substances

ASTM C666/C666M-15—Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C685/C685M-17—Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing

ASTM C803/C803M-18—Standard Test Method for Penetration Resistance of Hardened Concrete

ASTM C805/C805M-13a—Standard Test Method for Rebound Number of Hardened Concrete

ASTM C834-14—Standard Specification for Latex Sealants

ASTM C845/C845M-18—Standard Specification for Expansive Hydraulic Cement

ASTM C873/C873M-15—Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds

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ASTM C878/C878M-14a—Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete

ASTM C881/C881M-15—Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete

ASTM C900-15—Standard Test Method for Pullout Strength of Hardened Concrete

ASTM C920-14a—Standard Specification for Elastomeric Joint Sealants

ASTM C979/C979M-16—Standard Specification for Pigments for Integrally Colored Concrete

ASTM C989/C989M-18a—Standard Specification for Slag Cement for Use in Concrete and Mortars

ASTM C1012/C1012M-18b—Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

ASTM C1017/C1017M-13el—Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

ASTM C1064/C1064M-12—Standard Test Methods for Temperature of Freshly Mixed Hydraulic-Cement Concrete

ASTM C1074-17—Standard Practice for Estimating Concrete Strength by the Maturity Method

ASTM C1077-17—Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation

ASTM C1107/C1107M-14a—Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)

ASTM C1116/C1116M-10a(2015)—Standard Specification for Fiber-Reinforced Concrete

ASTM C1152/C1152M-04(2012)e1—Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

ASTM C1157/C1157M-11—Standard Performance Specification for Hydraulic Cement

ASTM C1218/C1218M-17—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1240-15—Standard Specification for Silica Fume Used in Cementitious Mixtures

ASTM C1260-14—Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar Bar Method)

ASTM C1289-16—Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board

ASTM C1293-08b(2015)—Standard Test Method for Determination Length of Change of Concrete Due to Alkali-Silica Reaction

ASTM C1315-11—Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete

ASTM C1567-13—Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

ASTM C1602/C1602M-18—Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

ASTM C1609/C1609M-12—Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)

ASTM C1610/C1610M-17—Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique

ASTM C1611/C1611M-14—Standard Test Method for Slump Flow of Self-Consolidating Concrete

ASTM C1621/C1621M-14—Standard Test Method for Passing Ability of Self-Consolidating Concrete Using Column Technique

ASTM C1761/C1761M-15—Standard Specification for Lightweight Aggregate for Internal Curing of Concrete

ASTM C1778-16—Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete

ASTM C1797-17—Standard Specification for Ground Calcium Carbonate and Aggregate Mineral Fillers for use in Hydraulic Cement Concrete

ASTM D98-15—Standard Specification for Calcium Chloride

ASTM D412-15a—Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

ASTM D638-14—Standard Test Method for Tensile Properties of Plastics

ASTM D698-12e2—Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort [12 400 ft-lbf/ft^3 (600 kN-m/m^3)]

ASTM D994/D994M-11—Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)

ASTM D1621-10—Standard Test Methods for Compressive Properties of Rigid Cellular Plastics

ASTM D1751-04(2013)e1—Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Non-extruding and Resilient Bituminous Types)

ASTM D1752-04a(2013)—Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction

ASTM D2240-15—Standard Test Method for Rubber Property—Durometer Hardness

ASTM D2940/D2940M-15—Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports

ASTM D3575-14—Standard Test Methods for Flexible Cellular Materials Made from Olefin Polymers

ASTM D4397-10—Standard Specification for Polyethylene Sheeting for Construction, Industrial, and Agricultural Applications

ASTM E165/E165M-12—Standard Practice for Liquid Penetrant Examination for General Industry

ASTM E329-14a—Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection

ASTM E488/E488M-15—Standard Test Methods for Strength of Anchors in Concrete Elements

ASTM E1155-14—Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers

ASTM E1444/E1444M-12—Standard Practice for Magnetic Particle Testing

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ASTM E1643-11—Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill under Concrete Slabs

ASTM E1745-11—Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs

ASTM F436-11—Standard Specification for Hardened Steel Washers

ASTM F593-13a—Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs

ASTM F594-09(2015)—Standard Specification for Stainless Steel Nuts

ASTM F844-07a(2013)—Standard Specification for Washers, Steel, Plain (Flat), Unhardened for General Use

ASTM F1554-18—Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength

1.4.1.3 *Other referenced standards*—Other standards referenced in this Specification:

AASHTO LRFD-US8 (2017)—LRFD Bridge Design Specifications, eighth editon

AASHTO M 182-05 (2017)—Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats

AASHTO M 251-06 (2016)—Standard Specification for Plain and Laminated Elastomeric Bridge Bearings

ANSI A118.1-19—American National Standard Specifications for Dry-Set Portland Cement Mortar

ANSI A118.4-19—American National Standard Specifications for Latex-Portland Cement Mortar

ANSI A118.6-19—American National Standard Specifications for Standard Cement Grouts for Tile Installation

ASHRAE 90.1-2019—Energy Standard for Buildings Except Low-Rise Residential Buildings

AWS C5.4-93—Recommended Practices for Stud Welding

AWS D1.1/D1.1M:2015—Structural Welding Code—Steel

AWS D1.4/D1.4M:2018—Structural Welding Code—Steel Reinforcing Bars

AWS D1.6/D1.6M:2017—Structural Welding Code—Stainless Steel

CRD-C513-74—Specifications for Rubber Waterstops

CRD-C572-74—Specifications for Polyvinylchloride Waterstop

CRSI RB4.1-16—Supports for Reinforcement Used in Concrete

MPI #79-16—Primer, Alkyd, Anti-Corrosive for Metal

NAVY MIL-C-882E-89—Cloth, Duck, Cotton or Cotton-Polyester Blend, Synthetic Rubber, Impregnated, and Laminated, Oil Resistant

NAVY MIL DOD-P-21035A-91—Paint High Zinc Dust Content, Galvanizing Repair

SSPC-Paint 20-04—Zinc Rich Primers IO and O

SSPC-PA1-16—Shop, Field and Maintenance Painting of Steel

SSPC-SP3-18—Power Tool Cleaning

PCI MNL-116-99—Manual for Quality Control for Plants and Production of Structural Precast Concrete Products

PCI MNL-124-11—Design for Fire Resistance of Precast/Prestressed Concrete

PTI/ASBI M50.3-19—Specification for Multistrand and Grouted Post-Tensioning

PTI M55.1-19—Specification for Grouting of Post-Tensioned Structures

1.5—Submittals

1.5.1 *General*—Provide submittals as required by this Specification in accordance with Contract Documents.

1.5.2 *Substitution*—Substitution requests shall specifically identify proposed substitution and demonstrate compliance with performance requirements.

1.5.3 *Contractor's quality control*—If specified, submit quality control plan showing means and methods to control purchase, use, and placement of materials. Provide information related to quality control in accordance with 1.7.2.

1.6—Preconstruction conference

1.6.1 If specified, schedule and attend preconstruction conference with Architect/Engineer, Owner, or Owner's Representative to review project requirements, acceptance criteria, and responsibilities.

1.7—Testing and inspection

1.7.1 *General*—Concrete materials and operations may be tested and inspected as Work progresses. Failure to detect defective Work will not prevent later rejection if discovered nor shall it obligate Architect/Engineer for final acceptance.

1.7.2 *Quality control: Duties and responsibilities of Contractor*

1.7.2.1 *Field technicians*—Field tests of concrete required in 1.7.2 shall be performed by ACI Concrete Field Testing Technician Grade I or acceptable equivalent. Equivalent certification programs shall include acceptable requirements for written and performance examinations.

1.7.2.2 Unless otherwise specified, Contractor assumes duties and responsibilities specified in 1.7.2.2(a) through 1.7.2.2(e).

1.7.2.2(a) Provide Owner's testing agency with access to project site or to source of materials to perform testing and inspection activities and assist Owner's testing agency in obtaining and handling samples at project site or at source of materials. Provide Owner's testing agency with requested documentation.

1.7.2.2(b) Advise Owner's testing agency at least 24 hours in advance of operations that require services specified in 1.7.3.2 through 1.7.3.5 to allow for scheduling of quality assurance tests, review of project requirements, and assignment of personnel.

1.7.2.2(c) Provide secure location and sources of water and electrical power on project site acceptable to Owner's testing agency for initial curing of concrete strength test specimens as required by ASTM C31/C31M.

1.7.2.2(d) Submit information on concrete materials and documentation that properties of proposed concrete mixtures meet requirements in Contract Documents.

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1.7.2.2(e) Submit concrete supplier's quality control program.

1.7.3 *Quality assurance: Duties and responsibilities of Owner's testing agency*

1.7.3.1 Owner's testing agencies that perform required tests of concrete materials will meet the requirements of ASTM C1077, which includes certification requirements for technicians. Owner's testing agencies that test or inspect placement of reinforcement will meet the requirements of ASTM E329.

1.7.3.2 Unless otherwise specified, Owner's testing agency will provide services specified in 1.7.3.2(a) through 1.7.3.2(c).

1.7.3.2(a) Owner's testing agency will inspect, sample, and test fresh and hardened concrete for conformance to requirements in Contract Documents. If material furnished or Work performed by Contractor fails to conform to Contract Documents, testing agency will report deficiency to Architect/Engineer, Owner, Contractor, and concrete supplier.

1.7.3.2(b) Owner's testing agency and its representatives are not authorized to revoke, alter, relax, enlarge, or release requirements in Contract Documents, or to accept or reject portions of Work.

1.7.3.2(c) Owner's testing agency will report test and inspection results of Work to Owner, Architect/Engineer, Contractor, and concrete supplier within 7 days after tests and inspections are performed. Strength test reports will include location in Work where concrete represented by each strength test was deposited, date and time sample was obtained, and batch ticket number. Strength test reports will include information on storage and curing of specimens before testing.

1.7.3.3 *Testing services*—If required by Owner or Architect/Engineer, Owner's testing agency will perform testing services specified in 1.7.3.3(a) through 1.7.3.3(e) at no cost to Contractor.

1.7.3.3(a) Review and test to verify Contractor's test results on proposed materials for compliance with Contract Documents.

1.7.3.3(b) Review and test to verify Contractor's test results on proposed concrete mixture for compliance with Contract Documents.

1.7.3.3(c) Obtain production samples of materials at plants or stockpiles during the course of Work and test for compliance with Contract Documents.

1.7.3.3(d) For each concrete mixture cast in 1 day, obtain samples of fresh concrete in accordance with ASTM C172/C172M. Truckloads or batches of concrete will be sampled on a random basis. Unless otherwise specified, at least one composite sample will be obtained for consecutive 150 yd^3 of concrete or 5000 ft^2 of surface area of slabs or walls, or fractions thereof. At least five strength tests for a given concrete mixture will be required for Work. If total quantity of a given concrete mixture is less than 50 yd^3, strength tests may be waived.

Sampled concrete used to mold strength test specimens (ASTM C31/C31M) will be tested for slump (ASTM C143/C143M) or slump flow (ASTM C1611/C1611M), air content (ASTM C231/C231M or ASTM C173/C173M), temperature (ASTM C1064/C1064M), and density (ASTM C138/C138M).

1.7.3.3(e) Owner's testing agency will conduct concrete strength tests by making and standard curing test specimens in accordance with ASTM C31/C31M and testing them according to ASTM C39/C39M. Unless otherwise specified, concrete strength test specimens for acceptance will be tested at 28 days.

1.7.3.4 *Additional testing and inspection services*—If specified, Owner's testing agency will perform additional testing and inspection services (a) through (e) to verify compliance with Contract Documents:

(a) Inspect concrete batching, mixing, and delivery operations.

(b) Inspect forms, foundation preparation, reinforcement, embedded items, reinforcement placement, and concrete placing, finishing, and curing operations.

(c) Sample concrete at point of placement and other locations as directed by Architect/Engineer and perform required tests.

(d) Review manufacturer's report for shipment of cement, reinforcement, and prestressing tendons, and conduct laboratory tests or spot checks of materials received for compliance with specifications.

(e) Other testing or inspection services as required by Architect/Engineer.

1.7.3.5 *Other testing services as needed*—Contractor shall pay for the following testing services performed by Owner's testing agency:

(a) Additional testing and inspection required because of changes in materials or mixture proportions requested by Contractor.

(b) Additional testing of materials or concrete because of failure to meet specification requirements.

1.7.4 *Tests on hardened concrete in place*

1.7.4.1 *General*—If necessary, Owner's testing agency will perform tests on hardened concrete. Testing shall be at Contractor's expense if this Specification requires tests to verify strength of concrete in structure and subsequent testing confirms concrete does not meet acceptance criteria.

Contractor shall not be responsible for costs if tests are not required by this Specification or subsequent testing confirms concrete meets acceptance criteria.

1.7.4.2 *Nondestructive tests for uniformity*—Use of the rebound hammer in accordance with ASTM C805/C805M or the pulse-velocity method in accordance with ASTM C597 may be specified by Architect/Engineer to evaluate uniformity of in-place concrete or to select areas to be cored. These methods shall not be used to evaluate in-place strength.

1.7.4.3 *Core tests*

1.7.4.3(a) If concrete strength is in doubt as defined in 1.7.6.1(b) or core testing is required for other reasons, cores will be obtained, moisture conditioned, prepared, and tested in accordance with ASTM C42/C42M, unless otherwise specified. Cores will be tested no earlier than 5 days after drilling or last wetting and no later than 7 days after cores were drilled from structure, unless otherwise specified.

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1.7.4.3(b) At least three cores will be taken from each area of in-place concrete that is considered potentially deficient as defined in 1.7.6.1(b). Architect/Engineer determines location of cores. If, before testing, cores show evidence of having been damaged, replacement cores will be taken.

1.7.4.3(c) Unless otherwise specified, fill core holes with concrete or mortar of strength equal to or greater than original concrete, and provide curing as specified in 5.3.6.5 for at least 3 days.

1.7.4.4 *Floor flatness and levelness*—Unless otherwise specified, floor flatness and levelness will be measured in accordance with ASTM E1155.

1.7.5 *Evaluation of concrete strength tests*

1.7.5.1 *Standard-cured strength test specimens*—Test results from standard-cured test cylinders will be evaluated separately for each specified concrete mixture. Evaluation is valid only if tests have been conducted in accordance with procedures specified. For evaluation, each specified mixture shall be represented by at least five strength tests.

1.7.5.2 *Core tests*—Core test results will be evaluated by Architect/Engineer and are valid only if tests are conducted in accordance with ASTM C42/C42M. Do not use core tests in place of standard-cured specimens specified in 1.7.5.1 for initial acceptance testing of concrete.

1.7.5.3 *In-place strength tests*

1.7.5.3(a) Results of in-place strength tests will be evaluated by Architect/Engineer and are valid only if tests are conducted using properly calibrated equipment in accordance with recognized standard procedures and an acceptable correlation between test results and concrete compressive strength is established and submitted.

1.7.5.3(b) The use of cast-in-place cylinders in accordance with ASTM C873/C873M does not require correlation; however, measured strengths shall be corrected using factors in ASTM C39/C39M if length-diameter ratio is less than 1.75.

1.7.6 *Acceptance of concrete strength*

1.7.6.1 *Standard-cured strength test specimens*—Strength of concrete is satisfactory provided that the criteria of 1.7.6.1(a) and 1.7.6.1(b) are met.

1.7.6.1(a) Every average of three consecutive strength tests equals or exceeds specified compressive strength, f_c'.

1.7.6.1(b) No strength test result falls below f_c' by more than 500 psi if f_c' is 5000 psi or less, or by more than $0.10f_c'$ if f_c' is greater than 5000 psi.

1.7.6.2 If either of the two requirements in 1.7.6.1 is not met, steps shall be taken to increase the average of subsequent strength test results.

1.7.6.3 *Core tests*—Strength of concrete in area represented by core tests is considered satisfactory if average compressive strength of cores is at least 85 percent of f_c', and if no single core strength is less than 75 percent of f_c'. Additional testing of cores extracted from locations represented by erratic core strength results will be permitted.

1.7.6.4 *In-place tests*—In-place tests shall not be used as the sole basis for accepting or rejecting concrete, but may be used, if specified, to evaluate concrete if strength test results of standard molded and cured cylinders fail to meet the criteria in 1.7.6.1.

1.7.7 *Acceptance of steel fiber-reinforced concrete*—Unless otherwise specified, steel fiber-reinforced concrete designated in Contract Documents for use in members to provide shear resistance is satisfactory if the criteria of 1.7.7.1 through 1.7.7.3 are met.

1.7.7.1 Compressive strength of cylinders prepared and tested in accordance with 1.7.3.3(e) comply with the criteria of 1.7.6.1.

1.7.7.2 Residual strength obtained from flexural testing in accordance with ASTM C1609/C1609M at midspan deflection of 1/300 of span length is not less than 1.7.7.2(a) and 1.7.7.2(b).

1.7.7.2(a) 90 percent of the measured first-peak strength obtained from the flexural test.

1.7.7.2(b) 90 percent of the strength corresponding to $7.5\sqrt{f_c'}$.

1.7.7.3 Residual strength obtained from flexural testing in accordance with ASTM C1609/C1609M at midspan deflection of 1/150 of span length is not less than 1.7.7.3(a) and 1.7.7.3(b).

1.7.7.3(a) 75 percent of the measured first-peak strength obtained from the flexural test.

1.7.7.3(b) 75 percent of the strength corresponding to $7.5\sqrt{f_c'}$.

1.7.8 *Field acceptance of concrete*

1.7.8.1 *Air content*—If measured air content at point of delivery is greater than the upper limit of 4.2.2.6(c), a check test of air content will be performed on a new sample from point of delivery. If check test fails, concrete has failed to meet the requirements of this Specification. If measured air content is less than lower limit of 4.2.2.6(c), adjustments will be permitted in accordance with ASTM C94/C94M, unless otherwise specified. If check test of the adjusted mixture fails, concrete has failed to meet the requirements of this Specification.

1.7.8.2 *Slump and slump flow*—If measured slump or slump flow at point of delivery is greater than specified in 4.2.2.1 or 4.2.2.2, respectively, a check test will be performed on a new sample from point of delivery. If check test fails, concrete is considered to have failed to meet the requirements of this Specification. If measured slump or slump flow is less than specified in 4.2.2.1 or 4.2.2.2, respectively, adjustments will be permitted in accordance with ASTM C94/C94M, unless otherwise specified. If the test of slump or slump flow of the adjusted mixture fails, concrete is considered to have failed to meet the requirements of this Specification.

1.7.8.3 *Temperature*—If measured concrete temperature at point of delivery is not within the limits of 4.2.2.4, or as otherwise specified, a check test will be performed at a new location in the sample. If check test fails, concrete is considered to have failed to meet the requirements of this Specification.

1.8—Acceptance of structure

1.8.1 *General*—Completed concrete Work shall conform to applicable requirements of this Specification and Contract Documents.

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1.8.1.1 Concrete Work that fails to meet one or more requirements in Contract Documents but subsequently is repaired to bring concrete into compliance will be accepted.

1.8.1.2 Concrete Work that fails to meet one or more requirements in Contract Documents and cannot be brought into compliance is subject to rejection.

1.8.1.3 Repair rejected concrete Work by removing and replacing or by additional construction to strengthen or otherwise satisfy project requirement as directed by Architect/Engineer. To bring rejected Work into compliance, use repair methods that meet applicable requirements for function, durability, dimensional tolerances, and appearance as determined by Architect/Engineer.

1.8.1.4 Submit proposed repair methods, materials, and modifications needed to repair concrete Work to meet requirements in Contract Documents.

1.8.1.5 Repair concrete Work as necessary to be in compliance with Contract Documents.

1.8.2 *Dimensional tolerances*

1.8.2.1 Unless otherwise specified, construction tolerances shall conform to ACI 117.

1.8.2.2 Concrete members with dimensions smaller than permitted tolerances may be considered deficient in strength and subject to provisions of 1.8.4.

1.8.2.3 Concrete members with dimensions larger than permitted tolerances are subject to rejection. Remove excess materials if required by Architect/Engineer.

1.8.2.4 Concrete surfaces that do not meet tolerances are subject to rejection.

1.8.2.5 Slabs not meeting tolerances may be corrected, provided they are brought into compliance with 1.8.3, 1.8.4, and 1.8.5.

1.8.2.6 Concrete members cast against formwork surfaces not meeting slope or planeness limitations are subject to rejection.

1.8.3 *Finishes*

1.8.3.1 Concrete surfaces not meeting the requirements of 5.3.3 shall be brought into compliance in accordance with 1.8.1.

1.8.4 *Strength of structure*

1.8.4.1 *Criteria for determining potential strength deficiency*—Strength may be considered deficient if Work fails to comply with requirements that control strength of structure including, but not limited to, conditions given in 1.8.4.1(a) through 1.8.4.1(f).

1.8.4.1(a) Concrete strength not meeting requirements of 1.7.6.1(b) and Contract Documents.

1.8.4.1(b) Reinforcement size, quantity, grade, position, or arrangement not meeting requirements in Contract Documents.

1.8.4.1(c) Concrete elements exceeding tolerances specified in Contract Documents.

1.8.4.1(d) Curing and protection not meeting requirements in Contract Documents.

1.8.4.1(e) Mechanical injury, construction fires, or premature removal of formwork resulting in deficient strength.

1.8.4.2 *Action required if strength is potentially deficient*—If structure strength is considered potentially deficient, actions given in 1.8.4.2(a) through 1.8.4.2(e) may be required by Architect/Engineer.

1.8.4.2(a) Structural analysis, additional testing, or both.

1.8.4.2(b) Core tests in accordance with ASTM C42/C42M.

1.8.4.2(c) Load tests may be required if core testing is inconclusive or impractical or if structural analysis does not confirm the safety of the structure.

1.8.4.2(d) Strengthening with additional construction or replacement of concrete Work shown to be deficient by structural analysis or by results of a load test.

1.8.4.2(e) Submittal of documentation for repair work proposed to bring strength-deficient Work into compliance with Contract Documents.

1.8.5 *Durability*

1.8.5.1 *Criteria for determining potential durability deficiency*—Durability of concrete Work may be considered deficient if it fails to comply with requirements that control structure durability, including, but not limited to, conditions given in 1.8.5.1(a) through 1.8.5.1(f).

1.8.5.1(a) Strength failing to comply with 1.7.6.1(b) or Contract Documents.

1.8.5.1(b) Materials for concrete not conforming to requirements in 4.2.1.1 to 4.2.1.7 or Contract Documents.

1.8.5.1(c) Concrete not conforming to durability requirements in 4.2.2.6 or Contract Documents.

1.8.5.1(d) Curing and protection not meeting requirements in 5.3.6 or Contract Documents.

1.8.5.1(e) If measured, internal early-age concrete temperatures or temperature differences greater than specified in Sections 8 and 13 or in Contract Documents.

1.8.5.1(f) Concrete exceeding the maximum allowable chloride ion content requirements in Table 4.2.2.6(e) or Contract Documents.

1.8.5.2 *Action required if durability is potentially deficient*—If structure durability is considered potentially deficient, actions given in 1.8.5.2(a) through 1.8.5.2(e) may be required by Architect/Engineer.

1.8.5.2(a) Obtain and test samples of constituent materials used in the concrete.

1.8.5.2(b) Obtain concrete samples from structure by coring, sawing, or other acceptable means.

1.8.5.2(c) Laboratory evaluation of concrete and concrete materials to assess concrete's resistance to weathering, chemical attack, abrasion, or other deterioration causes, and to protect reinforcement and metallic embedments from corrosion.

1.8.5.2(d) Repair or replace concrete rejected for durability deficiency as directed by Architect/Engineer.

1.8.5.2(e) Submittal of documentation for repair work proposed to bring durability-deficient Work into compliance with Contract Documents.

1.9—Protection of in-place concrete

1.9.1 *Loading and support of structural member or structure*—Do not allow construction loads to exceed loads that a structural member or structure is capable of supporting

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safely without damage. Provide supplemental support if construction loads are expected to exceed safe load capacity.

1.9.2 *Protection from mechanical damage*—Protect concrete from damage due to construction traffic, equipment, and materials. During the curing period, protect concrete from damage by mechanical disturbances, including load-induced stresses, shock, and vibration.

1.9.3 *Protection from environmental conditions*—During the curing period, protect concrete from damage due to weather.

SECTION 2—FORMWORK AND FORMWORK ACCESSORIES

2.1—General

2.1.1 *Scope*—This Section covers requirements for design and construction of formwork.

2.1.2 *Submittals*

2.1.2.1 Unless otherwise specified, comply with 2.1.2.1(a) through 2.1.2.1(f).

2.1.2.1(a) *Form-facing materials*—Submit product information on proposed form-facing materials if different from that specified in 2.2.1.1.

2.1.2.1(b) *Construction and movement joints*—Submit location and detail of construction and movement joints if different from those indicated in Contract Documents.

2.1.2.1(c) *Testing for formwork removal*—Submit method and correlation data for determining concrete strength for formwork removal if test methods of 2.3.4.2(b) through 2.3.4.2(d) are specified or proposed.

2.1.2.1(d) *Reshoring and backshoring procedure*—Submit procedure for reshoring and backshoring, including drawings signed and sealed by a licensed design engineer. Include on shop drawings the formwork removal procedure and magnitude of construction loads used for design of reshoring or backshoring system. Indicate in procedure the magnitude of live and dead loads assumed for required capacity of structure at time of reshoring or backshoring and in-place concrete strength required at time of execution.

2.1.2.1(e) Submit manufacturer's product data sheet on formwork release agent for use on each form-facing material.

2.1.2.1(f) Submit manufacturer's product data sheet on form liner proposed for use with each formed surface.

