Specifications for Structural Concrete

An ACI Standard

Reported by ACI Committee 301

W. Calvin McCall
Chair

Colin L. Lobo
Secretary

Jon B. Ardahl	Marwan A. Daye	Clifford Gordon†	David K. Maxwell
Domingo J. Carreira*	Mario R. Diaz	David P. Gustafson*	Timothy L. Moore
Oleh B. Ciuk	James A. Farny*	Jerry A. Holland	Jerry Parnes
Steven R. Close*	W. Bryant Frye	Roy H. Keck*	Aimee Pergalsky
D. Gene Daniel	Richard D. Gaynor	James A. Lee	James M. Shilstone, Sr.

Voting Subcommittee Members

James E. Anderson	Gene Hightower	G. Michael Robinson	Daniel J. Stanley
Ramon L. Carrasquillo	Narendra V. Jadhav	Edward D. Russell	Bruce A. Suprenant
Paul A. Decker	Michael L. Leming	Mehmet A. Samee	Robert L. Teerman
Dan Ellery†	William M. Klorman	W. Thomas Scott	Michael A. Whisonant
Alphonse E. Engelman	Mark A. Payne	William C. Sherman	Michelle L. Wilson
Thomas M. Greene	Kenneth B. Rear	Douglas J. Sordyl	Richard M. Wing

Consulting Members

Jeffrey W. Coleman	Gilbert J. Haddad	Ross S. Martin	Joseph A. McElroy
Steven H. Gebler	Atilano Lamana	Bryant Mather†	Carlos Videla

*Subcommittee chair.
†Deceased.

This specification is a Reference Specification that the Engineer or Architect can make applicable to any construction project by citing it in the Project Specifications. The Architect/Engineer supplements the provisions of this Reference Specification as needed by designating or specifying individual project requirements.

The document covers materials and proportioning of concrete; reinforcing and prestressing steels; production, placing, finishing, and curing of concrete; and formwork design and construction. Methods of treatment of joints and embedded items, repair of surface defects, and finishing of formed and unformed surfaces are specified. Separate sections are devoted to architectural concrete, lightweight concrete, mass concrete, prestressed concrete, and shrinkage-compensating concrete. Provisions governing testing, evaluation, and acceptance of concrete as well as acceptance of the structures are included.

Keywords: admixture; aggregate; air entrainment; architectural concrete; cement; cementitious materials; cold weather; compressive strength; concrete; concrete construction; concrete durability; concrete slab; consolidation; conveyor; curing; density; exposed-aggregate finish; finish; floors; formwork; grout; grouting; hot-weather; inspection; joint (construction, contraction, and isolation); lightweight concrete; mix; mixture proportion; placing; prestressed concrete; prestressing steel; reinforced concrete; reinforcement; repair; reshoring; shoring; shrinkage-compensating concrete; specification; subgrade; temperature; test; tolerance; water-cementitious material ratio; welded wire reinforcement.

NOTES TO SPECIFIER

This specification is incorporated by reference in the project specifications using the wording in P3 of the preface and including the information from the mandatory, optional, and submittal checklists following the specification.

PREFACE

P1. ACI Specification 301 is intended to be used by reference or incorporation in its entirety in the Project Specification. Do not copy individual Parts, Sections, Articles, or Paragraphs into the Project Specification, because taking them out of context may change their meaning.

P2. If Sections or Parts of ACI Specification 301 are copied into the Project Specification or any other document,

ACI 301-05 supersedes ACI 301-99 and became effective April 20, 2005.

do not refer to them as an ACI Specification, because the specification has been altered.

P3. A statement such as the following will serve to make ACI Specification 301 a part of the Project Specification:

"Work on (Project Title) shall conform to all requirements of ACI 301-05 published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by these Contract Documents."

P4. Each technical Section of ACI Specification 301 is written in the three-part Section format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

P5. The Specification is written to the Contractor. When a provision of this specification requires action on the Contractor's part, the verb "shall" is used. If the Contractor is allowed to exercise an option, the verb "may" or, when limited alternatives are available, the conjunctive phrase "shall either... or..." is used. Statements provided in the specification as information to the contractor use the verbs "may" or "will." Informational statements typically identify activities or options that "will" be taken or "may" be taken by the Owner or the Architect/Engineer.

CONTENTS

SECTION 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 *Work specified*—This Specification covers cast-in-place structural concrete.

Provisions of this Specification shall govern except where other provisions are specified in the Contract Documents.

1.1.2 *Work not specified*—The following subjects are not in the scope of this specification:

- Precast concrete products;
- Heavyweight shielding concrete;
- Slipformed paving concrete;
- Terrazzo;
- Insulating concrete;
- Refractory concrete;
- Shotcrete;
- Slipformed concrete walls; and
- Tilt-up concrete construction.