2.1.2.2 Comply with 2.1.2.2(a) through 2.1.2.2(f) if specified in Contract Documents.

2.1.2.2(a) Submit shop drawings for formwork, shoring, reshoring, and backshoring. If specified in Contract Documents or mandated by jurisdiction where Work will be performed, shop drawings shall be signed and sealed by a licensed design engineer.

2.1.2.2(b) Submit design calculations for formwork, shoring, reshoring, and backshoring. If specified in Contract Documents or mandated by jurisdiction where Work will be performed, design calculations shall be signed and sealed by a licensed design engineer.

2.1.2.2(c) Submit manufacturer's data sheet on form ties.

2.1.2.2(d) Submit manufacturer's data sheet on expansion joint materials.

2.1.2.2(e) Submit manufacturer's data sheet on waterstop materials and splices.

2.1.2.2(f) Submit manufacturer's data sheet for formwork materials not listed in 2.1.2.1 or 2.1.2.2(c) through 2.1.2.2(e) that are to be left in place within Work.

2.2—Products

2.2.1 *Materials*

2.2.1.1 *Form-facing materials*—Unless otherwise specified, form-facing material in contact with concrete shall be lumber, plywood, tempered concrete-form-grade hardboard, metal, plastic, or treated paper that creates specified appearance and texture of concrete surface.

2.2.1.2 *Formwork accessories*—Use commercially manufactured formwork accessories, including ties and hangers. Use form ties with ends or end fasteners that can be removed without damage to concrete. Where indicated in Contract Documents, use form ties with integral water barrier plates or other acceptable positive water barriers in walls. Unless otherwise specified, the break-back distance for ferrous ties shall be at least 3/4 in. for surface finish SF-2 or surface finish SF-3, as defined in 5.3.3.2. Where indicated in Contract Documents or if specified break-back distance is less than 3/4 in., use coated or corrosion-resistant ties.

2.2.1.3 *Formwork release agent*—Use commercially manufactured formwork release agent that reduces formwork moisture absorption, inhibits bond with concrete, and does not stain exposed concrete surfaces.

2.2.1.4 *Expansion joint filler*—Preformed expansion joint filler shall conform to ASTM D994/D994M, D1751, or D1752.

2.2.1.5 *Other embedded items*—Use waterstops, sleeves, inserts, anchors, and other embedded items of material and design as indicated in Contract Documents. Waterstop materials shall conform to CRD-C513 for rubber waterstop or CRD-C572 for polyvinyl chloride waterstop. Use factory-manufactured premolded mitered corners.

2.2.1.6 *Chamfer*—Unless otherwise specified, use lumber materials with dimensions of 3/4 x 3/4 in.

2.2.2 *Performance and design requirements*

2.2.2.1 Contractor is responsible for design of formwork.

2.2.2.2 Design formwork, shores, reshores, and backshores to support loads transmitted to them and to comply with applicable building code requirements. Design formwork and shoring for load redistribution resulting from stressing of post-tensioned reinforcement. Design formwork to maintain specified tolerances while withstanding pressures resulting from placement method, rate of placement, and vibration of concrete.

2.2.2.3 Unless otherwise specified, do not use earth cuts as forms for vertical or sloping surfaces.

2.2.2.4 Unless otherwise specified, limit deflection of facing materials for concrete surfaces exposed to view to 1/240 of center-to-center spacing of facing supports. For architectural concrete, refer to 6.2.2.1(a).

2.2.2.5 *Construction and movement joints*

2.2.2.5(a) Unless otherwise specified, submit details and locations of construction joints in accordance with the following requirements:

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(a) Locate joints within middle one-third of spans of slabs, beams, and girders. If a beam intersects a girder within the middle one-third of girder span, the distance between the construction joint in the girder and the edge of the beam shall be at least twice the width of the larger member.
(b) For members with post-tensioning tendons, locate joints where tendons pass through centroid of concrete section.
(c) Locate joints in walls and columns at underside of slabs, beams, or girders and at tops of footings or slabs.
(d) Make joints perpendicular to main reinforcement.

2.2.2.5(b) Provide movement joints as indicated in Contract Documents or in accepted alternative locations.

2.2.2.5(c) Provide keyways as indicated in Contract Documents. Unless otherwise specified, longitudinal keyways indicated in Contract Documents shall be at least 1-1/2 in. deep, measured perpendicular to the plane of the joint.

2.2.2.5(d) Design formwork to accommodate waterstop materials in joints at locations indicated in Contract Documents.

2.2.2.6 Provide temporary openings in formwork if needed to facilitate cleaning and inspection.

2.2.2.7 For post-tensioned applications, ensure that formwork allows movement resulting from application of prestressing force.

2.2.2.8 Fabricate formwork joints to inhibit leakage of mortar.

2.3—Execution

2.3.1 *Construction and erection of formwork*

2.3.1.1 Construct formwork to inhibit leakage of mortar from fresh concrete at joints in formwork and produce surface finish in accordance with 5.3.3.2. Remove leaked mortar from formwork joints before reuse.

2.3.1.2 Unless otherwise specified, place chamfer strips in corners of formwork to produce beveled edges on permanently exposed surfaces. Unless otherwise specified, do not bevel reentrant corners or edges of formed joints in concrete.

2.3.1.3 Inspect formwork and remove foreign material before concrete is placed.

2.3.1.4 At construction joints, lap form-facing materials over the concrete of previous placement. Place formwork against hardened concrete so offsets at construction joints conform to specified tolerances.

2.3.1.5 Unless otherwise specified, construct formwork so concrete surfaces conform to tolerances in ACI 117. Unless otherwise specified, class of surface for offset between adjacent pieces of formwork facing material shall be in accordance with 5.3.3.

2.3.1.6 Provide positive means, such as wedges or jacks, to adjust shores and struts. Do not make adjustments in formwork after concrete has reached initial setting. Brace formwork to resist lateral deflection and lateral instability.

2.3.1.7 To maintain specified elevation and thickness within tolerances, install formwork to compensate for deflection and anticipated settlement in formwork during concrete placement. Set formwork and intermediate screed strips for slabs to produce designated elevation, camber, and contour of finished surface before formwork removal. If using vibrating screeds or roller pipe screeds, edge forms and screed strips shall be strong enough to support such equipment.

2.3.1.8 Fasten form wedges in place after final adjustment of forms and before concrete placement.

2.3.1.9 Provide anchoring and bracing to control upward and lateral movement of formwork system.

2.3.1.10 Construct formwork for openings to facilitate removal and to produce opening dimensions as specified and within tolerances.

2.3.1.11 Provide runways for mobile equipment. Support runways directly on formwork or structural members. Do not support runways on reinforcement. Loading applied by runways shall not exceed capacity of formwork or structural members.

2.3.1.12 Position and secure sleeves, inserts, anchors, and other embedded items so that embedded items are positioned within ACI 117 tolerances.

2.3.1.13 Position and support expansion joint materials, waterstops, and other embedded items to prevent displacement. Fill voids in sleeves, inserts, and anchor slots temporarily with removable material to prevent concrete entry into voids.

2.3.1.14 Clean surfaces of formwork and embedded materials of mortar, grout, and foreign materials before placing concrete.

2.3.1.15 Cover formwork surfaces with an acceptable material that inhibits bond with concrete. If formwork release agent is used, apply to formwork surfaces in accordance with manufacturer's recommendations before placing reinforcement. Remove excess release agent on formwork before placing concrete. Do not allow formwork release agent to contact reinforcement or hardened concrete against which fresh concrete is to be placed.

2.3.1.16 Erect form-facing materials to produce surface finish in accordance with 5.3.3. Repair or replace used form-facing materials that do not produce surface finish in accordance with 5.3.3.

2.3.1.17 Install formwork to accommodate waterstop materials. Locate waterstops in joints where indicated in Contract Documents. Minimize number of splices in waterstop. Splice waterstops in accordance with manufacturer's written instructions. Install factory-manufactured premolded mitered corners.

2.3.2 *Removal of formwork*

2.3.2.1 If vertical formed surfaces require finishing, remove forms as soon as removal operations will not damage concrete.

2.3.2.2 If formed sloping surfaces require finishing, remove top forms as soon as removal will not allow concrete to sag. Perform repairs and finishing operations required. If forms are removed before end of specified curing period, provide curing and protection in accordance with Section 5.

2.3.2.3 Do not damage concrete during removal of vertical formwork for columns, walls, and sides of beams. Perform repair and finishing operations required on vertical surfaces.

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If forms are removed before end of specified curing period, provide curing and protection in accordance with Section 5.

2.3.2.4 Unless otherwise specified, leave formwork and shoring in place to support construction loads and weight of concrete in beams, slabs, and other structural members until in-place strength of concrete determined in accordance with 2.3.4 is at least f_c'.

2.3.2.5 Unless otherwise specified, form-facing material and horizontal facing support members are permitted to be removed in accordance with accepted formwork shop drawings before in-place concrete reaches specified compressive strength if formwork system is designed to allow facing removal without removing shores or other vertical supports. If forms are removed before end of specified curing period, provide curing and protection in accordance with Section 5.

2.3.2.6 Unless otherwise specified for post-tensioned structures, do not remove formwork supports until stressing records have been accepted by Architect/Engineer.

2.3.2.7 After ends or end fasteners of form ties have been removed, repair tie holes in accordance with 5.3.7.2.

2.3.3 *Reshoring and backshoring*

2.3.3.1 If the reshoring and backshoring procedure described in 2.1.2.1(d) is submitted, do not allow structural members to be loaded with combined dead and construction loads in excess of loads indicated in the accepted procedure.

2.3.3.2 If the reshoring and backshoring procedure described in 2.1.2.1(d) is submitted, install and remove reshores or backshores in accordance with accepted procedure.

2.3.3.3 In multistory buildings, place reshoring or backshoring over a sufficient number of stories to distribute weight of newly placed concrete, forms, and construction live loads in accordance with reshoring and backshoring procedure in 2.1.2.1(d).

2.3.3.4 Locate reshores and backshores in accordance with the reshoring and backshoring procedure in 2.1.2.1(d).

2.3.4 *Strength of concrete required for removal of formwork*

2.3.4.1 If removal of formwork, reshoring, or backshoring is based on concrete reaching a specified in-place strength, mold and field-cure cylinders in accordance with ASTM C31/C31M. Test cylinders in accordance with ASTM C39/C39M.

2.3.4.2 Alternatively, if specified, use one or more of the methods listed in 2.3.4.2(a) through 2.3.4.2(d) to evaluate in-place concrete strength for formwork removal.

2.3.4.2(a) Tests of cast-in-place cylinders in accordance with ASTM C873/C873M. This option is limited to slabs with concrete depths from 5 to 12 in.

2.3.4.2(b) Penetration resistance in accordance with ASTM C803/C803M.

2.3.4.2(c) Pullout strength in accordance with ASTM C900.

2.3.4.2(d) Maturity method in accordance with ASTM C1074.

2.3.5 *Field survey controls*

2.3.5.1 Establish and maintain survey controls and benchmarks in an undisturbed condition until completion of the concrete structure and its building envelope.

2.3.5.2 Before concrete is cast, inspect formwork for conformance to Contract Documents. If specified, notify Special Inspection or Owner's quality assurance inspection.

SECTION 3—REINFORCEMENT AND REINFORCEMENT SUPPORTS

3.1—General

3.1.1 *Scope*—This Section covers materials, fabrication, placement, and tolerances for steel reinforcement and reinforcement supports.

3.1.2 *Submittals*

3.1.2.1 Unless otherwise specified, comply with 3.1.2.1(a) through 3.1.2.1(j) before fabrication and execution.

3.1.2.1(a) *Reinforcement*—Submit manufacturer's certified test report for reinforcement.

3.1.2.1(b) *Placing drawings*—Submit placing drawings showing fabrication dimensions and placement locations of reinforcement and reinforcement supports. Placing drawings shall indicate locations of splices, lengths of lap splices, and details of mechanical and welded splices.

3.1.2.1(c) *Splices*—Submit request with locations and details of contact and non-contact lap, end-bearing, mechanical, and welded splices not indicated in Contract Documents.

3.1.2.1(d) *Mechanical splices*—Submit data on mechanical splices demonstrating compliance with 3.2.1.2(d) and 3.2.1.9.

3.1.2.1(e) *Column dowels*—Submit request to place column dowels without using templates.

3.1.2.1(f) *Field bending or straightening*—Submit request and procedure to field-bend or straighten reinforcing bars partially embedded in concrete at locations not indicated in Contract Documents.

3.1.2.1(g) *Epoxy-coated reinforcement*—If epoxy-coated steel reinforcement is specified, submit either: 1) Concrete Reinforcing Steel Institute (CRSI) Epoxy Coating Plant Certification; or 2) inspection and quality-control program of plant applying epoxy coating if proposed plant is not certified in accordance with CRSI Epoxy Coating Plant Certification Program.

3.1.2.1(h) *Field cutting of reinforcing bars*—Submit request for field cutting, including location and type of bar to be cut and reason field cutting is required. For flame cutting stainless steel reinforcement, include field temperature control procedure.

3.1.2.1(i) *Supports*—If coated reinforcement is required, submit description of reinforcement supports and materials for fastening coated reinforcement if not in conformance with CRSI RB4.1.

3.1.2.1(j) *Bar mats*—Submit manufacturer's test report on bar mats, including test reports on bars used to fabricate bar mats.

3.1.3 *Material storage and handling*

3.1.3.1 Handle and store reinforcement to maintain fabricated shape and material condition as required in 3.3.1.

3.1.3.2 When handling and storing coated reinforcement, use equipment and methods that do not damage the coating.

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If stored outdoors for more than 2 months, cover coated reinforcement with opaque protective material.

3.2—Products

3.2.1 *Materials*

3.2.1.1 *Steel reinforcing bars*—Reinforcing bars shall be deformed, except spirals, load-transfer dowels, and welded wire reinforcement, which may be plain. Reinforcing bars shall be grades, types of steel, and sizes required by Contract Documents and shall conform to one of the following:

(a) ASTM A615/A615M
(b) ASTM A706/A706M
(c) ASTM A955/A955M
(d) ASTM A996/A996M, rail-steel bars shall be Type R; axle steel bars shall be Type A
(e) ASTM A1035/A1035M

3.2.1.2 *Coated reinforcing bars*—If specified in Contract Documents, use zinc-coated (galvanized), epoxy-coated, or zinc and epoxy dual-coated reinforcing bars.

3.2.1.2(a) Unless otherwise specified, zinc-coated (galvanized) reinforcing bars shall conform to ASTM A767/A767M and other requirements as specified in Contract Documents. Coating damage incurred during shipment, storage, handling, and placing of zinc-coated (galvanized) reinforcing bars shall be repaired in accordance with ASTM A780/A780M. Damaged areas shall not exceed 2 percent of surface area in each linear foot of each bar or bar shall not be used. The 2 percent limit on maximum allowed damaged coating area shall include previously repaired areas damaged before shipment as required by ASTM A767/A767M.

3.2.1.2(b) Epoxy-coated reinforcing bars shall conform to ASTM A775/A775M or ASTM A934/A934M as specified in Contract Documents. Coatings shall be applied in plants that are certified in accordance with Concrete Reinforcing Steel Institute (CRSI) Epoxy Coating Plant Certification Program or an equivalent program acceptable to Architect/Engineer. Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated reinforcing bars shall be repaired. Repair damaged coating areas with patching material conforming to ASTM A775/A775M or ASTM A934/934M as applicable and in accordance with material manufacturer's written recommendations. Damaged coating area shall not exceed 2 percent of surface area in each linear foot of each bar or bar shall not be used. The 2 percent limit on damaged coating area shall include repaired areas damaged before shipment as required by ASTM A775/A775M or A934/A934M as applicable. Fading of coating color shall not be cause for rejection of epoxy-coated reinforcing bars.

3.2.1.2(c) Zinc and epoxy dual-coated reinforcing bars shall conform to ASTM A1055/A1055M. Coating damage incurred during shipment, storage, handling, and placing of zinc and epoxy dual-coated reinforcing bars shall be repaired. Repair damaged coating areas with patching material conforming to ASTM A1055/A1055M and in accordance with material manufacturer's written recommendations. Damaged coating area shall not exceed 2 percent of surface area in each linear foot of each bar or bar shall not be used. The 2 percent limit on damaged coating area shall include repaired areas damaged before shipment as required by ASTM A1055/A1055M. Fading of coating color shall not be cause for rejection of zinc and epoxy dual-coated reinforcing bars.

3.2.1.2(d) Mechanical splices for galvanized reinforcing bars shall be galvanized or coated with dielectric material. Mechanical splices used with epoxy-coated or dual-coated reinforcing bars shall be coated with dielectric material.

3.2.1.3 *Bar mats*—If specified, bar mats shall conform to ASTM A184/A184M. When welding bars, comply with 3.2.2.2. If coated bar mats are required, repair damaged coating in accordance with 3.2.2.2(b).

3.2.1.4 *Headed reinforcing bars*—Headed reinforcing bars shall conform to ASTM A970/A970M, including Annex A1, and other specified requirements.

3.2.1.5 *Wire*—Use plain or deformed wire as indicated in Contract Documents. Plain and deformed wire shall conform to 3.2.1.5(a) through 3.2.1.5(c)

3.2.1.5(a) Plain or deformed steel wire shall conform to ASTM A1064/A1064M.

3.2.1.5(b) Stainless steel wire shall conform to ASTM A1022/A1022M.

3.2.1.5(c) Epoxy-coated wire shall conform to ASTM A884/A884M. Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated wires shall be repaired. Repair damaged coating areas with patching material in accordance with material manufacturer's written recommendations. If damaged area exceeds 2 percent of surface area in each linear foot of each wire, wire shall not be used.

The 2 percent limit on damaged coating area shall include repaired areas damaged before shipment as required by ASTM A884/A884M. Fading of coating color shall not be cause for rejection of epoxy-coated wire reinforcement.

3.2.1.6 *Welded wire reinforcement*—Use welded wire reinforcement specified in Contract Documents and conforming to 3.2.1.6(a) through 3.2.1.6(e).

3.2.1.6(a) Plain welded wire reinforcement shall conform to ASTM A1064/A1064M, with welded intersections spaced no greater than 12 in. apart in direction of principal reinforcement.

3.2.1.6(b) Deformed welded wire reinforcement shall conform to ASTM A1064/A1064M, with welded intersections spaced no greater than 16 in. apart in direction of principal reinforcement.

3.2.1.6(c) Epoxy-coated welded wire reinforcement shall conform to ASTM A884/A884M. Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated welded wire reinforcement shall be repaired in accordance with ASTM A884/A884M. Repair damaged coating areas with patching material in accordance with material manufacturer's written recommendations. If damaged area exceeds 2 percent of surface area in each linear foot of each wire or welded wire reinforcement, the sheet containing the damaged area shall not be used. The 2 percent limit on damaged coating area shall include repaired areas damaged before shipment as required by ASTM A884/A884M.

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Fading of coating color shall not be cause for rejection of epoxy-coated welded wire reinforcement.

3.2.1.6(d) Stainless steel welded wire reinforcement shall conform to ASTM A1022/A1022M.

3.2.1.6(e) Zinc-coated (galvanized) welded wire reinforcement shall conform to ASTM A1060/A1060M. Coating damage incurred during shipment, storage, handling, and placing of zinc-coated (galvanized) welded wire reinforcement shall be repaired in accordance with ASTM A780/A780M. Reinforcement shall not be used if area of damaged coating exceeds 2 percent of surface area in each linear foot of each wire or welded wire reinforcement, including previously repaired areas of damaged coating and excluding cut ends.

3.2.1.7 *Headed shear stud reinforcement*—Headed studs and headed stud assemblies shall conform to ASTM A1044/A1044M.

3.2.1.8 *Reinforcement supports*—Provide reinforcement support types within structure as required by Contract Documents. Reinforcement supports shall conform to CRSI RB4.1.

3.2.1.9 *Mechanical splices*—Mechanical splices shall develop at least 125 percent of the specified yield strength of bars being spliced.

3.2.2 *Fabrication*

3.2.2.1 *Bending*—Bend reinforcement cold. Fabricate reinforcement in accordance with fabricating tolerances of ACI 117.

3.2.2.2 *Welding*

3.2.2.2(a) If welding steel reinforcing bars is specified, comply with AWS D1.4/D1.4M unless otherwise specified. Do not tack weld reinforcing bars. Welded assemblies of steel reinforcement produced under factory conditions, such as welded wire reinforcement, bar mats, and deformed bar anchors, are allowed.

3.2.2.2(b) After completing welds on zinc-coated (galvanized), epoxy-coated, or zinc and epoxy dual-coated reinforcing bars, coat welds and repair damaged coating in accordance with requirements in 3.2.1.2(a), 3.2.1.2(b), or 3.2.1.2(c), respectively.

3.2.2.2(c) If welding stainless steel reinforcing bars, comply with AWS D1.6/D1.6M.

3.3—Execution

3.3.1 *Preparation*—When concrete is cast, reinforcement shall be free of materials deleterious to bond. Reinforcement with rust, mill scale, or a combination of both will be considered satisfactory, provided minimum nominal dimensions, weight per foot, and minimum average height of deformations of a hand-wire-brushed test specimen are not less than applicable ASTM specification requirements.

3.3.2 *Placing*

3.3.2.1 *Tolerances*—Place, support, and fasten reinforcement to maintain its location during concrete placement in accordance with Contract Documents. Do not exceed tolerances specified in ACI 117 before concrete is placed.

3.3.2.2 *Reinforcement relocation*—If movement of reinforcement beyond specified placing tolerances is necessary to avoid interference with other reinforcement, conduits, or embedded items, submit resulting reinforcement arrangement. Placing concrete in area of relocated reinforcement is prohibited before receiving acceptance from Architect/Engineer.

3.3.2.3 *Concrete cover*—Unless otherwise specified, concrete cover for reinforcement shall conform to 3.3.2.3(a) through 3.3.2.3(e). Concrete cover tolerances shall comply with ACI 117. Position tie wire ends away from exposed concrete surfaces.

3.3.2.3(a) Nonprestressed cast-in-place concrete members shall have concrete cover for reinforcement given in Table 3.3.2.3(a).

Table 3.3.2.3(a)—Concrete cover for cast-in-place nonprestressed concrete members

Concrete exposure	Member	Reinforcement	Specified cover, in.
Cast against and permanently in contact with ground	All	All	3
Exposed to weather or in contact with ground	All	No. 6 through No. 18 bars	2
		No. 5 bar, W31 or D31 wire, and smaller	1-1/2
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 14 and No. 18 bars	1-1/2
		No. 11 bar and smaller	3/4
	Beams, columns, pedestals, and tension ties	Primary reinforcement, stirrups, ties, spirals, and hoops	1-1/2

3.3.2.3(b) Cast-in-place prestressed concrete members shall have concrete cover for reinforcement, ducts, and end fittings given in Table 3.3.2.3(b).

Table 3.3.2.3(b)—Concrete cover for cast-in-place prestressed concrete members

Concrete exposure	Member	Reinforcement	Specified cover, in.
Cast against and permanently in contact with ground	All	All	3
Exposed to weather or in contact with ground	Slabs, joists, and walls	All	1
	All other	All	1-1/2
Not exposed to weather or in contact with ground	Slabs, joists, and walls	All	3/4
	Beams, columns, and tension ties	Primary reinforcement	1-1/2
		Stirrups, ties, spirals, and hoops	1

3.3.2.3(c) Precast nonprestressed or prestressed concrete members manufactured under plant conditions shall have concrete cover for reinforcement, ducts, and end fittings given in Table 3.3.2.3(c).

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Table 3.3.2.3(c)—Concrete cover for precast nonprestressed or prestressed concrete members manufactured under plant conditions

Concrete exposure	Member	Reinforcement	Specified cover, in.
Exposed to weather or in contact with ground	Walls	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	1-1/2
		No. 11 bars and smaller; W31 and D31 wire, and smaller; tendons and strands 1-1/2 in. diameter and smaller	3/4
	All other	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	2
		No. 6 through No. 11 bars; tendons and strands larger than 5/8 in. diameter through 1-1/2 in. diameter	1-1/2
		No. 5 bar, W31 or D31 wire, and smaller; tendons and strands 5/8 in. diameter and smaller	1-1/4
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	1-1/4
		Tendons and strands 1-1/2 in. diameter and smaller	3/4
		No. 11 bar, W31 or D31 wire, and smaller	5/8
	Beams, columns, pedestals, and tension ties	Primary reinforcement	Greater of d_b and 5/8 and need not exceed 1-1/2
		Stirrups, ties, spirals, and hoops	3/8

3.3.2.3(d) For bundled bars, concrete cover shall be the smaller of (a) and (b):

(a) Equivalent diameter of the bundle

(b) 2 in.,

and for concrete cast against and permanently in contact with ground, the cover shall be 3 in.

3.3.2.3(e) For headed shear stud reinforcement, concrete cover for the heads and base rails shall be the same as for surrounding reinforcement.

3.3.2.4 *Reinforcement supports*—Install reinforcement supports in accordance with CRSI RB4.1.

3.3.2.4(a) In walls reinforced with epoxy-coated or dual-coated reinforcement, use epoxy-coated, polymer-coated, or composite spacers between reinforcement layers to maintain spacing.

3.3.2.4(b) Fasten epoxy-coated or dual-coated reinforcement with tie wires coated with epoxy or other polymer.

3.3.2.4(c) Support stainless steel reinforcement bars using stainless steel, plastic, or precast concrete bar supports. Fasten stainless steel reinforcement with stainless steel or plastic-coated tie wire.

3.3.2.5 *Welded wire reinforcement*—Support welded wire reinforcement in accordance with CRSI RB4.1 to maintain positioning during concrete placement.

3.3.2.5(a) *Welded wire reinforcement in slabs on composite steel deck and slabs-on-ground*—Reinforcement shall be placed into position before concrete placement. Unless otherwise specified, do not extend welded wire reinforcement through movement joints. Place reinforcement as indicated in Contract Documents. If reinforcement less than W4.0 or D4.0 is specified, the continuous support spacing shall not exceed 12 in. Reinforcement nearest edge of slab shall be no farther from edge of slab than the greater of specified cover or 2 in. Unless otherwise specified, overlap parallel wires at edges of reinforcement not less than 2 in.

3.3.2.5(b) *Welded wire reinforcement in elevated formed slabs, slabs on noncomposite steel deck, and members not covered in 3.3.2.5(a)*—Use sheets of welded wire reinforcement. Place and support reinforcement before concrete placement to maintain location within tolerances indicated for nonprestressed reinforcement in ACI 117. If reinforcement less than W4.0 or D4.0 is specified, the continuous support spacing shall not exceed 12 in. perpendicular to the direction of span. Lap splice edges and ends of welded wire reinforcement sheets as indicated in Contract Documents.

3.3.2.6 *Dowels*—Deformed bar dowels shall be secured into position using templates or by tying into position before concrete placement.

3.3.2.7 *Splices*—Splice reinforcement as indicated in Contract Documents. Mechanical splices for reinforcing bars not indicated in Contract Documents shall not be used unless accepted by Architect/Engineer. Remove coating on reinforcing bar in area of mechanical splice if required by splice manufacturer. After installing mechanical splices on zinc-coated (galvanized), epoxy-coated, or zinc and epoxy dual-coated reinforcing bars, repair damaged coating and areas of removed coating in accordance with 3.2.1.2(a), 3.2.1.2(b), or 3.2.1.2(c). Coat exposed parts of mechanical splices used on coated bars with same material used to repair damaged coating.

3.3.2.8 *Field bending or straightening*—Do not field bend reinforcing bars partially embedded in concrete unless otherwise specified. If bending is permitted and unless other methods are specified, bend or straighten reinforcing bars partially embedded in concrete in accordance with 3.3.2.8(a) through 3.3.2.8(d).

3.3.2.8(a) *Cold bending*—Reinforcing bar sizes No. 3 through No. 5 may be bent cold one time, provided reinforcing bar temperature is above 32°F. For other bar sizes, preheat reinforcing bars before field bending or straightening.

3.3.2.8(b) *Preheating*—Apply heat by methods that do not harm reinforcing bar material or cause damage to concrete. Preheat length of reinforcing bar equal to at least five bar diameters in each direction from center of bend but do not extend preheating below concrete surface. Do not allow temperature of reinforcing bar at concrete interface to exceed 500°F. Preheat temperature of reinforcing bar shall

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be between 1100 and 1200°F. Maintain preheat temperature until bending or straightening is complete.

Measure preheat temperature by temperature measurement crayons or pyrometer. Do not artificially cool heated reinforcing bars until bar temperature is less than 600°F. Heat shall not be applied to low-carbon chromium reinforcement complying with ASTM A1035/A1035M. Epoxy- and dual-coated reinforcing bars shall be heated by a method that does not damage the epoxy coating.

3.3.2.8(c) *Bend diameters*—Bend diameters shall conform to requirements of Table 3.3.2.8. In addition, beginning of bend shall not be closer to concrete surface than specified bend diameter.

Table 3.3.2.8—Minimum diameter of bend

Bar size	Inside bend diameter
No. 3 through 8	Six bar diameters
No. 3 through 5 stirrups and ties	Four bar diameters
No. 9, 10, and 11	Eight bar diameters
No. 14 and 18	Ten bar diameters

3.3.2.8(d) *Repair of bar coatings*—After field bending or straightening zinc-coated (galvanized), epoxy-coated, or zinc and epoxy dual-coated reinforcing bars, repair damaged coating in accordance with 3.2.1.2(a), 3.2.1.2(b), or 3.2.1.2(c).

3.3.2.9 *Field cutting reinforcement*—Field cut after acceptance by Architect/Engineer. Do not flame cut reinforcing bars conforming to ASTM A1035/A1035M or coated reinforcement conforming to ASTM A775/A775M, A934/A934M, A1055/A1055M, A884/A884M, or A1060/A1060M.

3.3.2.9(a) If zinc-coated (galvanized) reinforcing bars are cut in field, coat bar ends with a zinc-rich formulation used in accordance with manufacturer's recommendations, and repair damaged coating in accordance with 3.2.1.2(a).

3.3.2.9(b) If epoxy-coated reinforcing bars are cut in field, coat bar ends with same material used for repair of damaged coating, and repair damaged coating in accordance with 3.2.1.2(b).

3.3.2.9(c) If zinc and epoxy dual-coated reinforcing bars are cut in field, coat bar ends with same material used for repair of damaged coating, and repair damaged coating in accordance with 3.2.1.2(c).

3.3.2.9(d) Flame cutting of stainless steel reinforcement shall be in accordance with field temperature control procedure included with submittal 3.1.2.1(h).

3.3.2.10 *Reinforcement through expansion joint*—Do not continue reinforcement or other embedded metal items bonded to concrete through expansion joints. If specified, dowels may continue through expansion joints if unbonded on one side of the joint.

SECTION 4—CONCRETE MIXTURES

4.1—General

4.1.1 *Scope*—This Section covers requirements for materials, proportioning, production, and delivery of concrete.

4.1.2 *Submittals*

4.1.2.1 *Mixture proportions*—Concrete mixture proportions and characteristics.

4.1.2.1(a) Indicate proposed ranges of mixture proportions and changes in concrete materials to adjust concrete mixtures to accommodate changes in project conditions and comply with Contract Documents.

4.1.2.1(b) Include selected slump at the point of delivery. For self-consolidating concrete mixtures, include selected slump flow at the point of delivery and results of passing ability and static segregation, if specified.

4.1.2.2 *Mixture strength data*—Field test records used to establish the required average strength in accordance with 4.2.3.3.

4.1.2.3 *Concrete materials*—The information for concrete materials in 4.1.2.3(a) through 4.1.2.3(g), along with evidence demonstrating compliance with 4.2.1.

4.1.2.3(a) For cementitious materials: types, manufacturing locations, shipping locations, and certificates showing compliance with ASTM C150/C150M, ASTM C595/C595M, ASTM C618, ASTM C989/C989M, ASTM C1157/C1157M, or ASTM C1240.

4.1.2.3(b) For aggregates: types, sizes, pit or quarry locations, producers' names, aggregate supplier statement of compliance with ASTM C33/C33M, and unless otherwise specified, ASTM C1293 expansion data not more than 24 months old.

4.1.2.3(c) For use of aggregates derived from crushed hydraulic-cement concrete or other recycled aggregates: documentation required in Contract Documents.

4.1.2.3(d) For lightweight aggregate for internal curing: aggregate supplier statement of compliance with ASTM C1761/C1761M.

4.1.2.3(e) For mineral fillers: types, quarry locations, producers' names, and supplier statement of compliance with ASTM C1797.

4.1.2.3(f) For admixtures: types, brand names, producers' names, manufacturer's technical data sheets, and certificates showing compliance with ASTM C260/C260M, ASTM C494/C494M, ASTM C1017/C1017M, or ASTM D98.

4.1.2.3(g) For water and ice: source of supply; if nonpotable source is proposed for use, documentation on effects of water on strength and setting time in compliance with ASTM C1602/C1602M. If specified, documentation on optional requirements of ASTM C1602/C1602M.

4.1.2.4 *Field test records*—Data on materials and mixture proportions with supporting test results if field test records are used as the basis for selecting proportions and documenting conformance with specified requirements, in accordance with 4.2.3.4(a) or 4.2.3.4(b).

4.1.2.5 *Trial mixture records*—Data on materials and mixture proportions with supporting test results if trial mixture records are used as a basis for documenting compliance with specified requirements in accordance with 4.2.3.4(c).

4.1.2.6 *Durability requirements*—Documentation that concrete meets durability requirements of 4.2.2.6.

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4.1.2.7 *Resistance to alkali-silica reaction*—Information on one of the options for resistance to alkali-silica reaction listed in 4.2.2.6(a).

4.1.2.8 *Modulus of elasticity*—If specified, modulus of elasticity test results in accordance with 4.2.2.8

4.1.2.9 *Mixture proportion adjustments*—Except for those submitted in 4.1.2.1, requests for adjustments to mixture proportions or changes in materials made during the course of Work, along with supporting documentation showing conformance with Contract Documents.

4.1.2.10 *Calcium chloride*—Request to use calcium chloride and data demonstrating compliance with 4.2.2.6(e).

4.1.2.11 *Volumetric batching*—Request and description of method if concrete production by the volumetric batching method is proposed.

4.1.2.12 *Limits on discharge*—Request if maximum time limit or limit on mixer revolutions for discharge of concrete permitted by ASTM C94/C94M are proposed to be exceeded.

4.1.2.13 *Certification of production facilities and delivery vehicles*—Documentation of certification or approval.

4.1.3 *Quality control*

4.1.3.1 Maintain records verifying that materials used are of types and sizes specified or accepted and are in conformance with 4.2.1.

4.1.3.2 Ensure that production and delivery of concrete conform to 4.3.1 and 4.3.2.

4.1.3.3 Ensure concrete has the specified characteristics in the freshly mixed state at delivery.

4.1.4 *Material storage and handling*

4.1.4.1 *Cementitious materials*—Keep cementitious materials dry and free from contaminants.

4.1.4.2 *Aggregates*—Store and handle aggregate in a manner that avoids segregation and prevents contamination by other materials or other sizes of aggregates. Store aggregates in locations that permit them to drain freely. Do not use aggregates that contain frozen lumps.

4.1.4.3 *Water and ice*—Protect mixing water and ice from contamination during storage and delivery.

4.1.4.4 *Admixtures*—Protect stored admixtures against contamination, evaporation, or damage. To ensure uniform distribution of constituents, provide agitating equipment for admixtures used in the form of suspensions or unstable solutions. Protect liquid admixtures from freezing and from temperature changes that would adversely affect their characteristics.

4.2—Products

4.2.1 *Materials*

4.2.1.1 *Cementitious materials*—Unless otherwise specified, cementitious materials shall conform to 4.2.1.1(a) through 4.2.1.1(g). Use cementitious materials that meet the durability criteria of 4.2.2.6.

4.2.1.1(a) Portland cement conforming to ASTM C150/C150M.

4.2.1.1(b) Blended hydraulic cement, excluding Type IS (>70), conforming to ASTM C595/C595M. For sections of structure that are assigned Exposure Class F3, submit certification on cement composition verifying that concrete mixture conforms to Table 4.2.1.1(b).

Table 4.2.1.1(b)—Limits on supplementary cementitious materials for concrete assigned to Exposure Class F3

Supplementary cementitious material	Maximum percent of total cementitious material by mass*
Fly ash or natural pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989/C989M	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or natural pozzolans, slag cement, and silica fume	50†
Total of fly ash or natural pozzolans and silica fume	35†

*Total cementitious material also includes ASTM C150/C150M, C595/C595M, and C1157/C1157M cement. The maximum percentages above shall include:

(a) Fly ash or natural pozzolans present in ASTM C1157/C1157M or C595/C595M Type IP blended cement.

(b) Slag cement present in ASTM C1157/C1157M or C595/C595M Type IS blended cement.

(c) Silica fume conforming to ASTM C1240 present in ASTM C1157/C1157M or C595/C595M Type IP blended cement.

†Fly ash or natural pozzolans and silica fume shall constitute no more than 25 percent and 10 percent, respectively, of the total mass of the cementitious materials.

4.2.1.1(c) Hydraulic cement conforming to ASTM C1157/C1157M. For sections of structure that are assigned Exposure Class F3, submit certification on cement composition verifying that concrete mixture conforms to Table 4.2.1.1(b).

4.2.1.1(d) Fly ash or natural pozzolans conforming to ASTM C618.

4.2.1.1(e) Slag cement conforming to ASTM C989/C989M.

4.2.1.1(f) Silica fume conforming to ASTM C1240.

4.2.1.1(g) Use cementitious materials of same brand and type and from same manufacturing plant as cementitious materials used in concrete represented by submitted field test records or used in trial mixtures.

4.2.1.2 *Aggregates*—Unless otherwise specified, aggregates shall conform to ASTM C33/C33M. Aggregates used in concrete shall be obtained from the same sources and have the same size range as aggregates used in concrete represented by submitted field test records or used in trial mixtures. Aggregates determined to be susceptible to alkali-carbonate reactions in accordance with ASTM C1778 shall not be used.

4.2.1.2(a) Unless otherwise specified, aggregate derived from crushed hydraulic-cement concrete or other recycled aggregate is permitted if documentation required by Architect/Engineer is submitted and its use is accepted.

4.2.1.3 *Lightweight aggregate for internal curing*—Lightweight aggregate for internal curing shall be limited to prewetted fine aggregate conforming to ASTM C1761/C1761M.

4.2.1.4 *Water and ice*—Unless otherwise specified, mixing water for concrete and water used to make ice shall comply with ASTM C1602/C1602M.

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4.2.1.5 *Mineral fillers*—Unless otherwise specified, mineral fillers shall conform to ASTM C1797. Mineral fillers used in concrete shall be obtained from the same sources and be of the same types as those used in concrete represented by submitted field test records or used in trial mixtures. Unless otherwise specified, mineral filler derived from carbonate sources shall not be used in concrete for members assigned to Exposure Classes S1, S2, and S3.

4.2.1.6 *Admixtures*—Unless otherwise specified, admixtures shall conform to the following:

(a) Air-entraining admixtures conforming to ASTM C260/C260M.

(b) Chemical admixtures conforming to ASTM C494/C494M or ASTM C1017/C1017M.

(c) Calcium chloride conforming to ASTM D98. Use calcium chloride admixtures in solution form only.

4.2.1.6.1 Admixtures used in concrete shall be the same as those used in the concrete represented by submitted field test records or used in trial batches.

4.2.1.6.2 Calcium chloride admixtures shall not be used for concrete in members assigned to Exposure Classes S2 or S3. Use of chemical admixtures containing chloride ions shall be subject to limitations in 4.2.2.6(e).

4.2.1.7 *Steel fibers*—If steel fiber-reinforced concrete is specified in Contract Documents for providing shear resistance, steel fibers shall be deformed and conform to ASTM A820/A820M. Steel fibers shall have a length-to-diameter ratio of at least 50 and not exceed 100. Steel fibers for other applications shall be in accordance with Contract Documents.

4.2.1.8 *Change of materials*—If changes to brand, type, size, or source of cementitious materials; aggregates; water; ice; or admixtures are proposed, submit new field data, data from new trial batches, or other evidence that the change will not adversely affect relevant properties of concrete. Submit data before changes are made.

4.2.2 *Performance and design requirements*

4.2.2.1 *Slump*—Unless otherwise specified, select a target slump at the point of delivery for concrete mixtures used for Work. Selected target slump shall not exceed 9 in. Concrete shall not show visible signs of segregation. The target slump indicated on the submittal shall be used as the basis for acceptance during the project. Determine the slump by ASTM C143/C143M. Slump tolerances shall be in accordance with ACI 117.

4.2.2.2 *Self-consolidating concrete*—Unless otherwise specified, select a target slump flow at the point of delivery for self-consolidating concrete mixtures. Selected target slump flow shall not exceed 30 in. Concrete shall not show visible signs of segregation. The target slump flow value indicated on the submittal shall be used as the basis for acceptance during the project. Determine slump flow in accordance with ASTM C1611/C1611M. Slump flow tolerances shall be in accordance with ASTM C94/C94M. If specified, evaluate during the mixture qualification stage, proposed concrete mixtures for passing ability in accordance with ASTM C1621/C1621M and for static segregation in accordance with ASTM C1610/C1610M to meet criteria indicated in Contract Documents.

4.2.2.3 *Size of coarse aggregate*—Unless otherwise specified, nominal maximum size of coarse aggregate shall not exceed three-fourths of the minimum clear spacing between reinforcement, one-fifth of the narrowest dimension between sides of forms, or one-third of the thickness of slabs or toppings.

4.2.2.4 *Air content*

4.2.2.4(a) Concrete shall be air entrained for members assigned to Exposure Class F1, F2, or F3. The total air content shall be in accordance with 4.2.2.6(c), unless otherwise specified.

4.2.2.4(b) Unless otherwise specified, measure air content in accordance with ASTM C173/C173M or ASTM C231/C231M.

4.2.2.4(c) Unless otherwise specified, measure air content at point of delivery.

4.2.2.4(d) Concrete for slabs to receive a hard-troweled finish shall not contain an air-entraining admixture or have a total air content greater than 3 percent.

4.2.2.5 *Concrete temperature*

4.2.2.5(a) *Minimum temperature*—If the average of highest and lowest ambient temperature from midnight to midnight is expected to be less than 40°F for more than 3 successive days, deliver concrete to meet the following minimum temperatures immediately after placement unless otherwise specified:

(a) 55°F for sections with least dimension less than 12 in.

(b) 50°F for sections with least dimension 12 to 36 in.

(c) 45°F for sections with least dimension 36 to 72 in.

(d) 40°F for sections with least dimension greater than 72 in.

Temperature of concrete as placed shall not exceed these values by more than 20°F. These minimum temperature requirements may be terminated if temperatures above 50°F occur during more than half of any 24-hour duration.

4.2.2.5(b) *Maximum temperature*—Unless otherwise specified, temperature of concrete as delivered shall not exceed 95°F.

4.2.2.6 *Durability*

4.2.2.6(a) *Resistance to alkali-silica reaction*—Unless otherwise specified, or unless members are designated as being dry in service and not in contact with ground, or assigned to Exposure Class W0, use one of the three following options for qualifying concrete mixtures to reduce the potential of alkali-silica reaction.

Option (c) shall not be used with natural pozzolan or fly ash that has a CaO content greater than 18 percent, or for aggregate with expansion at 1 year greater than or equal to 0.24 percent when tested in accordance with ASTM C1293. Fly ash with an alkali content greater than 4.0 percent shall not be used in option (b) or (c).

(a) For each aggregate used in concrete, expansion determined in accordance with ASTM C1293 shall not exceed 0.04 percent at 1 year.

(b) For each aggregate used in concrete, expansion of the aggregate and cementitious materials combination determined in accordance with ASTM C1567 shall not exceed

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Table 4.2.2.6(b)—Requirements for Exposure Category S: sulfate exposure

Exposure class		Maximum *w/cm**	Minimum f_c', psi	Required cementitious materials†—types			Calcium chloride admixture
				ASTM C150/C150M	ASTM C595/C595M	ASTM C1157/C1157M	
S0		NA	2500	NA	NA	NA	No restriction
S1		0.50	4000	II‡§	Types with (MS) designation	MS	No restriction
S2		0.45	4500	V§	Types with (HS) designation	HS	Not permitted
S3	Option 1	0.45	4500	V plus pozzolan or slag cement‖	Types with (HS) designation plus pozzolan or slag cement‖	HS plus pozzolan or slag cement‖	Not permitted
	Option 2	0.40	5000	V#	Types with (HS) designation	HS	Not permitted

*The maximum *w/cm* limits do not apply to lightweight concrete.

†Alternative combinations of cementitious materials of those listed in this table are acceptable if tested for sulfate resistance and meeting the criteria in Table 4.2.2.6(b)1.

‡For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10 percent are acceptable if the *w/cm* does not exceed 0.40.

§Other available types of cement, such as Type III or Type I, are acceptable in Exposure Classes S1 or S2 if the C_3A contents are less than 8 or 5 percent, respectively.

‖The amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag used shall not be less than the amount tested in accordance with ASTM C1012/C1012M and meeting the requirements of Table 4.2.2.6(b)1.

#If Type V cement is used as the sole cementitious material, the optional sulfate resistance requirement of 0.040 percent maximum expansion in ASTM C150/C150M is applicable.

0.10 percent at an age of 16 days. Submit supporting data for each aggregate showing expansion in excess of 0.10 percent at 16 days when tested in accordance with ASTM C1260.

(c) Alkali content in concrete (LBA), excluding that from supplementary cementitious materials and pozzolan and slag cement in blended cements, shall not exceed 4 lb/yd^3 for aggregate with expansion greater than or equal to 0.04 percent and less than 0.12 percent or not exceed 3 lb/yd^3 for aggregate with expansion greater than or equal to 0.12 percent and less than 0.24 percent. Reactivity shall be determined by testing in accordance with ASTM C1293. Alkali content in concrete (LBA) shall be calculated as follows:

LBA = (cement content, lb/yd^3) × (equivalent alkali content of portland cement in percent/100 percent)

4.2.2.6(b) *Sulfate resistance*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.6(b), based on the exposure class assigned to members for sulfate exposure, or meeting other requirements specified in Contract Documents. Submit documentation verifying compliance with specified requirements.

Table 4.2.2.6(b)1—Requirements for establishing suitability of cementitious materials combinations exposed to water-soluble sulfate

Exposure class At 6 months		Maximum expansion when tested in accordance with ASTM C1012/C1012M, percent		
		At 6 months	At 12 months	At 18 months
S1		0.10	NA	NA
S2		0.05	0.10*	NA
S3	Option 1	NA	NA	0.10
	Option 2	0.05	0.10*	NA

*The 12-month expansion limit applies only if the measured expansion exceeds the 6-month maximum expansion limit.

4.2.2.6(c) *Freezing-and-thawing resistance*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.6(c) based on exposure class assigned to members for freezing-and-thawing exposure, or meeting other requirements specified in Contract Documents. Submit documentation verifying compliance with specified requirements.

Table 4.2.2.6(c)—Requirements for Exposure Category F: Freezing-and-thawing exposure

Exposure class	Maximum *w/cm**	Minimum f_c', psi	Air content	Additional requirements
F0	NA	2500	NA	
F1	0.55	3500	Table 4.2.2.6(c)1	NA
F2	0.45	4500	Table 4.2.2.6(c)1	NA
F3	0.40	5000	Table 4.2.2.6(c)1	Table 4.2.1.1(b)
F3 plain concrete	0.45	4500	Table 4.2.2.6(c)1	Table 4.2.1.1(b)

*The maximum *w/cm* limits do not apply to lightweight concrete.

Table 4.2.2.6(c)1—Total air content for concrete exposed to cycles of freezing and thawing

Nominal maximum aggregate size, in.	Total air content, percent*†	
	Exposure Classes F2 and F3	Exposure Class F1
3/8	7.5	6.0
1/2	7.0	5.5
3/4	6.0	5.0
1	6.0	4.5
1-1/2	5.5	4.5
2	5.0	4.0
3	4.5	3.5

*Tolerance on air content as delivered shall be ±1.5 percent.

†For f_c' equal to or greater than 5000 psi, it is acceptable to reduce air content by 1.0 percentage point.

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4.2.2.6(d) *In contact with water*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.6(d) based on exposure class assigned to members in contact with water, or meeting other requirements specified in Contract Documents. Submit documentation verifying compliance with specified requirements.

Table 4.2.2.6(d)—Requirements for Exposure Category W in contact with water

Exposure class	Maximum *w/cm**	Minimum f_c', psi	Additional minimum requirements
W0	NA	2500	None
W1	NA	2500	4.2.2.6(a)
W2	0.50	4000	4.2.2.6(a)

*The maximum *w/cm* limits do not apply to lightweight concrete.

4.2.2.6(e) *Corrosion protection of reinforcement*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.6(e) based on the exposure class assigned to members requiring protection against reinforcement corrosion, or meeting other requirements specified in Contract Documents. Submit documentation verifying compliance with specified chloride ion limits using either one of the following:

(1) Total chloride ion content calculated from measured chloride ion content of concrete materials and mixture proportions. Chloride ion contents of cementitious materials and mixing water shall be determined in accordance with ASTM C114; of aggregates on samples prepared as specified for concrete samples and tested in accordance with ASTM C1152/C1152M; and of admixtures as reported by the manufacturer. Total chloride content so determined shall be less than the limit for water-soluble chloride ions in Table 4.2.2.6(e).

(2) Water-soluble chloride ion content of a hardened sample from the concrete mixture determined in accordance with ASTM C1218/C1218M at an age between 28 and 42 days.

Table 4.2.2.6(e)—Requirements for Exposure Category C: Conditions requiring corrosion protection of reinforcement

Exposure class	Maximum *w/cm**	Minimum f_c', psi	Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by mass of cementitious materials†
Nonprestressed concrete			
C0	NA	2500	1.00
C1	NA	2500	0.30
C2	0.40	5000	0.15
Prestressed concrete			
C0	NA	2500	0.06
C1	NA	2500	0.06
C2	0.40	5000	0.06

*The maximum *w/cm* limits do not apply to lightweight concrete.

†The maximum cementitious materials content used in determining chloride content shall not exceed two times the mass of portland cement.

4.2.2.6(f) *Corrosion protection of stay-in-place galvanized forms*—Unless otherwise specified, the maximum water-soluble chloride ion content in concrete cast on stay-in-place galvanized forms shall comply with the limits for Exposure Class C1.

4.2.2.7 *Strength and* w/cm—The compressive strength and, if required, maximum *w/cm* of the concrete for each portion of Work, shall be as specified in Contract Documents.

4.2.2.7(a) Unless otherwise specified, strength requirements shall be based on compressive strength tests at 28 days. Compressive strength is measured using 6 x 12 in. or 4 x 8 in. cylindrical specimens made from the same sample of concrete, taken in accordance with ASTM C172/C172M at the point of delivery, handled and standard cured in accordance with ASTM C31/C31M, and tested in accordance with ASTM C39/C39M. A strength test at designated age is the average of at least two 6 x 12 in. cylinders or the average of at least three 4 x 8 in. cylinders made from the same concrete sample.