1.2—Definitions

acceptable or **accepted**—acceptable to or accepted by the Architect/Engineer.

ACI Concrete Field Testing Technician Grade 1—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. Such 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 or **Engineer/Architect**—the Architect, Engineer, architectural firm, engineering firm, or architectural and engineering firm issuing project drawings and

specifications or administering work under the Contract Documents.

architectural concrete—concrete that is exposed as an interior or exterior surface in the completed structure and is designated as architectural concrete in the Contract Documents; contributes to visual character of the completed structure and therefore requires special care in the selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance.

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 from above.

cement, expansive—a cement that, when mixed with water, produces a paste that, after setting, tends to increase in volume to a significantly greater degree than does portland cement paste; used to compensate for volume decrease due to shrinkage or to induce tensile stress in reinforcement.

cement, expansive Type K—a mixture of portland cement, anhydrous tetracalcium trialuminate sulfate (C_4A_3S•), calcium sulfate ($CaSO_4$), and lime (CaO); the $C_4A_3\overline{S}$ is a constituent of a separately burned clinker that is interground with portland cement, or alternatively, is formed simultaneously with the portland-cement clinker compounds during the burning process.

Contract Documents—a set of documents supplied by Owner to Contractor as the basis for construction; these documents contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

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

duct—a conduit (plain or corrugated) to accommodate prestressing steel for post-tensioned concrete.

exposed to public view—situated so that it can be seen from a public location after completion of the building.

high-early-strength concrete—concrete that is capable of attaining specified strength at an earlier age than 28 days through the use of high-early-strength cement or admixtures.

lightweight concrete—concrete of substantially lower density than normalweight concrete.

mass concrete—any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.

mass concrete, plain—Mass concrete containing no reinforcement or less reinforcement than necessary to be considered reinforced mass concrete.

mass concrete, reinforced—mass concrete containing adequate prestressed or nonprestressed reinforcement to act together with the concrete in resisting forces including those induced by temperature and shrinkage.

normalweight concrete—concrete having a density of approximately 150 lb/ft^3 made with gravel or crushed stone aggregates.

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

permitted—accepted or acceptable to the Architect/Engineer; usually pertains to a request by the Contractor, or to an item specified in the Contract Documents.

post-tensioning—a method of prestressing reinforced concrete in which tendons are tensioned after the concrete has hardened.

prestressed concrete—concrete in which internal stresses of sufficient magnitude and distribution are introduced to counteract to a desired degree the tensile stresses resulting from the service loads; in reinforced concrete, the prestress is commonly introduced by tensioning the tendons.

project drawings—graphic presentation of project requirements.

project specifications—the written document that details requirements for the Work in accordance with service parameters and other specific criteria.

reference specification—a standardized mandatory-language document prescribing materials, dimensions, and workmanship, incorporated by reference in Contract Documents, with information in the Mandatory Requirements Checklist required to be provided in the Project Specification.

reference 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 the 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 applied before the installation of the reshores.

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

sheathing, wood formwork—the materials forming the contact face of forms; also called lagging or sheeting.

shop drawing—a drawing that provides details for a particular task that is developed by the Contractor and reviewed by the Engineer. The shop drawing is prepared to the requirements of the project drawings and project specifications.

shore—a temporary support designed to support formwork, fresh concrete, and construction loads from above for recently built structures that have not developed full design strength.

shrinkage-compensating concrete—a concrete made using an expansive cement that increases in volume after setting, designed to induce compressive stresses in elastically restrained concrete to approximately offset the tensile stresses resulting from drying shrinkage.

strength test—the average of the compressive strengths of two or more cylinders made from the same sample of concrete and tested at 28 days or at the specified test age.

structural lightweight concrete—Structural concrete made with lightweight aggregate; the equilibrium density, as

calculated by ASTM C 567, usually is in the range of 90 to 115 lb/ft^3 with a minimum compressive strength of 2500 psi.

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

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

1.3—Reference standards and cited publications

1.3.1 *Reference standards*—Standards of ACI, ASTM, CRD, and AWS referred to in this Specification are listed with serial designation including year of adoption or revision and are part of this Specification.