4.2.2.8 *Modulus of elasticity*—If specified, submit test data for modulus of elasticity of proposed concrete mixtures. Modulus of elasticity shall be determined as the average of at least three cylinders made and cured in accordance with ASTM C192/C192M from the same concrete sample and tested in accordance with ASTM C469/C469M. Unless otherwise specified, test age shall be 28 days. Unless otherwise specified, average modulus of elasticity shall be equal to or exceed the specified value.

4.2.2.9 *Steel fiber-reinforced concrete*—If steel fiber-reinforced concrete is specified for providing shear resistance, the concrete mixture shall conform to ASTM C1116/C1116M. Unless otherwise specified, the mixture shall contain at least 100 lb of steel fibers per cubic yard of concrete and shall meet the requirements of 1.7.7. Steel fiber-reinforced concrete for other applications shall be in accordance with Contract Documents.

4.2.3 *Proportioning*

4.2.3.1 Proportion concrete to comply with 4.2.2 and so concrete can be worked readily into forms and around reinforcement without segregation, and to provide an average compressive strength to meet acceptance requirements of 1.7.6.1.

4.2.3.2 *Sample standard deviation*

4.2.3.2(a) *Field strength test records*—Field strength test records used to calculate sample standard deviation shall represent materials, mixture proportions, quality-control procedures, and climatic conditions similar to those expected in Work. Field strength test records shall have been obtained within the past 24 months and spanning no less than 45 calendar days for a class of concrete within 1000 psi of that specified for Work. Test records shall comply with one of the following:

(a) Data from a single group of at least 15 consecutive compressive-strength tests with the same mixture proportions.

(b) Data from two groups of consecutive compressive-strength tests totaling at least 30 compressive-strength tests. Neither of the two groups shall consist of fewer than 10 tests.

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4.2.3.2(b) *Calculate sample standard deviation*—Calculate the sample standard deviation s_s of strength test records as follows:

(a) For a single group of consecutive strength test results

$$s_s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{(n-1)}} \qquad (4.2.3.2(b)a)$$

where s_s is sample standard deviation; n is number of test results considered; $\bar{X}$ is average of n test results considered; and X_i is a test result

(b) For two groups of consecutive strength test results

$$s_s = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1+n_2-2)}} \qquad (4.2.3.2(b)b)$$

where s_s is standard deviation for the two groups combined; s_1 and s_2 are standard deviations for Groups 1 and 2, respectively, calculated in accordance with Eq. (4.2.3.2(b)a); and n_1 and n_2 are number of test results in Groups 1 and 2, respectively.

4.2.3.3 *Required average compressive strength* f_{cr}'—Calculate f_{cr}' for specified class of concrete in accordance with 4.2.3.3(a) or 4.2.3.3(b).

4.2.3.3(a) Use the sample standard deviation calculated in accordance with 4.2.3.2 to establish f_{cr}' in accordance with Table 4.2.3.3(a)1. Use the k-factor in Table 4.2.3.3(a)2 to adjust for total number of test results considered in calculating the sample standard deviation. Use larger of two values of f_{cr}' calculated.

Table 4.2.3.3(a)1—Required average compressive strength f_{cr}' if data are available to establish a sample standard deviation, psi

f_c', psi	f_{cr}', psi Use the larger of:
5000 or less	$f_{cr}' = f_c' + 1.34ks_s$
	$f_{cr}' = f_c' + 2.33ks_s - 500$
Over 5000	$f_{cr}' = f_c' + 1.34ks_s$
	$f_{cr}' = 0.90f_c' + 2.33ks_s$

Notes: f_{cr}' is required average compressive strength; f_c' is specified concrete strength; k is factor from Table 4.2.3.3(a)2; and s_s is standard deviation calculated in accordance with 4.2.3.2.

Table 4.2.3.3(a)2—*k*-factor for increasing sample standard deviation for number of strength tests considered in calculating standard deviation

Total number of tests considered	*k*-factor for increasing sample standard deviation
15	1.16
20	1.08
25	1.03
30 or more	1.00

Note: Linear interpolation for intermediate number of tests is acceptable.

4.2.3.3(b) If field strength test records are not available to calculate sample standard deviation, establish required average compressive strength f_{cr}' in accordance with Table 4.2.3.3(b).

Table 4.2.3.3(b)—Required average compressive strength f_{cr}' if data are not available to establish standard deviation

f_c', psi	f_{cr}', psi
Less than 3000	$f_c' + 1000$
3000 to 5000	$f_c' + 1200$
Over 5000	$1.1f_c' + 700$

4.2.3.4 *Documentation of average compressive strength*—Provide documentation indicating proposed concrete proportions will produce an average compressive strength equal to or greater than required average compressive strength. Documentation shall consist of field strength test records in accordance with 4.2.3.4(a) or 4.2.3.4(b), or test results of trial mixtures in accordance with 4.2.3.4(c).

4.2.3.4(a) *Field strength test data for single group of strength tests*—If field strength test data are available and represent a single group of at least 10 consecutive strength tests for one mixture, using materials and conditions similar to those expected for Work, and encompassing a period of not less than 45 days, the average of field strength tests shall equal or exceed f_{cr}'.

4.2.3.4(b) *Field strength test data for groups of strength tests*—If field strength test data represent two or more groups of strength tests for two or more mixtures with average strengths that encompass f_{cr}', plot the average strength of each group versus the *w*/*cm* or cementitious material content of the corresponding mixture proportions and interpolate between them to establish the required *w*/*cm* or cementitious material content to achieve f_{cr}'. Establish mixture proportions for f_{cr}' based on the required *w*/*cm* or cementitious material content.

4.2.3.4(c) *Trial mixtures*—Establish proportions for concrete mixtures proposed for Work based on laboratory or production trial mixtures to comply with the following:

(a) Use materials that conform to 4.2.1.1 through 4.2.1.7.

(b) Determine f_{cr}' in accordance with 4.2.3.3(a) if suitable field strength test data are available, or use Table 4.2.3.3(b).

(c) Make at least three trial mixtures for each concrete class with a range of proportions that will produce a range of compressive strengths that will encompass f_{cr}'. For concrete made with more than one type of cementitious material, the concrete supplier shall establish the *w*/*cm* and the relative proportions of the cementitious materials and admixtures, if any, that will produce required average compressive strength.

(d) Proportion trial mixtures to produce a slump as specified for proposed Work, and for air-entrained concrete, air content within the tolerance specified for proposed Work.

(e) For each trial mixture, make and cure three compressive strength cylinders for each test age in accordance

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with ASTM C192/C192M for laboratory trial mixtures or ASTM C31/C31M for production trial mixtures. Test for compressive strength in accordance with ASTM C39/C39M at 28 days or at the designated test age for f_c'.

(f) Establish mixture proportions based on trial mixture data to achieve an average compressive strength of at least f_{cr}' as determined in 4.2.3.3 and to not exceed maximum *w/cm*. The proposed concrete mixture shall meet other applicable requirements of 4.2.2.6 and trial mixture records shall have been developed less than 24 months from the date of submittal.

4.2.3.5 *Field verification of selected mixture proportions*—If required, conduct field verification of the effects of placement methods on concrete mixture characteristics. Using materials and mixture proportions accepted for use in Work, verify that concrete can be placed using the intended placing method. Place concrete mixture using project equipment and personnel. Evaluate the effect of placement methods on slump and air content. Make suitable corrections to placing methods or to mixture proportions, if needed. Submit adjustments to mixture proportions.

4.2.3.6 *Revisions to concrete mixtures*—When 15 consecutive compressive strength tests become available from the field, calculate the average compressive strength and standard deviation. Calculate a revised value for f_{cr}' in accordance with 4.2.3.3(a).

4.2.3.6(a) If actual average compressive strength $\bar{X}$ exceeds the revised value of f_{cr}' and requirements of 1.7.6.1 are met, it is acceptable to modify mixture proportions to achieve an average strength equal to the revised value of f_{cr}'. The revised mixture shall meet requirements of 4.2.2.

4.2.3.6(b) If actual average compressive strength $\bar{X}$ is less than revised value of f_{cr}' or if either of the two requirements in 1.7.6.1 is not met, take immediate steps to increase average compressive strength of the concrete.

4.2.3.6(c) Submit revised mixture proportions for acceptance before placing modified concrete in Work.

4.3—Execution

4.3.1 *Measuring, batching, and mixing*—Production facilities shall produce concrete of specified quality and conforming to this Specification.

4.3.1.1 *Ready mixed and site-produced concrete*—Unless otherwise specified, measure, batch, and mix concrete materials and concrete in conformance to ASTM C94/C94M. Unless otherwise specified, concrete production facilities and delivery vehicles shall be certified by the NRMCA Program for Certification of Ready Mixed Concrete Facilities, approved by a state highway agency, or certified by an equivalent program that audits for conformance to requirements of ASTM C94/C94M for production and delivery.

4.3.1.2 *Concrete produced by volumetric batching and continuous mixing*—Concrete produced by volumetric batching and continuous mixing shall conform to ASTM C685/C685M.

4.3.1.3 *Prepackaged dry materials used in concrete*—If packaged dry-combined materials are used, they shall conform to ASTM C387/C387M and satisfy requirements of this Specification.

4.3.2 *Delivery*—Transport and deliver concrete in equipment conforming to ASTM C94/C94M.

4.3.2.1 *Adjustments*—Unless otherwise specified, if concrete slump, slump flow, or air content determined on a preliminary sample in accordance with ASTM C94/C94M is less than required, adjustments are permitted by using admixtures or adding water up to amount allowed in accepted mixture proportions. Adjustment of mixture using admixtures or water shall be in accordance with ASTM C94/C94M. Do not exceed specified maximum *w/cm* or *w/cm* used in proportioning the concrete. Do not add water to concrete after discharge of more than 5 percent of delivered quantity. Measure slump, or slump flow, and air content of air-entrained concrete after adjustments to verify compliance with specified requirements.

4.3.2.2 *Limits on discharge*—Unless otherwise specified, discharge limits shall comply with ASTM C94/C94M. If discharge is acceptable after more than 1-1/2 hours have elapsed since batching, verify that air content of air-entrained concrete, slump, and temperature of concrete are as specified.

SECTION 5—HANDLING, PLACING, AND CONSTRUCTING

5.1—General

5.1.1 *Scope*—This Section covers the construction of cast-in-place concrete. Included are procedures for handling, placing, finishing, curing, and repair of surface defects.

5.1.2 *Submittals*

5.1.2.1 Submit the information specified in 5.1.2.1(a) through 5.1.2.1(j).

5.1.2.1(a) *Resolution of nonconformance*—Documentation of resolution of nonconformance identified on quality assurance test and inspection reports.

5.1.2.1(b) *Temperature measurement*—Proposed method for complying with requirements for measuring concrete temperatures.

5.1.2.1(c) *Qualifications of finishers*—Qualifications, as specified in 5.3.4.1, of finishing contractor and of flatwork finishers who will perform Work.

5.1.2.1(d) *Placement notification*—Notification of concrete placement at least 24 hours before placement.

5.1.2.1(e) *Preplacement plan*—Planned actions before concrete placement.

5.1.2.1(f) *Preplacement meeting*—Agenda for preplacement meeting to be held before start of placement activities.

5.1.2.1(g) *Temporary form spreaders*—Request to leave form spreaders in place.

5.1.2.1(h) *Qualifications of Adhesive Anchor Installers*–Qualifications of personnel who install adhesive anchors as described in 5.3.8.

5.1.2.1(i) *Contraction or expansion joints*—If contraction or expansion joints other than those indicated in Contract Documents are proposed, submit locations.

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5.1.2.1(j) *Sawed joints in slabs*—Submit request to saw joints in slabs or cut reinforcement at sawn joints in a manner that is not indicated in Contract Documents.

5.1.2.2 If specified, submit information specified in 5.1.2.2(a) through 5.1.2.2(m).

5.1.2.2(a) *Conveying equipment*—Description of conveying equipment.

5.1.2.2(b) *Surface cleaning*—If removal of stains, rust, efflorescence, and surface deposits is specified as described in 5.3.7.6, submit proposed method of removal.

5.1.2.2(c) *Wet-weather protection*—Wet-weather protection activities.

5.1.2.2(d) *Hot-weather placement*—Request for concrete temperature limit different than specified in 5.3.2.1(c), including documentation and procedures to demonstrate compliance with other requirements in Contract Documents.

5.1.2.2(e) *Cold-weather placement and protection activities*—Request for acceptance of proposed cold-weather placement, temperature-measuring methods, and protection activities.

5.1.2.2(f) *Initial curing*—Methods to be used for initial curing.

5.1.2.2(g) *Retarder for exposed-aggregate surface*—Manufacturer's data on retarder and proposed method of use if surface retarder is proposed for specified exposed-aggregate surface.

5.1.2.2(h) *Bonding agent*—If bonding material other than cement grout is proposed for two-course slabs or construction joints, submit applicable specification and manufacturer's data on bonding agent.

5.1.2.2(i) *Underwater placement*—If underwater placement is planned, submit proposed method.

5.1.2.2(j) *Curing method*—If a moisture-preserving method other than specified in 5.3.6 is proposed, submit the proposed method.

5.1.2.2(k) *Surface repair materials*—If a surface repair material other than that described in 5.2.1.6 is proposed, submit applicable repair material specification, manufacturer's data on the proposed repair material, and proposed preparation and application procedure.

5.1.2.2(l) *Installing sawed joints*—If proposed installation of sawed joints differs from 5.3.5.1, submit alternative.

5.1.2.2(m) *Preparing surfaces at construction joints*—If preparation methods needed to bond fresh concrete to hardened concrete are different from methods in 5.3.2.6(c) or 5.3.4.2(a), submit proposed methods.

5.1.2.3 *Joints not shown in Contract Documents*

5.1.2.3(a) Submit information on proposed location and treatment of construction joints not indicated in Contract Documents.

5.1.2.3(b) If movement joints other than those indicated in Contract Documents are proposed, submit locations.

5.1.3 *Delivery, storage, and handling*—Deliver, store, and handle products in accordance with manufacturer's recommendations. Do not use products stored beyond manufacturer's recommended shelf life.

5.2—Products

5.2.1 *Materials*

5.2.1.1 *Water for curing*—Unless otherwise specified, do not use seawater or water containing substances that will discolor or impair the durability of the concrete member.

5.2.1.2 *Curing compounds*—Unless otherwise specified, use membrane-forming curing compounds that conform to ASTM C309 or ASTM C1315. Silicate-based liquid surface densifiers are prohibited as curing compounds.

5.2.1.3 *Sheet materials for curing*—Unless otherwise specified, use sheet materials that conform to ASTM C171.

5.2.1.4 *Absorbent materials*—Unless otherwise specified, absorbent materials shall meet the requirements of AASHTO M 182.

5.2.1.5 *Evaporation reducers*—Liquid-applied evaporation reducers shall form a continuous film and reduce moisture loss from fresh concrete surface.

5.2.1.6 *Surface repair materials*—Unless otherwise specified, use repair mortar to repair surface defects. For concrete exposed to view, repair mortar shall match adjacent concrete color.

5.2.1.7 *Bonding material*—Accepted bonding agent applied in accordance with the manufacturer's requirements or portland-cement grout of the same proportions as the mortar in the concrete.

5.2.1.8 *Scrub coat*—For scrub coat material, mix one part portland cement and one part sand by loose volume with water. Use sand meeting the requirements of ASTM C144 or ASTM C404.

5.3—Execution

5.3.1 *Preparation*

5.3.1.1 Do not place concrete until data on materials and mixture proportions are accepted.

5.3.1.2 Remove hardened concrete and foreign materials from inner surfaces of conveying equipment.

5.3.1.3 Before placing concrete in forms, complete the following:

(a) Comply with formwork requirements specified in Section 2.

(b) Remove snow, ice, frost, water, and other foreign materials from surfaces against which concrete will be cast, and from reinforcement and embedded items.

(c) Comply with reinforcement placement requirements specified in Section 3.

5.3.1.4 Before placing a concrete slab-on-ground, remove contaminating materials from contact surface and complete the following:

(a) Subgrade and base shall be prepared in accordance with Contract Documents.

(b) Tolerance for the base material elevation shall be in accordance with ACI 117.

5.3.1.5 Make provisions in advance of concrete placement to limit the rate of evaporation of water from concrete surface during or immediately after placing or finishing.

5.3.1.6 During ambient temperature conditions described in 4.2.2.5(a), cure and protect the concrete in accordance with 5.3.6.5. Use heating, covering, or other means to main-

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tain required temperature without drying of concrete. Do not use unvented combustion heaters.

5.3.2 *Placement of concrete*

5.3.2.1 *Weather considerations*

5.3.2.1(a) *Wet weather*—Do not place concrete while rain, sleet, or snow is falling unless protection is provided. Do not allow precipitation to increase mixing water or to damage concrete surface.

5.3.2.1(b) *Cold weather*—Concrete temperatures at delivery shall meet the requirements of 4.2.2.5(a). Unless otherwise specified, massive metallic embedded items in concrete, including piping and conduit equal to or less than 1/4 in. wall thickness and individual or bundled metallic embedded items with a cumulative cross-sectional area less than 4 in.^{2}, shall be above 10°F. Maintain formwork contact surface temperature above 10°F and insulate or heat formwork as required to protect concrete from freezing. Maintain contact surface temperature above 32°F if placing concrete in contact with ground, subbase, or mud mat.

5.3.2.1(c) *Hot weather*—Unless otherwise specified, concrete temperature as placed shall meet the requirements of 4.2.2.5(b). If temperature of reinforcement, embedments, or forms is greater than 120°F, use a fine mist of water to moisten and cool hot surfaces. Remove standing water before placing concrete.

5.3.2.2 *Conveying*—Convey concrete from mixer to final deposition using equipment in 5.3.2.3 by methods that do not result in segregation or loss of constituents.

5.3.2.3 *Conveying equipment*—Use conveying equipment of sufficient capacity to meet the requirements of 5.3.2.4. Conveying equipment in contact with concrete shall not be made of aluminum.

5.3.2.3(a) Use belt conveyors with a discharge baffle or hopper at discharge end. Slope of conveyors shall not cause segregation on belt.

5.3.2.3(b) Use metal or metal-lined chutes having rounded bottoms, and sloped between 1:2 and 1:3. Chutes longer than 20 ft and chutes not meeting slope requirements may be used, provided discharge is into a hopper before distributing into forms.

5.3.2.3(c) Use pumping equipment that has sufficient capacity so that:

(a) Discharge of pumped concrete does not result in segregation.

(b) Modification of accepted concrete mixture is not required.

5.3.2.4 *Depositing*

5.3.2.4(a) Deposit concrete as near as practicable to its final position in the placement in a manner that does not cause segregation.

5.3.2.4(b) Deposit concrete in one layer or in multiple layers. Do not place fresh concrete against concrete that would result in cold joints unless construction joint requirements of 5.3.2.6 are met.

5.3.2.4(c) Do not place concrete that is contaminated with materials that are not specified or accepted.

5.3.2.4(d) Do not place concrete if it cannot be consolidated by available methods.

5.3.2.4(e) If temporary spreaders are used in forms, remove spreaders as the concrete is placed. Spreaders may be left in place if prior acceptance is obtained.

5.3.2.4(f) Unless otherwise specified, if placing beams, girders, or slabs monolithically with columns or walls, place horizontal elements after the underlying concrete is consolidated and there is no bleed water on the surface of vertical supporting member.

5.3.2.4(g) Place concrete for beams, girders, brackets, column capitals, haunches, and drop panels at same time as concrete for adjacent slabs.

5.3.2.4(h) If underwater placement is required, place concrete by an acceptable method. Deposit fresh concrete so concrete enters the mass of previously placed concrete and not in contact with water.

5.3.2.4(i) As indicated in Contract Documents, where higher-strength concrete used for columns and walls is required to be integrated with floor systems, extend higher-strength concrete through full floor system depth at least 2 ft past each face of columns and walls. Integrate and consolidate the concretes to achieve a monolithic mass.

5.3.2.5 *Consolidating*—Unless otherwise specified, consolidate concrete by vibration. Consolidate concrete around reinforcement, embedded items, and into corners of forms. Use immersion-type vibrators with nonmetallic heads for consolidating concrete around epoxy-coated or zinc and epoxy dual-coated reinforcing bars. Do not use vibrators to move concrete in a manner that will result in segregation. Spacing of immersion vibrator insertions shall not exceed 1-1/2 times the vibrator's radius of action in concrete being consolidated.

5.3.2.6 *Construction joints*—Install construction joints in accordance with 2.2.2.5. Remove laitance, clean, and dampen construction joints before placement of fresh concrete. If bond is required, use one of the following methods:

(a) Use a bonding material in accordance with 5.2.1.7.

(b) Use an acceptable surface retarder in accordance with manufacturer's recommendations.

(c) Finish the first concrete placement in accordance with 5.3.4.2(a) or roughen surface in a manner that exposes coarse aggregate and does not leave laitance, loosened aggregate particles, or damaged concrete at surface.

5.3.3 *Finishing formed surfaces*

5.3.3.1 *General*—Unless otherwise specified, provide surface finish on formed concrete surfaces in accordance with 5.3.3.1(a) or 5.3.3.1(b).

5.3.3.1(a) Provide surface finish SF-1 as defined in 5.3.3.2(a) for metal lap pan deck formed surfaces or if Contract Documents indicate that surfaces are buried or covered with subsequently installed building systems. Subsequently installed building systems hide the concrete surface from view in the completed structure, and do not include paints, sealers, or other materials that do not hide underlying concrete surface imperfections.

5.3.3.1(b) Provide surface finish SF-2, as defined in 5.3.3.2(b), for concrete surfaces other than those described in 5.3.3.1(a).

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5.3.3.2 *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Provide as-cast formed finishes to comply with 5.3.3.2(a), 5.3.3.2(b), or 5.3.3.2(c) as indicated in Contract Documents.

5.3.3.2(a) *Surface finish SF-1:*

(a) No formwork facing material is specified
(b) Patch voids larger than 1-1/2 in. wide or 1/2 in. deep
(c) Remove projections larger than 1 in.
(d) Tie holes need not be patched
(e) Surface tolerance Class D as specified in ACI 117

5.3.3.2(b) *Surface finish SF-2:*

(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/4 in.
(c) Patch tie holes
(d) Surface tolerance Class B as specified in ACI 117

5.3.3.2(c) *Surface finish SF-3:*

(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/8 in.
(c) Patch tie holes
(d) Surface tolerance Class A as specified in ACI 117

5.3.3.3 *Rubbed finish*—Provide a rubbed finish in accordance with Contract Documents. Rubbed finishes are permitted at time of form removal or delayed until work areas are accessible.

5.3.3.3(a) If finish is applied at form removal, wet the surface and rub it with an abrasive stone to draw out mortar and fill surface voids.

5.3.3.3(b) If rubbing is delayed or insufficient cement paste can be drawn from the concrete, mix grout consisting of 1 part by volume portland cement, 1-1/2 parts sand meeting the requirements of ASTM C144 or ASTM C404, and sufficient water to produce the consistency of thick paint. If accepted, packaged repair mortar or mortar additives are permitted. Scrub grout into voids and remove excess grout. Apply final finish using burlap, floating, or troweling.

5.3.3.4 *Special finishes*—If required, produce special finishes in accordance with Contract Documents

5.3.4 *Finishing unformed surfaces*

5.3.4.1 *Finisher qualifications*—Unless otherwise specified, at least one finisher or finishing supervisor shall be a certified ACI Advanced Concrete Flatwork Finisher or a certified ACI Flatwork Associate or equivalent.

5.3.4.2 *Finishes and tolerances*—Unformed surfaces shall receive finish defined in 5.3.4.2(a) through 5.3.4.2(h), as indicated in Contract Documents. If finish is not specified, finish surfaces as required by 5.3.4.2(h).

5.3.4.2(a) *Scratch finish*—Place, consolidate, strike off, and level concrete; cut high spots; and fill low spots. Roughen the surface with stiff brushes or rakes before concrete becomes too stiff to brush or rake.

5.3.4.2(b) *Float finish*—Place, consolidate, strike off, and level concrete; cut high spots; and fill low spots. Do not perform further finishing operations until concrete is ready for floating. Begin floating with hand float, bladed power float equipped with float shoes, or powered disk float when bleed water sheen has disappeared and surface has stiffened sufficiently to permit operation of the specific float apparatus. Unless otherwise specified, produce a finish that will meet tolerance requirements of ACI 117 for a conventional surface.

5.3.4.2(c) *Trowel finish*—Float concrete surface, then trowel the surface. Unless otherwise specified, tolerances for concrete floors shall be for a flat surface in accordance with ACI 117. Addition of water to surface to facilitate finishing is prohibited. Do not apply hard-troweled finish to concrete with total air content greater than 3 percent.

5.3.4.2(d) *Broom or belt finish*—After concrete has received float finish, give concrete surface a coarse-scored texture by drawing a broom or burlap belt across the surface.

5.3.4.2(e) *Dry-shake finish*—Blend metallic or mineral aggregate, as indicated in Contract Documents, with portland cement in the proportions recommended by the aggregate manufacturer. Finishing operations shall not seal the surface before the end of bleeding to minimize potential of delamination or blistering. Float-finish concrete surface and make initial application of dry material by mechanical spreader or by broadcasting with shovels. Begin final floating after final dry-shake application. Following floating, provide a hard-troweled finish. Alternatively, if specified in Contract Documents, use bagged, premixed material applied in accordance with manufacturer's recommendations.

5.3.4.2(f) *Topping for two-course slabs*—Prepare base slab, install bonding and topping materials, finish, cure, and install joints as indicated in Contract Documents. Unless otherwise specified, special wear-resistant aggregate is not required.

5.3.4.2(g) *Nonslip finish*—Unless otherwise specified, apply a broom or belt finish as indicated in 5.3.4.2(d).

5.3.4.2(h) *Unspecified unformed surface finishes*—If finish is not specified, apply the following finishes to unformed concrete surface:

(a) Scratch finish—For surfaces intended to receive bonded cementitious or setting beds
(b) Float finish—For walks; steps; and surfaces intended to receive waterproofing, roofing, insulation, or sand-bed terrazzo
(c) Trowel finish—For interior floors
(d) Broom finish—For parking structures and exterior surfaces, including slabs, ramps, walkways, and steps

5.3.4.3 *Slab surface measurement*—If slab surface measurement is indicated in Contract Documents, allow for measurement within 72 hours after finishing, before stressing post-tensioning reinforcement, and before removing supporting formwork or shoring.

Measurement of slab flatness and levelness shall be in accordance with 1.7.4.4, and measurement of slab elevation shall be in accordance with Contract Documents.

5.3.5 *Saw-cut joints*—Saw joints in slabs at locations indicated in Contract Documents or as accepted by Architect/Engineer. Do not cut reinforcement unless specifically identified in Contract Documents or as accepted by the Architect/Engineer.

5.3.5.1 Where saw-cut joints are required, start cutting as soon as concrete has gained sufficient strength to prevent dislodgement of coarse aggregate particles. Unless other

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wise specified, saw a continuous slot to a depth one-fourth the thickness of the slab but not less than 1 in.

5.3.6 *Curing and protection*

5.3.6.1 *Curing*—Unless otherwise specified, cure concrete in accordance with 5.3.6.2, 5.3.6.3, and 5.3.6.4.

5.3.6.2 *Initial curing of unformed concrete surfaces*—If bleed water sheen is not visible on surface of concrete after strike-off and initial bull floating, provide initial curing by means of fogging or application of evaporation reducer until final curing method is applied.

5.3.6.2(a) *Fogging*—Provide fogging equipment for complete coverage of area to be cured. Maintain visible water sheen without accumulation of standing water on concrete surface until final setting of concrete. Do not use fogging if temperature of air in contact with concrete is at or below 32°F.

5.3.6.2(b) *Evaporation reducer*—Apply in accordance with manufacturer's instructions. Apply evaporation reducer after strike-off or initial bull floating operations and do not use to increase concrete workability at the surface.

5.3.6.3 *Final curing of unformed concrete surfaces*—Unless otherwise specified, apply one of the methods in 5.3.6.5 after placement and finishing of concrete surfaces. Apply curing in a manner that prevents marring, marking, or discoloration of finished surface. Provide duration of curing in accordance with 5.3.6.6.

5.3.6.3(a) For concrete containing silica fume, use a curing method in 5.3.6.5 that supplies additional water during the entire curing period.

5.3.6.4 *Formed concrete surfaces*—Unless otherwise specified, after formwork has been loosened or removed so that concrete surface is exposed to ambient air, continue curing by one of the methods in 5.3.6.5. Provide duration of curing in accordance with 5.3.6.6. The duration that forms remained tightly in place can be included in the duration of curing.

5.3.6.5 *Curing methods*—Unless otherwise specified, use one or more of the following methods for curing formed surfaces or as final curing for unformed surfaces:

5.3.6.5(a) *Continuous fogging*—Cure in accordance with 5.3.6.2(a), except that accumulation of standing water on concrete surface is permitted. Do not use fogging if temperature of air in contact with concrete is at or below 32°F.

5.3.6.5(b) *Ponding*—Build a dike around concrete and flood surface with water. Entire surface is to remain covered continuously with water for duration of curing period. Temperature of water used shall be at least 50°F and not be more than 35°F colder than surface temperature of the concrete at the time the water and concrete come in contact.

5.3.6.5(c) *Continuous sprinkling*—Apply water to keep surfaces continuously wet. Concrete surface shall not be eroded by running water.

5.3.6.5(d) *Application of absorbent material*—Predampen absorbent materials before application. Keep concrete surfaces continuously wet. Apply additional water to absorbent materials without displacing them.

5.3.6.5(e) *Application of water-retention sheeting materials*—Cover exposed concrete surfaces. Tape sheets together or lap sheets, repair holes and gaps, and keep sheets in place.

5.3.6.5(f) *Application of a membrane-forming curing compound*—Apply compound in accordance with manufacturer's recommendation for specified concrete finish as soon as water sheen has disappeared from the concrete surface. For rough surfaces, such as those specified in 5.3.4.2(a), 5.3.4.2(b), and 5.3.4.2(d), apply curing compound in two applications at right angles to each other.

5.3.6.6 *Duration of curing*

5.3.6.6(a) Unless otherwise specified, continue curing measures for at least 7 days after placement. Unless otherwise specified, cure high-early-strength concrete for at least 3 days after placement.

5.3.6.6(b) Unless otherwise specified, curing measures may be terminated before the specified minimum duration in 5.3.6.6(a) if one of the following conditions is satisfied:

(a) Tests of at least two 6 x 12 in. or at least three 4 x 8 in. cylinders that have been field cured in accordance with ASTM C31/C31M indicate compressive strength of at least 70 percent of f_c' when tested in accordance with ASTM C39/C39M.

(b) The compressive strength of laboratory-cured cylinders, representative of the in-place concrete, exceeds 85 percent f_c', provided the temperature of the in-place concrete has been maintained at 50°F or higher during curing.

(c) Concrete strength reaches f_c' as determined by accepted in-place test methods meeting the requirements of 2.3.4.2.

5.3.6.6(c) Unless otherwise specified, if one of the curing methods in 5.3.6.5 is used initially, the curing method may be replaced by one of the other methods after concrete is 1 day old, provided the surface of concrete does not become dry before replacement method is applied.

5.3.6.7 *Thermal protection against cold weather*—Maintain in-place concrete temperature to prevent freezing of concrete and to ensure strength development.

5.3.6.7(a) Unless otherwise specified, duration of thermal protection shall be at least 3 days, or until one of the criteria of 5.3.6.6(b) has been met.

5.3.6.7(b) Unless otherwise specified, or if concrete is designated as mass concrete and removal of protection is addressed in thermal control plan, the maximum rate of temperature decrease, measured at the concrete surface, during thermal protection removal shall not exceed the following:

(a) 50°F/24 hours for sections with least dimension less than 12 in.

(b) 40°F/24 hours for sections with least dimension from 12 to 36 in.

(c) 30°F/24 hours for sections with least dimension greater than 36 to 72 in.

(d) 20°F/24 hours for sections with least dimension greater than 72 in.

Do not exceed these rates of temperature decrease until surface temperature of the concrete is within 20°F of ambient or surrounding temperatures, at which time all protection

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measures may be removed. Measure and record concrete temperature using accepted method.

5.3.7 *Repair of surface defects*

5.3.7.1 *General*—Repair tie holes and other surface defects in formed finishes in accordance with the requirements of 5.3.3 unless otherwise specified. Where concrete surface will be textured by sandblasting or bush-hammering, repair surface defects before texturing.

5.3.7.2 *Repair of tie holes*—Unless otherwise specified, patch tie holes. If portland-cement repair mortar conforming to 5.3.7.4 is used for patching, clean and dampen tie holes before applying mortar. If other materials are used, apply them in accordance with manufacturer's recommendations.

5.3.7.3 *Repair of surface defects other than tie holes*—Unless otherwise specified, repair surface defects by the following method. Outline repair area with a 1/2 in. deep saw cut that is perpendicular to the repair surface and remove defective concrete down to sound concrete. Dampen the area to be patched plus 6 in. around the patch area perimeter. Prepare scrub coat according to 5.2.1.8. Thoroughly brush scrub coat into the surface. When the scrub coat begins to lose water sheen, apply patching mortar prepared in accordance with 5.3.7.4 and consolidate mortar into place. Strike off mortar, finishing flush to the final surface. Leave the patch undisturbed for 1 hour before finishing. Keep the patch damp for 7 days.

5.3.7.4 *Site-mixed portland-cement repair mortar*—For surface repairs in concrete exposed to view, make a trial batch and check color compatibility of repair material with surrounding concrete.

5.3.7.5 *Repair materials other than site-mixed portland-cement mortar*—Use accepted alternative repair material.

5.3.7.6 *Removal of stains, rust, efflorescence, and surface deposits*—Remove stains, rust, efflorescence, and surface deposits at locations indicated in Contract Documents.

5.3.8 *Installation of adhesive anchors*—Install adhesive anchors in accordance with Manufacturer's Printed Installation Instructions (MPII).

5.3.8.1 Install adhesive anchors in concrete that is at least 21 days old.

5.3.8.2 Adhesive anchors installed in holes horizontally or upwardly inclined and designated in Contract Documents to support sustained tension shall be installed by personnel certified in accordance with ACI Adhesive Anchor Installer Certification Program or other accepted equivalent program.

SECTION 6—ARCHITECTURAL CONCRETE

6.1—General

6.1.1 *Scope*—This Section covers construction requirements for concrete designated as architectural concrete in Contract Documents.

6.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Section 1 through 5 are applicable for architectural concrete.

6.1.3 *Submittals*

6.1.3.1 *Shop drawings and data*—Submit shop drawings of formwork for architectural concrete, including formwork for field mockups. Show jointing of facing panels; locations and details of form ties, rustications, and recesses; and details of joints, anchorages, and other accessories.

6.1.3.2 Unless otherwise specified, comply with 6.1.3.2(a) through 6.1.3.2(e).

6.1.3.2(a) *Field mockups*—Mockups are required for architectural concrete. Submit location for field mockup.

6.1.3.2(b) *Specified finishes*—If architectural concrete reference sample(s) is not specified, submit finish sample(s) exhibiting the desired surfaces, color, and texture. Minimum size of the sample(s) shall be 18 in. x 18 in.

6.1.3.2(c) *Form face, form liner, and molds*—Submit technical data and samples of form face, form liner, and molds.

6.1.3.2(d) *Compressible tape*—Submit technical data and sample of compressible tape.

6.1.3.2(e) *Form joint caulking*—Submit technical data and sample of form joint caulking.

6.1.3.3 *Initiation of Work*—Do not begin Work under this Section until submittals and completed field mockups have been reviewed and accepted. Do not construct forms or place concrete until submitted plans for batching, mixing, placing, curing, and producing specified finishes have been accepted.

6.1.3.4 *Waste wash-water disposal plan*—If required, submit plan for disposal of wastewater resulting from washing concrete surfaces.

6.1.3.5 *Personnel experience*—If required, submit records showing previous experience with architectural concrete.

6.1.4 *Quality control*

6.1.4.1 *Manufacturer's technical specialists*—If required, provide manufacturer's technical specialists to inspect and direct installation of supplied systems and products.

6.1.4.2 *Architectural preconstruction conference*—Attend preconstruction conference(s) specific to architectural concrete Work with Architect/Engineer and Owner, or Owner's representative to review delivery, installation, acceptance criteria, tolerances, and repair procedures.

6.1.4.3 *Architectural concrete reference*—If specified in Contract Documents, surface quality and appearance of mockup shall match a reference sample or portions of an existing structure designated by Architect/Engineer.

6.1.4.4 *Field mockup*

6.1.4.4(a) Construct field mockups using same procedures, equipment, and materials that will be used for production of architectural concrete. Accepted field mockup will serve as the reference to which architectural concrete will be compared for periodic and final acceptance. Construct field mockups at an acceptable location on site. Provide a simulated repair area to demonstrate an acceptable repair procedure. Repair procedure shall provide an acceptable color and texture match. Protect from physical damage and retain mockups until final acceptance of architectural concrete.

6.1.4.4(b) For formed architectural concrete surfaces, include vertical and horizontal rustication joints, and any sculptured features. Demonstrate color and texture. Cure the mockup as intended with the structure. If required, apply sealers and coatings to only a portion of the mockup. Construct mockup to include at least two lift heights planned for placement of architectural concrete.

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6.1.4.4(c) For flatwork, construct at least a 10 x 10 ft mockup for review and acceptance using procedures in 6.1.4.4(a).

6.1.4.5 *Periodic acceptance*

6.1.4.5(a) Architect/Engineer will periodically observe completed portions of architectural concrete for conformance with accepted field mockup. The frequency of periodic acceptance and acceptance criteria will be established at preconstruction conference.

6.1.4.5(b) Architectural concrete declared unacceptable during periodic observation shall be repaired or replaced. Submit a revised method of producing acceptable concrete before proceeding with additional architectural concrete construction.

6.1.5 *Product delivery, storage, and handling*

6.1.5.1 Store and protect forms and liners in accordance with manufacturer's recommendations. Protect forms, liners, and other forming materials from weather and other environmental detriments. Clean forms after each use and discard or repair damaged forms as required to ensure conformance of Work with accepted field mockup.

6.1.5.2 Deliver materials specified in Contract Documents to project site in manufacturer's original containers or packaging.

6.2—Products

6.2.1 *Materials*

6.2.1.1 *Cementitious materials*—Unless otherwise specified, cementitious materials shall conform to Section 4. Use one source, type, and brand of cementitious materials for architectural concrete. Ensure sufficient supply of cementitious materials.

6.2.1.2 *Water*

6.2.1.2(a) Concrete mixing water shall conform to requirements of Section 4 and shall be free of oil or impurities capable of discoloring concrete surface.

6.2.1.2(b) Water for waterblasting and for wash down shall be free of oil or impurities capable of staining concrete surface.

6.2.1.3 *Aggregate*—Aggregate shall comply with requirements of Section 4 and other requirements indicated in Contract Documents. Ensure sufficient supply of aggregate as used in accepted field mockup to complete Work.

6.2.1.4 *Concrete*—Concrete shall match color and finish of accepted field mockup.

6.2.1.5 *Curing materials*—Curing materials shall conform to requirements in Section 5. Curing method shall be the same as used to produce accepted field mockup.

6.2.1.6 *Reinforcement, reinforcement supports, spacers, and tie wires*

6.2.1.6(a) Use stainless steel, plastic, or plastic-coated wire-reinforcement supports and spacers near exposed surfaces. Do not use plastic-coated products if cement paste will be removed to expose aggregate.

6.2.1.6(b) Use plastic-coated tie wire for epoxy-coated reinforcement. Use stainless steel or plastic-coated tie wire for securing other reinforcement.

6.2.1.7 *Formwork*—Unless otherwise specified, provide formwork with a structurally rated plywood with a non-porous finished surface bonded to a sanded hardwood veneer substrate.

6.2.1.8 *Form ties*

6.2.1.8(a) Provide specified cone diameter for form ties, as indicated in Contract Documents.

6.2.1.8(b) Steel washers shall not be used with snap ties for architectural concrete.

6.2.1.9 *Rustications*—If indicated in Contract Documents, provide specified rustications and reveal strips. Rustication or reveal strips shall be nonabsorbent and of sufficient stiffness to maintain alignment during concrete casting. Fabricate metal strips from same metal as metal form face.

6.2.1.10 *Form-release agents*—Use form-release agents accepted for field mockup.

6.2.1.11 *Miscellaneous*

6.2.1.11(a) *Compressible tape*—Use compressible tape accepted for field mockup.

6.2.1.11(b) *Form sealant*—Sealant for form caulking shall conform to ASTM C920, Type A, Grade NS, or ASTM C834.

6.2.1.11(c) *Abrasive material*—If applicable, use abrasive material previously tested and accepted for field mockup for the specified texture. Ensure sufficient supply to complete total amount of surface specified.

6.2.1.11(d) *Surface retarders*—Use surface retarders accepted on field mockup.

6.2.1.11(e) *Acid*—Use muriatic or phosphoric acid to produce acid etch finish on both accepted mockup and Work.

6.2.2 *Performance and design requirements*

6.2.2.1 *Formwork*

6.2.2.1(a) Design forms that produce required finish. Limit deflection of facing materials between studs and deflection of studs and walers to 0.0025 times the clear span—that is, clear span divided by 400.

6.2.2.1(b) Where as-cast surfaces, including plywood form finish, are specified, concrete surfaces shall comply with ACI 117 tolerances for Class A surface.

6.2.2.1(c) Form face, form liner, and molds shall result in a concrete surface matching accepted field mockup.

6.2.2.1(d) Where panels for as-cast surfaces are separated by recessed or emphasized joints, provide, in the structural design of forms, the locations of ties within joints so patches of tie holes will be in the recessed or emphasized joints, unless otherwise specified.

6.2.2.1(e) Do not reuse forms with surface wear, tears, or defects that would produce concrete surfaces not conforming to accepted mockup. Clean and coat forms before reuse.

6.2.3 *Proportioning concrete mixtures*—For a concrete mixture of a specified color, use materials and proportions used in accepted field mockup. For architectural concrete exposed to cycles of freezing and thawing, use air-entrained concrete complying with 4.2.2.6(c) for the designated exposure class. Proportion concrete for specified compressive strength of at least 5000 psi if acid etch, mechanical tooling, or waterblasting is required.

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6.3—Execution

6.3.1 *Preparation*—Clean and inspect formwork and batching, mixing, conveying, and placing equipment before use.

6.3.2 *Formwork*—Erect forms in accordance with Contract Documents and accepted shop drawings. Provide rustication joints and chamfers in accordance with Contract Documents and accepted shop drawings. Seal form joints, chamfers, and rustication joints. Provide closure backing materials if indented rustication is used over a ribbed form liner, and seal joint between rustication strip and form with nonabsorbent caulking.

6.3.3 *Placement of reinforcement*—Provide specified concrete cover over reinforcement and steel embedments. Use reinforcement supports in sufficient number, size, and location to prevent displacement of reinforcement and gouging of forming materials. Use reinforcement supports or spacers in walls and columns that maintain cover between reinforcement and face of concrete within ACI 117 tolerances. Bend back and keep tie wires from form face. Before placement of concrete, remove tie wire clippings from horizontal surfaces that will be sandblasted, exposed to view, or exposed to weather.

6.3.4 *Batching, mixing, and transporting*—Mix and transport architectural concrete in equipment that results in completed Work having color and texture of accepted field mockup.

6.3.5 *Conveying and placement*—Schedule arrival of concrete to avoid delays in placement. Support runs or gangways for the concrete transporters, pump lines, wheelbarrows, other similar equipment, and foot traffic that will not displace reinforcement or interfere with concrete placing operations.

6.3.6 *Form surface preparation*

6.3.6.1 Prepare untreated natural wood forms with cement, lime slurry, or other methods or materials to condition the wood surface. Remove any cement or lime slurry residue from form face after treatment is dry.

6.3.6.2 Seal form joints and tie holes by taping or with nonabsorbent caulking. Clean taper ties and she-bolts and lubricate with nonstaining grease or form-release agent before each use.

6.3.6.3 Keep form face clean until concrete is placed.

6.3.7 *Formwork removal*—Schedule formwork removal in accordance with 2.3.2.1 through 2.3.2.5 and maintain surface appearance matching accepted field mockup. Prevent damage to concrete during formwork removal.

6.3.8 *Surface repair and patching of tie holes*

6.3.8.1 *General*—Repair surface and patch tie holes to match adjacent surface before surface treatments are applied. Proceed with repair work after form removal and surface finishing.

6.3.8.2 *Color and texture match*—Repairs in as-cast architectural concrete shall match color and texture of surrounding surfaces as performed on simulated repair area of the accepted field mockup.

6.3.8.3 *Exposed aggregate*—Any finishing process intended to expose aggregate on the surface shall show aggregate faces in repaired areas. Repaired areas shall contain the same aggregates as the surrounding concrete for a depth of at least 1 in. In exposed-aggregate finish, the repair mixture shall contain the same selected colored aggregates. After repair has reached minimum compressive strength required by 6.3.9.2, 6.3.9.3, and 6.3.9.4 for the method of aggregate exposure, expose aggregates together with aggregates of adjoining surfaces by a process of mortar removal so that appearance matches accepted field mockup.

6.3.8.4 *Curing repairs*—Cure repairs in accordance with procedures used on accepted field mockup.

6.3.9 *Finish*—Finishes shall be as specified in Contract Documents.

6.3.9.1 *Textured finishes*—If specified, use textured forms or textured form liners of plastic, wood, or sheet metal. Secure liner panels in forms in accordance with manufacturer's recommendations. Do not use nail heads, screw heads, or washers that transfer impressions to the surface of the concrete. Seal edges of textured panels to each other or to divider strips to prevent leakage of cement paste. Use a sealant that will not discolor concrete surface.

6.3.9.2 *Exposed-aggregate finishes*—Expose aggregate to match accepted field mockup.

6.3.9.2(a) *Retarded vertical surfaces*—If specified, use accepted surface retarder. After form removal, remove the retarded outer layer of cement paste by hand brushing, high-pressure water washing, or light abrasive blasting. Schedule procedures and adjust timing for weather conditions to achieve aggregate exposure matching that of the mockup. The retarded surface shall not be removed until the unretarded concrete has reached an in-place compressive strength of at least 1000 psi.

6.3.9.2(b) *Retarded horizontal unformed surfaces*—If specified, use accepted surface retarder. Spray retarder on fresh cast horizontal surfaces after concrete consolidation, seeding of architectural aggregate if specified, and final finishing. Apply chemical retarder in accordance with manufacturer's recommendations. Remove the retarded surface cement paste after the mortar retaining the aggregate has set sufficiently to prevent dislodgment of the aggregate.

6.3.9.2(c) *Waterblast*—If specified, waterblast vertical surfaces when compressive strength exceeds 1500 psi. Expose aggregate to match accepted field mockup. If required, dispose of water used for blasting in accordance with submitted disposal plan.

6.3.9.2(d) *Acid etch*—If specified, use acid etching on horizontal surfaces only. Do not acid etch until concrete has a compressive strength of at least 3000 psi and is at least 14 days old. Wet concrete surface before applying acid. Continue application to match accepted field mockup. When acid bubbling stops, flush acid and debris from concrete surface by applying water under pressure. Protect adjacent materials, surfaces, and finishes from acid and waste wash-water during application and cleanup. If required, dispose of waste wash-water in accordance with submitted disposal plan.

6.3.9.3 *Abrasive blast*—If specified, begin abrasive blasting when concrete has a compressive strength of at least 2000 psi and after safe removal of forms and supports. Achieve degree of abrasive blasting exhibited in approved

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field mockup. Repair cracks before abrasive blasting. If abrasive grits contain free water for dust abatement, wash abrasive blasting debris off finished wall surface before drying occurs.

6.3.9.4 *Mechanical tooling (bush-hammering)*—If specified, begin mechanical tooling when concrete has a compressive strength of at least 4500 psi. Multiple bush-hammers used for tooling shall have equal wear on teeth. Maintain control of concrete chips, dust, and debris in each work area. Limit migration of airborne materials by using tarpaulins, wind-breaks, and similar devices.

6.3.9.5 *As-cast formed finish*—If specified, produce as-cast formed finish in accordance with Contract Documents and to meet the surface finish requirements SF-3 as defined in 5.3.3.2(c).

6.3.10 *Curing architectural concrete*—Cure architectural concrete in accordance with Section 5. Use curing methods from accepted field mockup that are compatible with any specified sealers or coating that may be applied to architectural concrete surface.

6.3.11 *Final cleanup*—Protect architectural concrete surfaces from damage, staining, or contaminants from subsequent construction. Do not apply additional sealers or coatings unless accepted by Architect/Engineer. Clean concrete surfaces before final submittal for acceptance. Use cleaning materials and processes that were used on approved mockup. Protect adjacent materials during cleaning operations.

6.3.12 *Final acceptance of architectural concrete*—Upon completion of architectural concrete, including surface repairs and patching of tie holes, final acceptance is based on matching the architectural cast-in place concrete with accepted field mockup when viewed at 20 ft in daylight. Defective Work not conforming to Contract Documents, including repair areas not accepted, shall be removed and replaced.

SECTION 7—LIGHTWEIGHT CONCRETE

7.1—General

7.1.1 *Scope*—This Section covers construction requirements for concrete designated as lightweight concrete in Contract Documents.

7.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements in Sections 1 through 5 are applicable for lightweight concrete.

7.1.3 *Submittals*—Comply with 4.1.2 and 7.1.3.1 through 7.1.3.3.

7.1.3.1 *Concrete density*—Submit results of concrete density tests performed in accordance with ASTM C567/C567M. Include correlation between fresh density and equilibrium density.

7.1.3.2 *Batching and mixing*—Submit batching and mixing procedures that vary from requirements in 4.3.1.

7.1.3.3 *Review of submittals*—Obtain Architect/Engineer's acceptance of required submittals before placing lightweight concrete.

7.1.4 *Aggregate storage and handling*—Maintain lightweight aggregate at a moisture condition before batching that ensures concrete can be placed at required slump. Do not handle aggregate in a manner that causes degradation or segregation.

7.2—Products

7.2.1 *Aggregates*—Fine and coarse lightweight aggregates shall conform to ASTM C330/C330M. Normalweight aggregate used in lightweight concrete shall conform to 4.2.1.2.

7.2.2 *Mixtures*

7.2.2.1 *Density*—Proportion lightweight concrete to meet equilibrium density specified in Contract Documents. Unless otherwise specified, calculate the approximate equilibrium density of mixture from measured or calculated oven-dry density in accordance with ASTM C567/C567M.

Correlate equilibrium density with fresh density of concrete. Fresh density will be used as the basis for acceptance during construction.

7.3—Execution

7.3.1 *Field quality acceptance*

7.3.1.1 *Density*—Acceptance of lightweight concrete in field will be based on fresh density measured in accordance with ASTM C138/C138M. Required fresh density is based on specified equilibrium density and correlation with fresh density, as established in 7.1.3.1. Unless otherwise specified, do not use concrete for which fresh density varies by more 4 lb/ft^3 from the required fresh density.

7.3.1.2 *Air content*—Air content of lightweight concrete will be determined in accordance with ASTM C173/C173M.

SECTION 8—MASS CONCRETE

8.1—General

8.1.1 *Scope*—This Section covers construction requirements for concrete designated as mass concrete in Contract Documents.

8.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Sections 1 through 5 are applicable for mass concrete.

8.1.3 *Temperature limits*—Unless otherwise specified, the following temperature limits shall apply for mass concrete placements:

(a) Maximum temperature in concrete after placement shall not exceed 160°F.

(b) Maximum temperature difference between center and surface of placement shall not exceed 35°F.

8.1.4 *Submittals*—Comply with 4.1.2 and, unless otherwise specified, submit a thermal control plan for each mass concrete placement. Unless otherwise specified, the thermal control plan shall include:

(a) Concrete materials, mixture proportions, and ranges of chemical admixture dosages

(b) Permissible changes to concrete materials and mixture proportions that do not require the thermal control plan to be updated

(c) Calculated or measured adiabatic temperature rise of concrete

(d) Upper limit for concrete temperature at time of placement

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(e) Description of specific measures and equipment that will be used to ensure maximum temperature in placement will not exceed specified maximum temperature limit
(f) Calculated maximum temperature in placement based on expected conditions at time of placement and use of proposed measures to control temperatures
(g) Description of specific measures and equipment that will be used to ensure temperature difference will not exceed specified temperature difference limit
(h) Calculated maximum temperature difference in placement based on expected conditions at time of placement and use of proposed measures to control temperature differences
(i) Description of equipment and procedures that will be used to monitor and log temperatures and temperature differences
(j) Drawing of locations for temperature sensors in placement
(k) Description of format and frequency of reporting temperature data
(l) Description of measures to address and reduce excessive temperatures and temperature differences, if they occur
(m) Description of curing procedures, including materials and methods, and curing duration
(n) Description of formwork removal procedures to ensure temperature difference at temporarily exposed surface will not exceed temperature difference limit, and how curing will be maintained.

Update thermal control plan if changes in concrete materials or mixture proportions affect compliance with temperature limits.

8.2—Products

8.2.1 *Materials*

8.2.1.1 *Cementitious materials*—Unless otherwise specified, cementitious materials shall comply with 4.2.1.1.

8.3—Execution

8.3.1 *Curing and protection*

8.3.1.1 *Preservation of moisture*

8.3.1.1(a) If strength criterion in 5.3.6.6(b) is used to terminate curing, strength shall be evaluated at a formed or finished exterior surface using 2.3.4.2(b), 2.3.4.2(c), or 2.3.4.2(d). If 2.3.4.2(d) is used, temperature sensors for measuring maturity shall be installed 2 to 3 in. below concrete surface.

8.3.1.1(b) Unless otherwise specified, preserve moisture by maintaining forms in place. For surfaces not in contact with forms, apply one of the methods specified in 5.3.6.5(e) and 5.3.6.5(f). Unless otherwise specified, do not use methods specified in 5.3.6.5(a) through 5.3.6.5(d).

8.3.1.2 *Controlling concrete temperature*—Control concrete temperature and temperature difference within concrete from time concrete is placed until time internal temperature has cooled from its maximum so that difference between average daily ambient temperature and internal temperatures at time of protection removal is less than specified temperature difference limit.

8.3.1.2(a) *Monitoring temperatures*—Unless otherwise specified or required in the thermal control plan, place one temperature sensor at the center of largest portion of placement and one temperature sensor at a depth 2 to 3 in. at center of exterior surface that is nearest to the center of the placement. Place a backup sensor at each sensor location. In addition, provide a temperature sensor in a shaded location for monitoring ambient on-site temperature.

Unless otherwise specified, monitor temperatures hourly using electronic sensors capable of measuring temperature from 32 to 212°F to an accuracy of 2°F. Ensure temperature sensors are operational before placing concrete. Unless otherwise specified, provide data from sensors to Architect/Engineer daily, until requirements of 8.3.1.2 are met.

8.3.1.2(b) *Excessive temperatures or temperature differences*—Compare temperatures and temperature differences with maximum limits specified in 8.1.3 every 12 hours or at intervals in the accepted thermal control plan. If either exceeds specified limits, take immediate action as described in accepted thermal control plan to remedy situation. Do not place additional mass concrete until cause of excessive temperature or temperature difference has been identified and corrections are accepted.

SECTION 9—POST-TENSIONED CONCRETE

9.1—General

9.1.1 *Scope*—This Section covers construction requirements for structural members designated as post-tensioned concrete in Contract Documents.

9.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements in Sections 1 through 5 are applicable for post-tensioned concrete.

9.1.3 *Submittals*

9.1.3.1 *Required submittals before execution of Work*—Submit information specified in 9.1.3.1(a) through 9.1.3.1(c).

9.1.3.1(a) *Drawings*—Shop drawings of post-tensioned structural concrete members providing the following information in addition to that required by Sections 2 and 3:
(a) Sizes and heights of tendon supports, including bars and chairs
(b) Location of tendons throughout their length
(c) Size, details, location, materials, and grade of prestressing steel for tendons and accessories
(d) Jacking procedures, stressing sequence, and tensioning forces
(e) Wobble and curvature friction coefficients and anchor set
(f) Calculated prestressing steel elongations
(g) Details of reinforcement to prevent bursting and spalling
(h) Prestressing steel trimming procedures and details of anchorage capping procedure
(i) Duct characteristics, including size, material, thickness, support spacing, vents, inlets, and outlets

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(j) If specified, shop drawings shall be signed and sealed by a licensed design engineer and reviewed by Architect/Engineer.

9.1.3.1(b) *Contractor proposed substitution*—Contractor proposed deviations from post-tensioning design shall be indicated, in proposed substitution request, and include drawings and calculations signed and sealed by a licensed design engineer.

9.1.3.1(c) *Grout certification*—For grouted tendons, provide written certification that grout constituents comply with 9.2.2 and any other requirements in Contract Documents.

Unless otherwise specified, test reports to be submitted include the following:

(a) Cement mill test reports
(b) Admixtures test reports
(c) Test reports for other constituents used in the grout
(d) Manufacturer's current certified mill test reports for prepackaged grouts, if used

9.1.3.2 *Optional submittals*—If specified, submit the information in 9.1.3.2(a) through 9.1.3.2(h).

9.1.3.2(a) Test data substantiating expected curvature and wobble coefficients and expected anchorage set.

9.1.3.2(b) Results of tests required in 9.1.5.1, including demonstration of compliance with 9.2.1.1 and 9.2.1.2.

9.1.3.2(c) Duct stiffness test data.

9.1.3.2(d) Elongation calculations and tendon group final effective force calculations that account for loss of prestress due to anchorage set, friction, and long-term effects. Calculations shall be signed and sealed by a licensed design engineer.

9.1.3.2(e) If Contract Documents delegate structural design of post-tensioned concrete members to Contractor, submit drawings and design criteria used for designing post-tensioning, signed and sealed by a licensed design engineer. Submit design calculations.

9.1.3.2(f) Jack clearances.

9.1.3.2(g) Written grouting procedures at least 4 weeks before the start of construction of post-tensioned members. Develop grouting procedures to ensure the annular space in the ducts will be completely filled by grout. These procedures shall cover the following:

(a) Type, quantity, and brand of materials used in grouting, including certifications required
(b) Type of equipment to be used, including capacity as well as provisions for backup equipment and spare parts
(c) Types and locations of grout vents, both inlets and outlets
(d) Types and sizes of grout hoses and connections
(e) Duct cleaning methods before grouting
(f) Mixing and pumping procedures, including means to measure volume of grout pumped
(g) Direction of grouting
(h) Sequence of use for inlets and outlets
(i) Procedures for handling blockages, including duct flushing
(j) Procedures for possible regrouting
(k) Names of the persons in charge and other personnel who will perform the grouting operation, including their relevant experience and skill

9.1.3.2(h) Results of grouting field trial and field mockup tests.

9.1.3.3 *Required submittals during execution of Work*—Submit information specified in 9.1.3.3(a) through 9.1.3.3(d).

9.1.3.3(a) Certified mill test reports for samples taken from the production lot of prestressing steel used in Work.

9.1.3.3(b) Stressing jack calibration certificates, including gauge pressure readings and calibration charts, for each set of equipment that will be used in Work. Certificates shall be submitted before stressing.

9.1.3.3(c) Stressing records are required for review before trimming prestressing steel that extends past anchorages. Submit the following data:

(a) Project name
(b) Floor number and concrete placement number
(c) Tendon identification mark
(d) Calculated elongation
(e) Calculated gauge pressure reading to achieve specified stressing force based on supplied calibration chart
(f) Elongation achieved
(g) Actual gauge pressure reading
(h) Date of stressing operation
(i) Name and signature of stressing operator and inspector
(j) Serial or identification number of jacking equipment
(k) Date of accepted shop drawings used for installation and stressing
(l) Weather conditions, including temperature and rainfall
(m) If applicable, summary of problems encountered and corrective action taken

9.1.3.3(d) Record grouting operation and submit grouting records within 72 hours of grouting completion. Information in grouting records shall include:

(a) Date of grouting
(b) Number of days from stressing to grouting
(c) Type of grout mixture and additives
(d) Lot numbers of prepackaged tendon grout, if used
(e) Tendon(s) grouted, injection end, and applied grouting pressure
(f) If applicable, summary of problems encountered and corrective action taken
(g) Volume of grout pumped into duct compared with volume of duct adjusted for grout displaced by prestressing tendon

9.1.4 *Personnel qualifications*

9.1.4.1 *Installer certification*—Unless otherwise specified, installation shall be performed by personnel certified in accordance with the Post-Tensioning Institute (PTI) training and certification programs.

9.1.4.1(a) *Multistrand and grouted post-tensioning*—At least 50 percent of installation personnel shall be certified in accordance with PTI Level 1 Multistrand and Grouted PT Installation Program. Crew foreman shall be certified in accordance with PTI Level 2 Multistrand and Grouted PT Specialist Program. Submit qualifications of installation personnel.

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9.1.4.1(b) *Unbonded post-tensioning*—At least 50 percent of installation personnel shall be certified in accordance with PTI Level 1 Unbonded PT Installation Program. Crew foreman shall be certified in accordance with PTI Level 2 Unbonded PT—Installer, Inspector or Ironworker Program. Submit qualifications of installation personnel.

9.1.4.2 *Tensioning personnel certification*—Unless otherwise specified, tensioning shall be performed by personnel certified in accordance with PTI training and certification programs.

9.1.4.2(a) *Multistrand and grouted post-tensioning*—The tensioning crew foreman and at least 50 percent of tensioning personnel shall be certified in accordance with PTI Level 2 Multistrand and Grouted PT Specialist Program and remainder of tensioning personnel shall be certified in accordance with PTI Level 1 Multistrand and Grouted PT Installation Program. Submit qualifications of tensioning personnel.

9.1.4.2(b) *Unbonded post-tensioning*—The tensioning crew foreman and at least 50 percent of tensioning personnel shall be certified in accordance with PTI Level 2 Unbonded PT Installer, Inspector or Ironworker Program and remainder of tensioning personnel shall be certified in accordance PTI Level 1 Unbonded PT Installation Program. Submit qualifications of tensioning personnel.

9.1.4.3 *Grouting personnel certification*—Unless otherwise specified, grouting shall be performed by personnel certified in accordance with PTI Level 1 Multistrand and Grouted PT Installation Program. Unless otherwise specified, grouting operations shall be supervised and under immediate control of a person certified in accordance with PTI Level 2 Multistrand and Grouted PT Specialist Program and in accordance with ASBI Grouting Certification Program. The supervisor shall provide close observation and control of grouting operations necessary for compliance with specified requirements. If specified, supervisor shall be named and shall furnish proof of experience. Submit qualifications of grouting personnel.

9.1.4.4 *Inspection personnel certification*—Unless otherwise specified, inspection shall be performed by personnel certified in accordance with PTI training and certification programs.

9.1.4.4(a) *Multistrand and grouted post-tensioning*—Inspection shall be performed by personnel certified in accordance with the PTI Level 2 Multistrand and Grouted PT Inspector Program. Submit documentation of inspector certification. Inspection shall include:

(a) Material cleanliness
(b) Location and quantity of materials
(c) Tensioning of prestressing tendons
(d) Length of strand tails after trimming
(e) Permanent grout caps
(f) Tendon grouting

9.1.4.4(b) *Unbonded post-tensioning*—Inspection shall be performed by personnel certified in accordance with the PTI Level 2 Unbonded PT Inspector Program. Submit documentation of inspector certification. Inspection shall include:

(a) Material cleanliness
(b) Location and quantity of materials
(c) Tensioning of prestressing
(d) Length of strand tails after trimming
(e) Installation of encapsulation caps
(f) Grouting of stressing pockets

9.1.5 *Quality control*

9.1.5.1 *Testing*

9.1.5.1(a) *Testing of multistrand and grouted tendon components*—Test components of multistrand and grouted tendon systems in accordance with system approval testing requirements of PTI/ASBI M50.3.

9.1.5.1(b) *Testing of unbonded tendon components*—Test components of unbonded tendon systems in accordance with the requirements of ACI 423.7.

9.1.5.1(c) *Grout quality-control testing*—Test grout in accordance with laboratory and field testing requirements of PTI M55.1 for the grout class provided.

9.1.6 *Product delivery, handling, and storage*—Deliver, handle, and store materials to prevent mechanical damage and corrosion.

9.1.6.1 *Handling*

9.1.6.1(a) Identify wedges and anchorages by individual concrete placement area, floor sequence, or both. Use materials only in their identified concrete placement areas. In the event materials intended for one concrete placement area are exchanged into another concrete placement area, notify Architect/Engineer of exchanges for tracking purposes.

9.1.6.1(b) Protect tendons, accessories, and equipment from exposure to water and deicing salts. Do not damage sheathing or anchorages during handling and storage.

9.1.6.1(c) Unload tendons as close as practicable to the designated storage area to avoid excessive handling.

9.1.6.1(d) Do not use chains or hooks.

9.1.6.2 *Storage*

9.1.6.2(a) Store materials and equipment in a dry area on dunnage. Do not expose materials to water, snow, deicing salts, or other corrosive elements. If storage longer than 1 month is required, protect sheathing and other plastics from exposure to direct sunlight.

9.1.6.2(b) Store cement and prepackaged tendon grout to prevent hydration during storage. Use only cement or prepackaged grout that has been stored in accordance with manufacturer's requirements for grouting. Do not use prepackaged grout that has exceeded its shelf life.

9.1.6.2(c) Inspect tendons and accessory items before installation.

9.2—Products

9.2.1 *Materials*—Use materials that conform to the requirements of 9.2.1.1 through 9.2.1.3.

9.2.1.1 *Multistrand and grouted tendon materials*—Use materials that conform to the requirements of PTI/ASBI M50.3. Post-tensioning system tendon protection level shall be as indicated in Contract Documents.

9.2.1.2 *Unbonded tendon materials*—Use materials that conform to the requirements of ACI 423.7. For unbonded tendons, provide full encapsulation of prestressing steel conforming to ACI 423.7. If specified, submit encapsulation

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system test data to demonstrate compliance with watertightness requirements of ACI 423.7 If specified, non-encapsulated tendons are allowed in slabs-on-ground that:

(a) Are not exposed to external sources of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources; or

(b) Do not have stressing pockets subject to wetting or direct contact with soil during service.

9.2.1.3 *Prestressing steel*—Prestressing steel shall be of the type and minimum tensile strength specified in Contract Documents and shall conform to one of the following specifications:

(a) ASTM A416/A416M
(b) ASTM A421/A421M
(c) ASTM A722/A722M
(d) ASTM A779/A779M
(e) ASTM A882/A882M

Prestressing steel shall be clean and free of scale, oil, dirt, and pitting. Surface rust shall be removable with a fine steel wool pad or by vigorous rubbing with a cloth. Pits on steel surface shall not exceed 0.002 in. in diameter or length.

9.2.2 *Grout mixtures for grouted tendons*—Unless otherwise specified, use grout materials, admixtures, and testing that conform to PTI M55.1 with the following exception: water-soluble chloride ion content of grout shall not exceed 0.06 percent by mass of cement when tested in accordance with ASTM C1218/C1218M.

9.2.2.1 *Grout classes for grouted tendons*—Use grout class defined in 9.2.2.1(a) through 9.2.2.1(d) as indicated in Contract Documents.

9.2.2.1(a) *Class A grout*—Cement and water.

9.2.2.1(b) *Class B grout*—Cement, water, and field added admixtures

9.2.2.1(c) *Class C grout*—Prepackaged materials and water added in the field

9.2.2.1(d) *Class D grout*—Special materials, blended to achieve specific properties for a particular project as specified in Contract Documents.

9.2.2.2 *Field testing*

9.2.2.2(a) *Field trial tests*—If specified, conduct field trial batching and testing in accordance with PTI M55.1 for the grout class with the same materials, personnel, and equipment to be used in production grouting.

Unless otherwise specified, conduct field trial tests at least 1 week before start of production grouting. If field mockup tests are specified, conduct field trial tests at the same time as field mockup tests.

9.2.2.2(b) *Field mockup tests*—If specified, conduct field mockup tests of grouting in accordance with PTI M55.1. Field mockup tests shall verify and demonstrate that materials, outlets, inlets, mixer, grouting equipment, methods, and procedures are appropriate and will result in complete filling of duct.

Schedule field mockup tests in advance of production grouting. At least 4 weeks before the scheduled start of field mockup tests, submit a written field mockup test plan that covers test setup, materials, ducts, inlets, outlets, anchorages, prestressing element, and grouting and dissection procedures. Supervisory personnel and equipment used for mockup tests shall be the same as those used for production grouting.

9.2.3 *Tape for repair of sheathing*—Tape used shall:

(a) Be self-adhesive and moisture-proof
(b) Be nonreactive with sheathing, coating, or prestressing steel
(c) Have ability to conform to sheathing surface
(d) Have at least 2 in. width
(e) Have a contrasting color to the tendon sheathing

9.3—Execution

9.3.1 *Inspection*—Conduct and document a visual inspection of applicable installation, tensioning, grouting, and finishing for conformance to requirements of this Specification and Contract Documents.

9.3.2 *Multistrand and grouted tendon installation*

9.3.2.1 Bearing surface between anchorage and concrete shall be concentric with the tendon. Bearing plate or anchorage shall be perpendicular to direction of tendon at anchorage.

9.3.2.2 Keep tendons and ducts dry. Do not start grouting until concrete temperature around tendon is 40°F or higher. Maintain concrete temperature around bonded tendons at 40°F or higher for at least 3 days after grouting.

9.3.2.3 If the tendon extends beyond member ends or if tendons are outside the concrete of post-tensioned concrete member, cover exposed and other specified parts of the tendon with additional corrosion protection coating. Coating shall be shop-applied or field-applied and shall be plastic, epoxy, or other acceptable material.

9.3.2.4 Keep end anchorages protected from concrete and free of loose rust, grease, oil, and other debris.

9.3.2.5 *Ducts*

9.3.2.5(a) Keep ducts, anchorage block-outs, openings, vents, inlets, and outlets clean and free of debris, fuel, oil, other contaminants, and site trash before and after installing tendons. Use temporary plugs, seals, and covers as needed.

Before placing concrete, repair damaged ducts by removing locally damaged duct and splicing duct or couplers onto the damaged section, or by other means acceptable to Architect/Engineer.

9.3.2.5(b) Before grouting, ducts shall be blown with oil-free, compressed air to remove water and debris blockages that interfere with grout injection. If specified, test ducts using pressurized air to locate potential grout leaks.

9.3.2.5(c) *Duct support spacing*—Duct support spacing (ℓ) shall conform the following values:

(a) Galvanized metal round duct: $\ell \leq 4$ ft
(b) Plastic round duct: $\ell \leq 2$ ft
(c) Plastic flat duct (with strand preinstalled in duct): $\ell \leq 2$ ft
(d) Plastic flat duct (without strand preinstalled in duct): $\ell \leq 1$ ft

9.3.3 *Unbonded tendon installation*

9.3.3.1 Support prestressing tendons at intervals not exceeding 4 ft.

9.3.3.2 Attach tendons to reinforcement supports to prevent reinforcement without damaging sheathing

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9.3.3.3 Keep tendons and accessories clean and undamaged. Unless otherwise specified, protect exposed components within 1 working day after their exposure during installation.

9.3.3.4 Prevent water from entering tendons during installation.

9.3.3.5 *Stressing-end anchorage*

9.3.3.5(a) Install stressing-end anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall not start closer than 1 ft from stressing-end anchorage.

9.3.3.5(b) Attach stressing-end anchorages to bulkhead forms. Connections shall be sufficiently rigid to avoid accidental loosening. Attach anchor to form edge using fasteners that will not corrode or are protected from corrosion by other means.

9.3.3.5(c) Top, bottom, and edge concrete cover for anchorages shall not be less than specified cover to reinforcement. Unless otherwise specified, concrete cover from exterior edge of concrete to wedge cavity area of anchor shall be at least 1-1/2 in. for non-encapsulated tendons and at least 2 in. for encapsulated tendons.

9.3.3.5(d) Pocket formers used to provide a void form at stressing-end and intermediate anchorages shall prevent intrusion of concrete or cement paste into wedge cavity. At angled slab edges, concrete cover given in 9.3.3.5(c) shall be maintained to anchor edges.

9.3.3.5(e) Cap wedge cavity and install sleeves and seals connecting sheathing to anchorage to completely seal the area against moisture. Install cap after coating the tendon end and wedge area with post-tensioning coating material conforming to ACI 423.7. For non-encapsulated applications, capping of wedge cavity and installing sleeves and seals is not required.

9.3.3.5(f) Unless otherwise specified, concrete cover from the exterior edge of concrete shall be at least 3/4 in. to strand tail for non-encapsulated tendons and at least 1 in. to encapsulation cap for encapsulated tendons.

9.3.3.6 *Intermediate anchorages*

9.3.3.6(a) Embed intermediate anchorages in the first concrete placed at a construction joint. Unless otherwise specified, make the joint watertight.

9.3.3.6(b) Install intermediate anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall be at least 1 ft from intermediate anchorage.

9.3.3.6(c) Top and bottom cover requirements given in 9.3.3.5(c) shall apply to intermediate anchorages.

9.3.3.6(d) Cap wedge cavity and install sleeves and seals connecting sheathing to anchorage on both sides of anchorage to completely seal the area against moisture. Coat exposed prestressing steel and wedge area with post-tensioning coating material conforming to requirements of ACI 423.7. Protection of intermediate anchorage shall be completed within 1 working day of exposure. For non-encapsulated applications, capping of wedge cavity and installing sleeves and seals is not required.

9.3.3.7 *Fixed-end anchorages*

9.3.3.7(a) *Wedge-type anchorages*—Fixed-end anchorages using wedges for gripping strand shall be seated onto prestressing steel by any method that permanently attaches anchorage onto strand. These methods shall include one of the following: pulling wedges into the anchor cavity; pushing wedges into the anchor cavity without applying force on the strand; or other method that will prevent release of prestressing steel and satisfies these requirements.

Temporary force applied to seat wedges shall be limited to a percentage of the minimum breaking strength of the prestressing steel as follows:

(a) Strand pull method = 80 to 85 percent
(b) Strand push method = 85 to 90 percent
(c) Wedges push method = 85 to 120 percent

9.3.3.7(b) Install fixed-end anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall not start closer than 1 ft from fixed-end anchorage.

9.3.3.7(c) Place fixed-end anchorages in formwork at locations indicated on shop drawings and secure them to maintain their position during concrete placement. Concrete cover requirements given in 9.3.3.5(f) apply to fixed-end anchorages.

9.3.3.7(d) Cap wedge cavity and install sleeves and seals connecting sheathing to anchorage to seal the area against moisture. Install cap after coating tendon end and wedge area with same post-tensioning coating material used over tendon length and conforming to requirements of ACI 423.7. For non-encapsulated applications, capping of wedge cavity and installing sleeves and seals is not required.

9.3.3.8 *Sheathing inspection and repair*

9.3.3.8(a) After installing tendons in forms, inspect sheathing for damage. Repair damaged areas, including any breech or split, by restoring post-tensioning coating in the damaged area and repairing sheathing in conformance with 9.3.3.8(b).

9.3.3.8(b) Sheathing repairs shall be watertight, without air spaces, and performed using tape conforming to 9.2.3 and sheathing repair procedures acceptable to Architect/Engineer.

9.3.4 *Tendon tolerances*

9.3.4.1 Unless otherwise specified, deviations between profiles of bonded tendons and design profiles shall be in accordance with PTI/ASBI M50.3.

9.3.4.2 For unbonded post-tensioning, place tendons within the tolerances of ACI 117 for reinforcement placement, distance between reinforcement, and concrete cover except that in slabs, straight tendon runs shall not deviate horizontally more than 1 in. in 15 ft of tendon length.

9.3.4.2(a) Unless otherwise specified, deviations between profiles of single-strand unbonded tendons and design profile shall not exceed:

(a) 1/4 in. for member depth less than or equal to 8 in.
(b) 3/8 in. for member depth greater than 8 in. and less than or equal to 2 ft
(c) 1/2 in. for member depth greater than 2 ft

9.3.4.2(b) Lateral deviations in unbonded tendon location are allowed if necessary to avoid openings, ducts, chases, and inserts. Lateral deviations shall have a radius of curvature no less than 480 strand diameters. If radius of curvature less than 480 strand diameters is necessary, provide addi-

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tional hairpin reinforcement that is accepted by Architect/Engineer.

9.3.5 *Concrete placement*

9.3.5.1 *General*—Prevent water and cementitious paste from entering tendons during concrete placing and curing.

9.3.5.2 *Placement*—Maintain position of post-tensioning tendons and nonprestressed reinforcement within tolerance during concrete placement. Ensure formwork and tendon supports maintain tendon profile within tolerance during concrete placement.

9.3.5.3 *Protection of tendons*—Support pump lines, chutes, and other concrete placing equipment above tendons.

9.3.6 *Tensioning*

9.3.6.1 *Sequence*—Stress tendons in sequence and construction stages specified in Contract Documents. In-place concrete strength at stressing shall not be less than required in Contract Documents.

9.3.6.2 *Tensioning multistrand tendons*—Tension tendons composed of multiple strands in a common duct simultaneously, unless the tendon system requires that strands are stressed individually.

9.3.6.3 *Tendon stressing*—Tension prestressing steel using a hydraulic jack equipped with a gauge calibrated with the jack. The calibrated jack-gauge system shall be capable of measuring jacking force within an accuracy of 2 percent.

Apply required jacking force to produce the prestressing force indicated in Contract Documents or shop drawings and measure prestressing steel elongation. Verify that prestressing force is sufficient by comparing measured elongations to calculated elongations.

If measured elongations differ from calculated elongations by more than 7 percent, determine the cause of discrepancy and resolve.

Maintain and submit a record of elongations and gauge pressure readings for each tendon. Do not remove stressing tails, grout ducts, or grout stressing pockets until Architect/Engineer has accepted elongation records.

9.3.6.4 *Loss of prestressing force*—The total loss of prestressing force in any post-tensioned structural concrete member due to unreplaced broken tendons shall not exceed 2 percent of the total prestressing force.

9.3.6.5 *Formwork removal*—Refer to 2.3.2.6 for requirements for removal of formwork supports.

9.3.6.6 *Prevention of damage to tendons*—Protect tendons from mechanical damage, welding sparks, flame, or electric ground currents. Do not conduct burning and welding operations in the vicinity of tendons, except as allowed by 9.3.8.1 and 9.3.8.2.

9.3.7 *Grouting*

9.3.7.1 *Time between application of prestressing and grouting*—Grout as soon as practicable after stressing prestressing steel in ducts. Time from installing prestressing steel in ducts to grouting after stressing shall not exceed the intervals indicated in Table 9.3.7.1 unless temporary corrosion protection measures are accepted by Architect/Engineer.

Table 9.3.7.1—Permissible intervals between prestressing steel installation and grouting without the use of corrosion protection for different exposures

Over saltwater or damp atmosphere (relative humidity greater than 70 percent)	7 days
Moderate atmosphere (relative humidity between 40 percent and 70 percent)	20 days
Dry atmosphere (relative humidity less than 40 percent)	40 days

9.3.7.2 *Grout mixing*—Mix grout in a mechanical mixer capable of continuous mixing that will produce a grout free of lumps and undispersed cement. Pass grout through the No. 16 sieve into pumping equipment that has provisions for recirculation.

9.3.7.3 *Apply grout under positive pressure*—Grouting pressure at the inlet shall not exceed 145 psi for internal plastic, or oval or flat metal ducts, or 245 psi for internal circular metal ducts without written acceptance of Architect/Engineer.

9.3.7.4 *Grouting procedure*—The method of injecting grout shall ensure complete filling of ducts and complete surrounding of strand or bar with grout. Inject grout from lowest grout inlet in an uphill direction. Use grout within 30 minutes of first addition of water. Maintain a continuous, one-way flow of grout within a grouting stage. Perform grouting of tendon(s) in one operation. Pump grout through duct so it flows continuously out of the first outlet after the inlet. Continue pumping until no visible slugs of water or air eject from vents and outlets and consistency of grout flowing out is similar to injected grout, at which time the outlet shall be closed. Unless otherwise specified, grout injection rate shall be between 16 and 50 ft of duct per minute.

If one-way grout flow cannot be maintained, grouting shall be continued from next available outlet that has steady grout outflow with no visible air or water. Discard grout when it loses consistency required for pumping.

9.3.7.5 *Grouting vertical tendons*—For vertical tendons, provide a standpipe at tendon upper end to store bleed water and grout. The standpipe shall maintain grout level at an elevation that prevents bleeding from causing grout level to drop below the highest point of the uppermost anchorage device. Provide a standpipe that allows bleed water to rise into standpipe, and not into the uppermost part of the tendon and anchorage device.

Maintain grout level above bearing plate and anchorage.

For vertical tendons longer than 100 ft or if the grouting pressure exceeds the maximum specified pumping pressure, grout shall be introduced into one or more of the uppermost intermediate grout vents where air and water has been completely purged. Procedure for pumping from intermediate grout vents shall maintain a one-way flow of grout.

9.3.7.6 *Record keeping*—Maintain record of grouting operations for each tendon and submit a written report in accordance with 9.1.3.3(d) to Architect/Engineer within 72 hours after grouting.

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9.3.7.7 *Completion of grouting*—Fill voids between prestressed reinforcement, ducts, and anchorage fittings. Continue injection until grout of the same consistency as grout injected flows from vent and drain openings without presence of water or air bubbles. Close vent and drain openings progressively in the direction of flow. After vent and drain openings have been closed, raise grouting pressure to at least 50 psi and plug injection hole.

9.3.7.8 *Measures taken after grouting*—Not less than 24 hours after grouting, grout level in outlets and grout caps shall be inspected and topped as necessary with freshly mixed grout.

9.3.8 *Tendon finishing*

9.3.8.1 *Tendon finishing for multistrand and grouted post-tensioned tendons*—Within 1 day after acceptance of stressing records described in 9.1.3.3(c), cut tendon tails. Strand tails protruding beyond wedges after cutting shall be at least 1/2 in. If cutting is delayed, seal tendon openings and temporarily weatherproof exposed tendon ends according to the specified tendon protection level.

Unless otherwise specified, remove tendon tails by plasma cutting, abrasive wheel, or mechanical shears. Ground connection for plasma cutting shall be placed directly on strand bundle being cut off.

If specified, install permanent grout caps, and close grout vents within 1 day of cutting tendon tails.

9.3.8.2 *Tendon finishing for unbonded post-tensioned tendons*

9.3.8.2(a) *Trimming tendons*—After acceptance of stressing records described in 9.1.3.3(c), cut excess tendon tails. Strand tails shall be at least 1/2 in. from face of anchor casting after cutting.

For encapsulated tendons, strand length protruding from face of anchor casting after cutting shall not be more than maximum specified by encapsulation system manufacturer and shall not interfere with proper sealing of end cap. Concrete cover for the tendon shall comply with 9.3.3.5(f).

Cut tendon tails within 1 working day after acceptance of stressing records by Architect/Engineer. For encapsulated tendons, install encapsulation caps within 8 hours after cutting off tendon tails.

For tendons with encapsulated anchorages, remove excess lengths of tendons beyond anchorages to ensure proper fit of encapsulation cap. Cutting of tendons shall not damage wedges or compromise encapsulation system.

9.3.8.2(b) *Tendon protection*—If cutting or capping is delayed more than 7 days after stressing, provide protection to prevent moisture from reaching anchorages.

9.3.8.2(c) *Sealing anchorages*—Before grouting stressing pockets, seal encapsulated stressing-end anchorages in unbonded construction with watertight cap filled with post-tensioning coating.

9.3.8.2(d) *Filling stressing pockets*—Fill stressing pockets with nonmetallic, nonshrink grout within 1 day after cutting prestressing steel. Grout used for pocket filling shall not contain chlorides or other chemicals known to be deleterious to prestressing steel and shall be nonreactive with prestressing steel, anchorage materials, and concrete.

SECTION 10—SHRINKAGE-COMPENSATING CONCRETE FOR INTERIOR SLABS

10.1—General

10.1.1 *Scope*—This Section covers requirements for concrete made with cementitious material conforming to ASTM C845/C845M for interior slabs designated in Contract Documents to be constructed of shrinkage-compensating concrete.

10.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Sections 1 through 5 are applicable for shrinkage-compensating concrete for interior slabs.

10.1.3 *Submittals*

10.1.3.1 Obtain Architect/Engineer's acceptance of required submittals before placing concrete.

10.1.3.2 Submit expansion test results determined in accordance with ASTM C878/C878M for proposed concrete mixture proportions. Include intermediate expansion data so that age at which 70 percent of 7-day laboratory expansion occurs can be determined.

10.1.3.3 Submit placing sequence that shall include sequence of placements, minimum time between placements, and layout of each placement.

10.2—Products

10.2.1 *Materials*

10.2.1.1 *Cementitious materials*—Unless otherwise specified, cementitious material shall conform to ASTM C845/C845M.

10.2.1.2 *Admixtures*—Unless otherwise specified, do not use accelerating admixtures or admixtures containing calcium chloride.

10.2.2 *Performance and design requirements*

10.2.2.1 *Air content*—Concrete for interior slabs to receive a hard-troweled finish shall not contain an air-entraining admixture or have total air content greater than 3 percent.

10.2.2.2 *Expansion*—Unless otherwise specified, concrete expansion, determined in accordance with ASTM C878/C878M, shall be at least 0.03 percent and not more than 0.06 percent at 7 days of soaking.

10.2.2.3 *Slump*—Unless otherwise specified, slump at point of placement shall not exceed 6 in.

10.2.3 *Proportioning*—Conform to 4.2.3 and 10.2.3.1 through 10.2.3.3.

10.2.3.1 If laboratory trial mixtures are used, procedures of ASTM C192/C192M shall be modified as follows: stop the concrete mixer after initial mixing cycle and cover mixer for 20 minutes, unless otherwise specified. After this time period, add water as necessary to produce a slump within 3/4 in. of specified slump. Concrete shall then be mixed for an additional 2 minutes.

10.2.3.2 For proposed concrete mixture, provide laboratory test results for three expansion specimens cast and tested in accordance with ASTM C878/C878M. Submit expansion test results.

10.2.3.3 *Revisions to concrete mixtures*—If concrete materials are changed or mixture proportions are revised in

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accordance with 4.2.3.6, evaluate the effect on expansion in accordance with ASTM C878/C878M and submit test results.

10.2.4 *Reinforcement*—Use reinforcement as specified in Contract Documents.

10.2.5 *Isolation-joint filler materials*—Unless otherwise specified, use compressible isolation-joint filler material that does not develop a stress greater than 25 psi at 50 percent strain when tested in accordance with ASTM D1621 or ASTM D3575.

10.3—Execution

10.3.1 *Reinforcement*

10.3.1.1 Unless otherwise specified, provide 1.5 in. cover from top surface for reinforced slabs-on-ground.

10.3.2 *Placing*

10.3.2.1 *Placing sequence*—Sequence of concrete placements shall be in accordance with accepted placement sequence and shall permit previous placements to have two adjacent edges free to expand.

10.3.2.2 Unless otherwise specified, time between casting adjoining sections shall be at least that required to produce 70 percent of 7-day laboratory expansion of the concrete mixture as determined in accordance with ASTM C878/C878M and as submitted in accordance with 10.1.3.2.

10.3.3 *Isolation joints*—Provide isolation joints at junctions with columns, walls, drains, or other rigid obstructions in the structure in accordance with Contract Documents.

10.3.4 *Curing*—Unless otherwise specified, water-cure shrinkage-compensating concrete for at least 7 days in accordance with 5.3.6.5(a) or 5.3.6.5(b).

SECTION 11—INDUSTRIAL FLOOR SLABS

11.1—General

11.1.1 *Scope*—This Section covers construction requirements for concrete slabs-on-ground that are designated as industrial floor slabs in Contract Documents.

11.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Sections 1 through 5 are applicable for industrial floor slabs.

11.1.3 *Submittals*

11.1.3.1 Obtain acceptance of required submittals from Architect/Engineer before placing concrete.

11.1.3.2 In addition to submittal requirements of Sections 2 through 5, submit information specified in 11.1.3.2(a) through 11.1.3.2(e).

11.1.3.2(a) Manufacturer's data sheet for load-transfer devices at joints.

11.1.3.2(b) Manufacturer's data sheet on saw used to install contraction joints.

11.1.3.2(c) Manufacturer's data sheet for sheet materials for curing, liquid-applied membrane-forming curing compounds, or other materials for curing. If curing compound is specified, submit method of removal if used in areas to receive subsequent finish flooring.

11.1.3.2(d) Plan for protecting concrete against anticipated ambient conditions during transportation, placement, finishing, and specified curing period.

11.1.3.2(e) Plan for joint layout.

11.1.3.3 Submit 11.1.3.3(a) through 11.1.3.3(g), if specified.

11.1.3.3(a) Drying shrinkage test results, for proposed concrete mixture determined in accordance with ASTM C157/C157M, except that instead of storage for 28 days in lime-saturated water, specimens are subjected to 7 days of moist curing followed by at least 21 days of air drying, unless a longer drying period is specified in Contract Documents. The initial length of specimens used as the basis for length change shall be measured at 24 hours ± 1/2 hour upon demolding specimens and drying-shrinkage measurements shall begin at completion of 7-day moist-curing period.

11.1.3.3(b) Manufacturer's data sheet for vapor retarder.

11.1.3.3(c) Manufacturer's data sheet for joint filler.

11.1.3.3(d) Manufacturer's data sheet for liquid-applied surface densifiers.

11.1.3.3(e) Manufacturer's data sheet for mineral or metallic shake hardeners.

11.1.3.3(f) Plan showing extent of each placement, placing sequence, and schedule for each placement.

11.1.3.3(g) Design of construction joint forms.

11.2—Products

11.2.1 *Materials*—Materials used for industrial slab construction shall conform to Sections 2, 3, and 4, except as modified in this Section.

11.2.1.1 *Cementitious materials*—Conform to 4.2.1.1. ASTM C150/C150M Type III, or other high-early-strength hydraulic cement shall not be used.

11.2.1.2 *Aggregates*

11.2.1.2(a) Unless otherwise specified, use aggregates with a nominal maximum size of 1-1/2 in. conforming to requirements of 4.2.1.2.

11.2.1.2(b) Unless otherwise specified, use aggregate base course conforming to ASTM D2940/D2940M.

11.2.1.3 *Admixtures*

11.2.1.3(a) Unless otherwise specified, calcium chloride or admixtures containing chloride from sources other than impurities in admixture ingredients are prohibited.

11.2.1.3(b) Air-entraining admixtures are prohibited in concrete mixtures for use in slabs to receive a hard-troweled finish.

11.2.2 *Concrete mixture*—Unless otherwise specified, proportion concrete mixture to satisfy the following:

(a) Specified compressive strength of 3500 psi at 28 days

(b) Slump between 4 and 6 in.

(c) Shrinkage limit, if specified in Contract Documents

11.2.2.1 *Air content*—Concrete for slabs to receive a hard-troweled finish shall not have total air content greater than 3 percent.

11.2.2.2 *Concrete temperature*—Unless otherwise specified, maximum temperature of concrete, as delivered, shall be 95°F.

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11.2.3 *Field verification of selected mixture proportions*—Comply with 4.2.3.5 to verify the concrete mixture can be finished to achieve a hard-troweled finish.

11.2.4 *Vapor retarder*—Unless otherwise specified, vapor retarder shall conform to ASTM E1745 Class A and shall be at least 10 mil thick.

11.2.5 *Reinforcement*—If specified, use deformed reinforcing bars, tendons, or deformed or plain welded wire reinforcement in conformance with Contract Documents. Supports shall be used at a spacing to result in reinforcement placement in accordance with Contract Documents. If used, welded wire reinforcement shall have a wire spacing of at least 14 in. in both directions.

11.2.6 *Fibers*—If specified, use fibers in concrete mixture in accordance with Contract Documents.

11.2.7 *Load-transfer devices*—If specified, provide load-transfer devices at joints indicated in Contract Documents.

11.2.8 *Joint filler materials*—Unless otherwise specified, use a two-component semi-rigid joint filler material. Joint filler shall have 100 percent solids, a Shore A hardness of at least 85 when measured in accordance with ASTM D2240 at 70 to 77°F, and an elongation below 90 percent when measured in accordance with ASTM D638.

11.2.9 *Isolation-joint filler materials*—Unless otherwise specified, use joint material that prevents bond and allows for horizontal and vertical movement of slab relative to fixed abutting elements and penetrations. Use compressible isolation-joint filler material that does not exceed a stress of 25 psi at 50 percent strain when tested in accordance with ASTM D1621 or ASTM D3575.

11.2.10 *Curing materials*

11.2.10.1 *Curing compounds*—Membrane-forming curing compounds shall meet requirements of 5.2.1.2.

11.2.10.2 *Sheet materials*—Moisture-retaining sheet materials shall meet requirements of ASTM C171. Sheet material shall be non-staining and absorbent.

11.2.11 *Liquid surface densifier*—If specified, use an acceptable liquid surface densifier in areas where indicated.

11.2.12 *Mineral or metallic shake surface hardeners*—If specified, use an acceptable dry-shake hardener in areas where indicated.

11.3—Execution

11.3.1 *Preparation*—Proof-roll prepared base in accordance with Contract Documents. Unless otherwise specified, compact aggregate base course to at least 95 percent of maximum density determined in accordance with ASTM D698. Comply with requirements of 5.3.1 and verify that base surface elevation is within a tolerance of +0 in. and –1/2 in. of planned elevation. This base surface elevation tolerance shall be maintained during casting of concrete. If specified, install acceptable vapor retarder in accordance with ASTM E1643 directly beneath slab in areas as indicated in Contract Documents. Lap seams at least 6 in. and tape continuously. Repair punctures in vapor retarder.

11.3.2 *Measuring, batching, and mixing*—Conform to 4.3.1.

11.3.3 *Delivery*—Conform to 4.3.2.

11.3.4 *Concrete placement*—Conform to 5.3.2.

11.3.5 *Finishing and initial curing of slab surface*—Unless otherwise specified, comply with 5.3.4.2(c) and 5.3.6.2 to provide a hard-troweled finish. Water shall not be added to slab surface during finishing. If required, apply shake surface hardener according to manufacturer's recommendation.

11.3.5.1 *Surface flatness and levelness*—Unless otherwise specified, overall surface flatness shall be F_F 35, and overall levelness shall be F_L 25. Local area minimum values shall be F_F 23 and F_L 17 as determined in accordance with ASTM E1155.

11.3.6 *Joints*—Construct movement joints as indicated in Contract Documents.

11.3.6.1 *Isolation joints*—Install isolation joint material to full depth of slab.

11.3.6.2 *Construction joints*—Comply with 2.2.2.5, 2.3.1.4, and 5.3.2.6. Construction joints shall be perpendicular to slab surface; include load-transfer devices, but do not include keyways. Unless otherwise specified, doweled construction joints designed to allow joint widening shall be saw cut to one-fourth slab thickness or 2 in., whichever is smaller. Align saw cut with joint. Remove concrete dust from saw-cut operation and protect joints from damage due to construction activities.

11.3.6.3 *Contraction joints*—Unless otherwise specified, saw cut all contraction joints and comply with 5.3.5. If early-entry dry-cutting saws are used, replace skid plate and blade as recommended by equipment manufacturer to minimize saw-cut raveling. Install saw cuts perpendicular to slab surface. Remove concrete dust from saw-cut operation. Protect joints from damage due to construction activities.

11.3.6.4 *Consolidation and load-transfer devices*—Comply with 5.3.2.5. Install devices at slab mid-depth and secure to avoid displacement. Consolidate concrete around load-transfer devices by vibration adjacent to the devices.

11.3.7 *Curing and protection*—Comply with 5.3.6 and provide curing for at least 7 days unless otherwise specified. If a sheet material is used, apply as soon as practicable without marring finished surface. Place moisture-retaining sheet materials in a manner to prevent surface discoloration or marking. Keep slab continuously wet after final finishing is completed and during curing period. If a curing compound is used, including those considered self-dissipating, do not apply where subsequent finish flooring or surface densifier is to be installed unless compound is compatible with flooring system or it will be removed by method acceptable to finish flooring or surface densifier manufacturer.

11.3.8 *Liquid surface densifier*—If specified, apply liquid surface densifier in accordance with manufacturer's recommendations. If applied after curing period, remove curing cover or curing compound, allow slab surface to air-dry for at least 7 days, and apply product.

11.3.9 *Joint filling*—Unless otherwise specified, fill joints with a semi-rigid joint filler. Install joint filler full depth of saw cuts. Unless otherwise specified, do not install joint filler earlier than recommended by filler manufacturer. Joints shall be overfilled and shaved flush. During project warranty period, monitor joint filler for separation, sagging,

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bulging, or other deformation and monitor concrete deterioration along joints as joints widen. Separations, sagging, bulging, or other deformations, and joint deterioration shall be corrected within project warranty period.

SECTION 12—TILT-UP CONSTRUCTION

12.1—General

12.1.1 *Scope*—This Section covers construction requirements for concrete panels designated as tilt-up construction in Contract Documents.

12.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Sections 1 through 5 are applicable for tilt-up construction.

12.1.3 *Submittals*—Unless otherwise specified, submit items specified in 12.1.3.1 through 12.1.3.8.

12.1.3.1 *Bearing shims*—Manufacturer's product data sheet for bearing shims to be used.

12.1.3.2 *Coloring agents*—Data on coloring agents.

12.1.3.3 *Bond breaker*—Data on bond breaker.

12.1.3.4 *Drawings*

12.1.3.4(a) *Lifting and bracing design drawings*—These panel drawings include locations for lifting inserts, brace inserts, minimum concrete strength for lifting, added reinforcement for lifting, and bracing design. Panel design shall include bracing to maintain panel tolerances until final structural connections are made. Lifting and bracing design drawings shall be signed and sealed by a licensed design engineer. If specified, submit design calculations signed and sealed by licensed design engineer.

12.1.3.4(b) *Reinforcement placing drawings*—These drawings shall include reinforcing bar sizes, locations, lengths, splices, and quantities.

12.1.3.5 *Field mockups*—If specified, field mockups shall be two panels unless otherwise specified. Each panel shall be at least 4 x 8 ft, constructed and erected using materials and methods detailed in panel shop drawings. Include edge and reveal procedures, special finishes, color, repair, and aggregate sizes. Maintain field mockups until completion of Work.

12.1.3.6 *Grout*—Panel grout manufacturer's data sheet or producer's mixture proportions.

12.1.3.7 *Sandwich panel insulation system*—Details of wythe connections, and thickness and type of insulation to be used to construct insulated sandwich panels.

12.1.3.8 *Defects repair*—Methods and materials for repair of defects.

12.1.4 *Tilt-up contractor qualifications*—Provide documentation of tilt-up contractor's qualifications. Workers shall be proficient in production and erection operations and shall be under direct supervision of an ACI-certified Tilt-Up Supervisor. The tilt-up concrete erector shall submit documentation of at least 2 years of experience in tilt-up product erection, including projects similar in size and scope.

12.2—Products

12.2.1 *Aggregates*—Unless otherwise specified, aggregates shall conform to requirements of Section 4.

12.2.1.1 *Facing aggregates*—Provide fine and coarse aggregate for each type of exposed finish from a single source pit or quarry.

12.2.2 *Bearing shims*—Unless otherwise specified, plastic bearing shims with adequate capacity to support the applied loads before grouting panels.

12.2.3 *Bond breaker*—Bond breaker shall be compatible with curing compound and with coating applied to interior or exterior concrete panels or floor slab.

12.2.4 *Cast-in anchors and connections*

12.2.4.1 *Lifting inserts*—Provide, from a single-source manufacturer, structural inserts and components to engage lifting inserts for lifting tilt-up panels.

12.2.4.2 *Bracing inserts*—Provide structural inserts from a single-source manufacturer for temporary bracing of tilt-up panels.

12.2.5 *Coloring agent*—Coloring agent shall conform to ASTM C979/C979M.

12.2.6 *Curing compound and bond breaker*—Curing compound and bond breaker may be same product, if accepted. If curing compound is not same product as bond breaker, compatibility shall be determined before application of curing compound.

12.2.7 *Face thickness*—Minimum thickness of face shall be the largest of 1 in., 1-1/2 times nominal maximum size of aggregate used, and minimum thickness to provide 3/4 in. cover over reinforcement.

12.2.8 *Grout*—Portland cement used in grout shall conform to ASTM C150/150M. Nonshrink grout shall conform to ASTM C1107/C1107M.

12.2.9 *Sandwich panel insulation systems*—Unless otherwise specified, wythe connectors used in construction of insulated concrete sandwich panels shall maintain effective acceptable material *R*-value of panels as specified in ASHRAE 90.1.

12.3—Execution

12.3.1 *Casting bed*—Cast panels on floor slab or waste slab. Waste slabs, if specified or used, shall be at least 2 in. thick if cast on compacted base or at least 3 in. if compacted base is not used. Compressive strength of waste slab concrete shall be at least 2500 psi at 28 days.

12.3.1.1 Casting bed and side forms shall be free of debris that would affect the surface finish.

12.3.1.2 Seal joints between casting bed and side forms.

12.3.1.3 Treat saw cuts, cracks, or joints in casting bed with a filler material that will minimize mirroring of casting surface on tilt-up panel surface.

12.3.1.4 For panels cast in a vertical stack, consider the troweled surface of a panel a casting bed.

12.3.2 *Bond breaker*—Apply bond breaker to casting surface in accordance with manufacturer's recommendations.

12.3.3 *Reveals*—Fasten reveals (rustication) or false joints to prevent movement or floating during concrete placement operations.

12.3.3.1 Reveals shall be located within ACI 117 tolerances for cast-in-place concrete.

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12.3.3.2 Verify correct alignment between adjacent reveals before placement of concrete.

12.3.4 *Panel identification*—Each panel shall have a panel mark that corresponds to identification marks on shop drawings. Mark test cylinders and test beams with the same identification.

12.3.5 *Side forms*—Side forms shall remain in place and be braced until panels achieve compressive strength of 500 psi.

12.3.6 *Placing concrete*—Do not place concrete until side forms and reinforcement placement have been accepted.

12.3.7 *Anchorage devices*—Set anchorage devices into fresh concrete and consolidate concrete around anchorage devices.

12.3.8 *Finishes*—Concrete finishes shall be as indicated in Contract Documents.

12.3.8.1 Repair panels and casting bed with acceptable concrete repair material.

12.3.8.2 Exposed faces shall match accepted mockup panel.

12.3.9 *Smooth panel finish (SPF)*—Smooth finishes shall be the result of casting on a hard-troweled surface. Unless otherwise specified, the requirements of finish SPF-2 shall apply.

12.3.9(a) *Smooth Panel Finish-3 Architectural (SPF-3)*—Mockup panels are required and shall be prepared in accordance with 12.1.3.5. Surfaces of completed panels shall comply with (a) through (d).

(a) Panel surfaces shall have no surface voids, or surface offsets greater than 1/8 in. Floor slab surface texture defects showing on panel surface shall be ground or patched flush with panel surface.

(b) Repair cracks that allow water to seep through the panel to the interior surfaces after the panel has been installed in its designed location and the final surface finish has been applied.

(c) Surface voids and offsets greater than 1/8 in. shall be ground or filled with patching material.

(d) Upon completion of surface repairs and patching, for final acceptance, panels shall match the appearance of the accepted mockup panel when viewed from a distance of 10 ft in daylight.

12.3.9(b) *Smooth Panel Finish-2 Standard (SPF-2)*—Surfaces of completed panels shall comply with (a) through (c).

(a) Floor contraction joints showing on panel surface shall be ground or patched flush with the panel surface.

(b) Repair cracks that allow water to seep through the panel to the interior surfaces after the panel has been installed in its designed location and the final surface finish has been applied.

(c) Surface voids and offsets greater than 1/4 in. shall be ground or filled with patching material to present a finished surface ready for painting. Patches shall match panel texture. Patches shall also match panel color for surfaces not to be painted.

12.3.9(c) *Smooth Panel Finish-1 Utility (SPF-1)*—Unless otherwise specified, surfaces of completed panels shall comply with (a) and (b).

(a) Panel surfaces shall not have voids or other surface deformations greater than 1/2 in. diameter or depth.

(b) Repair cracks that allow water to pass through the panel to the interior surface after the panel has been installed in its designed location and the final surface finish has been applied.

12.3.10 *Textured finishes*—Textured finishes shall be the result of casting on fluted, sculptured, or textured form liners.

12.3.11 *Treated textured finishes*—Treated textured finishes shall be the combined result of casting on fluted, sculptured, or textured form liners followed by breaking off portions of surface projections.

12.3.11.1 Achieve uniformity of cleavage by alternately striking opposite sides of flute.

12.3.12 *Retarded exposed-aggregate finishes*—To achieve retarded exposed-aggregate finishes, apply surface retarder to face of casting bed in accordance with manufacturer's recommendations.

12.3.12.1 Expose coarse aggregate by washing and brushing, lightly abrasive blasting, or waterblasting surface mortar in accordance with surface retarder manufacturer's directions. Use corrosion-resistant supports. Unless otherwise specified, expose aggregate to produce 3/8 in. aggregate exposure.

12.3.13 *Bush-hammered exposed-aggregate finish*—Concrete shall achieve lifting strength stated in panel design drawings before applying bush-hammered finish.

12.3.14 *Hand-placed aggregate for exposed-aggregate finish*—Secure hand-placed facing aggregate, natural stone, or cobblestone over casting bed with a concrete or cement-sand grout mixture.

12.3.14.1 Roughen exposed surface of facing concrete for bond with backing concrete. Fill remaining panel thickness with backing concrete.

12.3.14.2 Do not place backing concrete directly on facing aggregate.

12.3.14.3 The backing concrete shall be placed within 3 hours of facing concrete or cement-sand grout mixture placement. Facing concrete or cement-sand grout mixture shall be wet cured.

12.3.14.4 Do not use curing compound between facing concrete or cement-sand grout mixture and backing concrete.

12.3.15 *Abrasive finish*—Unless otherwise specified, abrasive blast mortar to produce a 1/8 in. aggregate reveal. If abrasive medium contains water, wash abrasive blasting debris from finished wall surface before drying occurs.

12.3.16 *Veneer faced finish*—Place veneer brick, tile, terra cotta, or natural stone on casting bed.

12.3.16.1 Provide accepted means for mechanical connection of natural stone face material to backing concrete. Unless otherwise specified, provide bond-break material between face material and backing concrete.

12.3.16.2 Place backing concrete to achieve specified panel thickness.

12.3.17 *Erection of panels*

12.3.17.1 Concrete strength at time of erection shall be in accordance with lifting and bracing design drawings.

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12.3.17.2. Brace panels in accordance with lifting and bracing design drawings.

12.3.17.3 Unless otherwise specified, panels shall be braced in position until the lateral-load-resisting system of the structure is complete and final panel attachments are made.

12.3.17.4 Welding to attach panels to building frame and to each other shall be performed by certified welder in accordance with AWS D1.1/D1.1M.

12.3.17.5 Repair erection damage to concrete tilt-up panels in accordance with accepted repair procedure.

12.3.18 *Tolerances*—Tolerances shall conform to ACI 117.

12.3.19 *Testing for panel erection*

12.3.19.1 Unless otherwise specified, cast and field cure cylinders in accordance with ASTM C31/C31M and test cylinders in accordance with ASTM C39/C39M. Alternatively, use accepted methods of determining in-place strength in accordance with 2.3.4.2.

12.3.19.2 If test cylinders are used, for each concrete casting, make at least four cylinders for each 50 yd^3 or fraction thereof. Specimens shall be field cured. Mark specimens for proper identification with associated panels. If alternative testing is used, conduct one test per panel.

12.3.19.3 One strength test shall be performed before panel erection. The strength test result shall equal or exceed the minimum strength required for erection. Remaining specimens shall be kept in reserve for additional testing, if required.

SECTION 13—PRECAST STRUCTURAL CONCRETE

13.1—General

13.1.1 *Scope*—This Section covers construction requirements for members designated as precast structural concrete in Contract Documents.

13.1.2 *General requirements*—Unless otherwise specified in this Section or in Contract Documents, requirements of Sections 1 through 5 are applicable for precast structural concrete.

13.1.2.1 If lightweight precast concrete members are specified, comply with Section 7 in addition to provisions of this Section.

13.1.3 *Submittals*

13.1.3.1 Submittals requirements before execution of Work are given in 13.1.3.1(a) through 13.1.3.1(g).

13.1.3.1(a) *Shop drawings*—Submit shop drawings for erection of precast concrete members, including member locations, plan views, elevations, dimensions, handling procedures, and connection details. Shop drawings shall indicate structural design criteria. If specified, submit shop drawings for fabrication in accordance with Contract Documents.

13.1.3.1(b) *Structural design calculations*—If specified, submit structural calculations prepared, signed, and sealed by an engineer licensed in the jurisdiction of the project. Calculations shall include design of systems, members, and connections in accordance with 13.2.1.

If analysis and design use computer programs, submitted calculations shall include design assumptions, input data, and computer-generated output.

13.1.3.1(c) *Erection plan*—If specified, submit an erection plan indicating erection sequence, temporary bracing, and connection and grouting sequences.

13.1.3.1(d) *Design modifications*—If modifications to design in Contract Documents are proposed, notify Architect/Engineer and submit drawings. If specified, submit design calculations conforming to 13.1.3.1(b). Maintain specified design requirements if altering size of members and alignment.

13.1.3.1(e) *Erector certification*—Unless otherwise specified, submit a current certificate furnished by Precast/Prestressed Concrete Institute (PCI) designating erector certification.

13.1.3.1(f) *Plant certification*—Unless otherwise specified, submit current certificates furnished by Precast/Prestressed Concrete Institute (PCI) designating plant and personnel certification.

13.1.3.1(g) *Welding procedure and certificates*—Submit welding procedure reference specifications and personnel certificates meeting the requirements of 13.1.4.5.

13.1.3.2 If specified, submit material test reports or material certificates, signed by manufacturers or suppliers, certifying that the following items comply with reference specification requirements:

(a) Cementitious materials
(b) Concrete aggregates
(c) Reinforcement and prestressing steel
(d) Admixtures
(e) Bearing pads
(f) Structural-steel shapes and hollow structural sections
(g) Insulation
(h) Other components specified in Contract Documents with applicable standards

13.1.4 *Quality control and quality assurance*

13.1.4.1 *Erector qualifications*—Unless otherwise specified, precast concrete erector shall be qualified by the PCI Erector Certification Program in the category specified in Contract Documents before beginning work at the project site.

If an erector is not qualified by PCI, erector shall have acceptable experience in precast concrete erection on at least three projects comparable in scope to Work. Erector not qualified by PCI shall retain a PCI Certified Field Auditor to conduct a field audit of a project in the same category as this project before start of erection.

13.1.4.2 *Fabricator qualifications*—Unless otherwise specified, fabricator shall be certified in accordance with PCI Plant Certification program for specified group and category specified in Contract Documents.

Unless otherwise specified, testing and inspection shall be performed by PCI-certified personnel. Unless otherwise specified, fabricator shall have at least 5 years of experience in producing precast concrete members similar to those required in Work.

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13.1.4.3 *Owner testing*—Owner may employ an independent testing agency to evaluate fabricator's quality control and testing methods.

13.1.4.3(a) Allow Owner's testing agency access to material storage areas, concrete production equipment, concrete casting, and curing facilities. Cooperate with and provide necessary facilities for Owner's testing agency and provide samples of materials and concrete mixtures as requested for additional testing and evaluation.

13.1.4.4 *Field testing and inspections*—Owner's testing agency may perform testing and inspections given in 13.1.4.4(a) through 13.1.4.4(c) at no cost to Contractor.

13.1.4.4(a) Visually inspect welds in accordance with AWS D1.1/D1.1M and AWS D1.4/D1.4M. Remove, reweld, or repair unsatisfactory welds.

13.1.4.4(b) Field welds will be subject to visual inspection and dye penetrant or magnetic particle testing in accordance with ASTM E165/E165M or ASTM E1444/E1444M.

13.1.4.4(c) Grout will be tested for compressive strength in accordance with ASTM C109/C109M for sand-cement and non-shrink grout. Strength of grout is satisfactory if 28-day compressive strength is equal to or exceeds specified grout strength.

13.1.4.4.1 Testing agency will report test results within 7 days from inspection and in writing as directed by Owner.

13.1.4.4.2 Additional testing and inspection, at Contractor's expense, will be performed to determine compliance of corrected Work with Contract Documents.

13.1.4.5 *Welding*—Unless otherwise specified, use certified welders. Comply with AWS D 1.1/D 1.1M and AWS D1.4/D1.4M.

13.1.4.6 *Preconstruction conference*—Unless otherwise specified, schedule a preconstruction conference at the project site. Design and construction representatives, including special inspector, shall be invited to attend the conference.

13.1.4.7 *Retention of records*—Unless a longer period is specified, retain quality-control records and compliance certificates for each type of precast member for at least 6 years.

13.1.5 *Product delivery, storage, and handling*

13.1.5.1 Store members to prevent contact with soil, to prevent permanent staining, to control cracking, and to maintain dimensions within specified product tolerance.

13.1.5.2 Place stored members so identification marks are visible and units can be inspected.

13.1.5.3 Deliver precast concrete members in such quantities and at such times to comply with precast installation sequence to ensure stability of structure.

13.1.5.4 Handle and transport members in a position consistent with their shape and design as indicated on shop drawings.

13.1.5.5 Lift and support members only at designated points indicated on shop drawings.

13.2—Products

13.2.1 *Performance requirements*

13.2.1.1 *Structural design*—Unless otherwise specified, design each member for required loads, handling, transportation, erection, and other design criteria indicated in Contract Documents.

13.2.1.2 *Fire resistance*—Provide precast concrete members with fire resistance as indicated in Contract Documents. If fire resistance is determined by calculation, submit calculation of fire resistance rating determined in accordance with PCI MNL-124 or ACI 216.1.

13.2.2 *Form materials and accessories*

13.2.2.1 *Forms*—Use forms that are dimensionally stable and non-absorptive and that will provide continuous precast concrete surfaces within fabrication tolerances. Use forms that are nonreactive with materials in concrete and are suitable for producing specified finishes in accordance with 13.2.13.

13.2.3 *Prestressing steel*

13.2.3(a) *General*—Use materials as specified in Contract Documents and conforming to Section 3, unless otherwise specified. Prestressing steel shall be clean and free of scale, oil, dirt, and pitting. A light coating of rust that can be removed with fine steel wool is acceptable.

13.2.3(b) *Prestressing strand*

(a) ASTM A416/A416M

(b) ASTM A886/A886M

(c) ASTM A910/A910M

13.2.3(c) *Unbonded post-tensioning tendons*—ASTM A416/A416M with corrosion inhibitor coating conforming to ACI 423.7.

13.2.3(d) *Post-tensioning bars*—ASTM A722/A722M.

13.2.4 *Concrete materials*

13.2.4.1 *General*—Unless otherwise specified, materials shall conform to Section 4 and the following supplemental requirements.

13.2.4.2 *Aggregates*—Aggregates used for exposed-aggregate finish shall comply with ASTM C33/C33M, except for gradation. Obtain adequate quantities of fine and coarse aggregate for each type of exposed finish for entire project. Aggregates shall be from the same source to match the approved finish sample. If lightweight aggregates are specified, comply with Section 7 except as modified in Contract Documents.

13.2.5 *Bearing pads and other accessories*

13.2.5.1 Unless otherwise specified, provide one of the bearing pads for precast concrete members listed in 13.2.5.1(a) through 13.2.5.1(e).

13.2.5.1(a) *Elastomeric pads*—AASHTO M 251, plain, vulcanized, 100 percent polychloroprene (neoprene) elastomer, molded to size or cut from a molded sheet, 50 to 70 Shore A Durometer measured according to ASTM D2240, with a tensile strength of at least 2250 psi measured according to ASTM D412.

13.2.5.1(b) *Random-oriented, fiber-reinforced elastomeric pads*—Preformed, randomly oriented synthetic fibers set in elastomer. Surface hardness of 70 to 90 Shore A Durometer measured according to ASTM D2240. Capable of supporting a compressive stress of 3000 psi without cracking, splitting, or delaminating in the internal portions of the pad.

13.2.5.1(c) *Cotton-duck-fabric-reinforced elastomeric pads*—Preformed, horizontally layered, cotton-duck fabric

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bonded to an elastomer. Surface hardness of 80 to 100 Shore A Durometer measured according to ASTM D2240. Conforming to Division II, Section 18.10.2 of AASHTO LRFD-US8 or NAVY MIL-C-882E.

13.2.5.1(d) *Low-friction pads*—Tetrafluoroethylene, glass-fiber-reinforced, bonded to stainless or mild-steel plates, or random-oriented, fiber-reinforced elastomeric pads.

13.2.5.1(e) *High-density plastic*—Multimonomer, nonleaching, plastic strip or shim capable of supporting design loads with no visible expansion.

13.2.5.2 *Other accessories*

13.2.5.2(a) *Reglets*—If specified, provide surface-mounted reglets meeting the requirements in Contract Documents.

13.2.6 *Grout materials*

13.2.6.1 *Sand-cement grout*—Unless otherwise specified, use portland cement ASTM C150/C150M Type I, natural or manufactured sand conforming to ASTM C144 or ASTM C404, to produce a grout strength as specified in Contract Documents. If more than one grout type is required, each type shall be used in specified locations. If grout will be in contact with prestressing steel, constituent materials used shall be such that the water-soluble chloride ion (Cl^-) content of grout shall not exceed 0.06 percent of mass of cement as tested in accordance with ASTM C1218/C1218M.

13.2.6.2 *Nonshrink grout*—If specified, use premixed, prepackaged nonshrink grout complying with ASTM C1107/C1107M. Unless otherwise specified, use nonferrous grouts. If specified, submit field installation procedures. If grout will be in contact with prestressing steel, constituent materials used shall be such that the water-soluble chloride ion (Cl^-) content of grout shall not exceed 0.06 percent of mass of cement as tested in accordance with ASTM C1218/C1218M.

13.2.6.3 *Epoxy-resin grout*—If specified, use a two-component, mineral-filled, epoxy-resin grout meeting the requirements of ASTM C881/C881M for the type, grade, and class specified.

13.2.7 *Insulated member components and accessories*

13.2.7.1 *General*—If specified, provide insulated precast concrete members of the specified thickness and *R*-value. Use insulation material meeting the requirements of 13.2.7.2 through 13.2.7.4 at specified locations.

13.2.7.2 *Molded-polystyrene board insulation*—Rigid, cellular polystyrene thermal insulation complying with ASTM C578.

13.2.7.3 *Extruded-polystyrene board insulation*—Rigid, cellular polystyrene thermal insulation complying with ASTM C578.

13.2.7.4 *Polyisocyanurate board insulation*—Square-edged, rigid, cellular, polyisocyanurate thermal insulation complying with ASTM C591 or ASTM C1289.

13.2.7.5 *Wythe connectors*—Provide wythe connectors manufactured to connect wythes of precast concrete members. Unless otherwise specified, wythe connectors shall be one of the following:

(a) Glass-fiber and vinyl-ester polymer connectors
(b) Polypropylene pin connectors
(c) Stainless-steel pin connectors
(d) Bent zinc-coated (galvanized) reinforcing bars
(e) Zinc-coated (galvanized) welded wire trusses
(f) Zinc-coated (galvanized) bent wire connectors
(g) Epoxy-coated carbon fiber grid
(h) Cylindrical corrosion-resistant steel sleeve anchors

13.2.8 *Concrete mixtures*

13.2.8.1 *General*—Prepare concrete mixtures for each type of concrete required.

13.2.8.2 *Normalweight concrete mixtures*—Proportion mixtures by laboratory trial mixture or field test data methods according to Section 4 with materials to be used on project to provide normalweight concrete with the following properties, unless otherwise specified:

(a) Specified compressive strength at 28 days: at least 5000 psi
(b) Maximum *w*/*cm*: 0.45
(c) Air content as required by 4.2.2.6(c)

13.2.8.3 *Lightweight concrete mixtures*—If lightweight concrete is specified, proportion mixtures by laboratory trial mixture or field test data methods according to Section 7, with materials to be used on project, to provide lightweight concrete with the following properties, unless otherwise specified:

(a) Specified compressive strength at 28 days: at least 5000 psi
(b) Specified equilibrium density: 115 lb/ft^3 measured in accordance with ASTM C567/C567M
(c) Air content as required by 4.2.2.6(c)

13.2.9 *Form fabrication*

13.2.9.1 Formwork shall comply with Section 2 except as modified in this Section.

13.2.9.2 Maintain forms to provide completed precast concrete members of specified shapes, lines, and dimensions within fabrication tolerances specified in ACI ITG-7. Unless otherwise specified, edges and corners shall be chamfered.

13.2.10 *Hardware*

13.2.10.1 *Steel connection materials*—Provide steel connection materials of the grades, types, and surface finish indicated in Contract Documents. Weld headed concrete anchors and deformed bar anchors used for anchorage in accordance with AWS D1.1/D1.1M, AWS D1.4/D1.4M, and AWS C5.4.

13.2.10.1(a) Carbon steel shapes and plates shall conform to ASTM A36/A36M.

13.2.10.1(b) Carbon-steel headed studs shall conform to ASTM A108 Grades 1010 through 1020, cold finished, AWS D 1.1/D 1.1M Type A or B, with arc shields and with minimum mechanical properties specified in PCI MNL-116 Table 3.2.3.

13.2.10.1(c) Malleable iron castings shall conform to ASTM A47/A47M Grade 32510 or 35028.

13.2.10.1(d) High-strength, low-alloy structural steel shall conform to ASTM A992/A992M or ASTM A572/A572M.

13.2.10.1(e) Carbon-steel structural tubing shall conform to ASTM A500/A500M Grade B or C.

13.2.10.1(f) Wrought carbon-steel bars shall conform to ASTM A675/A675M Grade 65 (Grade 450).

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13.2.10.1(g) Deformed-steel wire or bar anchors shall conform to ASTM A1064/A1064M or ASTM A706/A706M.

13.2.10.2 *Hardware surface finish*—Surface finish shall comply with 13.2.10.2(a) through 13.2.10.2(c) as indicated in Contract Documents.

13.2.10.2(a) *Shop prime finish*—If shop prime finish is specified, prepare surfaces in accordance with SSPC-SP3. Primer shall be lead- and chromate-free, rust-inhibitive primer, complying with performance requirements of MPI #79. Shop apply in accordance with SSPC-PA1.

13.2.10.2(b) *Galvanized finish*—If galvanized finish is specified, apply zinc coating by hot-dip process in accordance with ASTM A123/A123M, after fabrication, or ASTM A153/A153M, as applicable. For steel shapes, plates, and tubing to be galvanized, limit silicon content of steel to less than 0.03 percent or to between 0.15 and 0.25 percent or limit sum of silicon content and 2.5 times phosphorous content to 0.09 percent. Repair damaged galvanized areas with zinc paint with dry film containing not less than 94 percent zinc dust by mass and complying with NAVY MIL DOD-P-21035A or SSPC-Paint 20.

13.2.10.2(c) *Galvanizing paint*—If galvanizing paint finish is specified, apply zinc paint with dry film containing not less than 94 percent zinc dust by mass and complying with NAVY MIL DOD-P-21035A or SSPC-Paint 20. Comply with paint manufacturer's requirements for surface preparation.

13.2.10.3 *Bolted connectors*—If specified, provide bolted connectors of the grade and type indicated.

13.2.10.3(a) Carbon-steel bolts and studs shall conform to ASTM A307 Grade A or ASTM F1554 Grade 36. Carbon-steel nuts shall conform to ASTM A563 Grade A. Flat unhardened steel washers shall conform to ASTM F844.

13.2.10.3(b) High-strength bolts and nuts shall conform to ASTM A193/A193M Grade B5 or B7, ASTM A325, or ASTM A490 Type 1 heavy hex steel structural bolts. Heavy hex carbon-steel nuts shall conform to ASTM A563. Hardened carbon-steel washers shall conform to ASTM F436/F436M.

13.2.10.4 *Stainless-steel connection materials*—If specified, provide stainless-steel connection materials of the grades and types specified. Weld headed concrete anchors and deformed bar anchors used for anchorage in accordance with AWS D1.6/D1.6M and AWS C5.4.

13.2.10.4(a) Stainless-steel plate shall conform to ASTM A666/C66M Type 304, Type 316, or Type 201.

13.2.10.4(b) Stainless-steel bolts, hex cap screws, and studs shall conform to ASTM F593 alloy 304 or 316. Stainless-steel nuts shall conform to ASTM F594. Nuts and washers shall conform to same alloy as bolts, screws, and studs.

13.2.10.4(c) Stainless-steel headed studs shall conform to ASTM A276/A276M, with minimum mechanical properties for studs specified in PCI MNL-116 Table 3.2.3.

13.2.10.5 *Cast-in anchors, inserts, plates, angles, and other anchorage hardware*—Position embedded anchorage hardware for attachment of loose hardware and secure in place during precasting operations. Locate anchorage hardware as indicated on shop drawings. Fabricate anchorage hardware to comply with design requirements.

13.2.10.6 Furnish loose hardware items, including steel plates, clip angles, seat angles, anchors, dowels, cramps, hangers, and other hardware, for securing precast concrete members to supporting and adjacent construction. Provide locations, setting diagrams, templates, instructions, and installation directions for installation of each anchorage device.

13.2.11 *Fabrication*

13.2.11.1 Provide specified sizes and shapes of precast members as indicated in Contract Documents.

13.2.11.2 Provide specified cast-in reglets, slots, holes, and other accessories as indicated in Contract Documents.

13.2.11.3 Openings larger than 10 in. in any dimension shall be formed or saw cut. Do not drill or cut openings without obtaining acceptance from Architect/Engineer.

13.2.11.4 *Reinforcement*

13.2.11.4(a) Place nonprestressed reinforcement and prestressing steel within tolerances specified in ACI ITG-7. Arrange, space, and tie bars and reinforcement supports to hold reinforcement in position during concrete placement and consolidation operations. Position wire tie ends away from exposed concrete surfaces.

13.2.11.4(b) Install welded wire reinforcement in lengths as long as practicable. Unless otherwise specified, lap adjoining pieces at least one full wire spacing and use wire to tie laps. Offset laps of adjoining widths to prevent continuous laps in either direction.

13.2.11.5 Place concrete in a continuous operation.

13.2.11.6 Consolidate concrete by internal vibration, external vibration, or both, without dislocating or damaging reinforcement and embedments.

13.2.11.7 Identify pickup points of precast concrete members and orientation in structure with permanent markings, complying with markings indicated on shop drawings. Imprint or permanently mark casting date and member identification on each precast concrete member on a surface that will not show in completed structure.

13.2.11.8 Cure concrete by moisture retention or by accelerated heat curing using steam or radiant heat and moisture. Cure members until the concrete compressive strength exceeds the greater of release strength specified in Contract Documents or structural design submittal.

13.2.11.9 *Maximum concrete temperature during curing*—Unless otherwise specified, maximum concrete temperature during curing shall not exceed 160°F. Measure the temperature inside the portion of the member that is likely to experience the highest concrete temperature during curing.

13.2.11.10 Prestress the precast concrete members by pretensioning or post-tensioning methods if specified.

13.2.11.10(a) Delay detensioning or post-tensioning of precast prestressed concrete members until concrete reaches the compressive strength required for release or tensioning.

13.2.11.10(b) Detension pretensioned steel by gradually releasing tensioning jacks or by flame-cutting tendons, using a sequence and pattern to prevent shock or uneven loading.

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