1.3.1.1 *ACI standards*

ACI 117-90 Standard Specifications for Tolerances for Concrete Construction and Materials

ACI 423.6-01 Specification for Unbonded Single-Strand Tendons

1.3.1.2 *ASTM standards*

A 82-02 Standard Specification for Steel Wire, Plain, for Concrete Reinforcement

A 184/ A 184M-01 Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement

A 185-02 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete

A 416/A 416M-02 Standard Specification for Steel Strand, Uncoated Seven-Wire, for Prestressed Concrete

A 421/A 421M-02 Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

A 496-02 Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement

A 497/A 497M-02 Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete

A 615/A 615M-04b Standard Specification for Deformed and Carbon Steel Bars for Concrete Reinforcement

A 706/A 706M-04b Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

A 722/A 722M-98 (2003) Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete

A 767/ A 767M-00b Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement

A 775/ A 775M-04a Standard Specification for Epoxy-Coated Steel Reinforcing Bars

A 779/A 779M-00 Standard Specification for Steel Strand, Seven-Wire, Uncoated, Compacted, Stress-Relieved for Prestressed Concrete

A 780-01 Standard Practice for Repair of Damaged Hot-Dip Galvanized Coatings

A 882/A 882M-04a Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand

A 884/A 884M-04 Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Reinforcement

A 934/A 934M-04 Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars

A 955/ A 955M-04a^{e1} Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement

A 970/ A 970M-04a^{e1} Standard Specification for Welded or Forged Headed Bars for Concrete Reinforcement

A 996/A 996M-04 Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

C 31/C 31M-03a Standard Practice for Making and Curing Concrete Test Specimens in the Field

C 33-03 Standard Specification for Concrete Aggregates

C 39/C 39M-03 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 42/ C 42M-04 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C 94/C 94M-04 Standard Specification for Ready-Mixed Concrete

C 138/C 138M-01a Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete

C 143/ C143M-03 Standard Test Method for Slump of Hydraulic-Cement Concrete

C 150-04a Standard Specification for Portland Cement

C 171-03 Standard Specification for Sheet Materials for Curing Concrete

C 172-04 Standard Practice for Sampling Freshly Mixed Concrete

C 173/ C 173M-01^{e1} Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C 192/C 192M-02 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 231-04 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C 260-01 Standard Specification for Air-Entraining Admixtures for Concrete

C 309-03 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

C 330-04 Standard Specification for Lightweight Aggregates for Structural Concrete

C 387-04	Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete
C 404-03	Standard Specification for Aggregates for Masonry Grout
C 494/C 494-04	Standard Specification for Chemical Admixtures for Concrete
C 567-04	Standard Test Method for Determining Density of Structural Lightweight Concrete
C 595-03	Standard Specification for Blended Hydraulic Cements
C 597-02	Standard Test Method for Pulse Velocity Through Concrete
C 618-03	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C 684-99 (2003)	Standard Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens
C 685/C 685M-01	Standard Specification for Concrete Made By Volumetric Batching and Continuous Mixing
C 803/C 803M-03	Standard Test Method for Penetration Resistance of Hardened Concrete
C 805-02	Standard Test Method for Rebound Number of Hardened Concrete
C 845-04	Standard Specification for Expansive Hydraulic Cement
C 873-04	Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C 878-03	Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete
C 881/C 881M-02	Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
C 900-01	Standard Test Method for Pullout Strength of Hardened Concrete
C 928-00	Standard Specification for Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs
C 939-02	Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
C 989-04	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C 1017/ C 1017M-03	Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1012-04	Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
C 1059-99	Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete
C 1064/ C 1064M-04	Standard Test Methods for Temperature of Freshly Mixed Portland Cement Concrete
C 1074-04	Standard Practice for Estimating Concrete Strength by the Maturity Method
C 1077-02	Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C 1107-02	Standard Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)
C1157-03	Standard Performance Specification for Hydraulic Cement
C 1218/ C 1218M-99	Standard Test Method for Water-Soluble Chloride in Mortar and Concrete
C 1240-04	Standard Specification for Silica Fume Used in Cementitious Mixtures
C 1315-03	Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete
C 1602/ C 1602M-04	Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
D 98-98	Standard Specification for Calcium Chloride
D 994-98 (2003)	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
D 1621-04	Standard Test Methods for Compressive Properties of Rigid Cellular Plastics
D 1751-99	Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Non-extruding and Resilient Bituminous Types)
D 1752-04	Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
D 3575-00^{e1}	Standard Test Methods for Flexible Cellular Materials Made from Olefin Polymers
E 329-03	Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction
E 1155-96(2001)	Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers

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

ANSI/ AWS D1.4-98	Structural Welding Code—Reinforcing Steel
CRD-C 513-74	Specification for Rubber Waterstops
CRD-C 572-74	Specification for Polyvinyl chloride Waterstops

1.3.2 *Cited publications*—Publications cited in this Specification:

ACI 318-05	Building Code Requirements for Structural Concrete
ACI CP1-04	ACI Certification Concrete Field Testing Technician—Grade I
ACI CP10-95	ACI Certification Flatwork Technician and Flatwork Finisher
ACI SP-15	Field Reference Manual: Specifications for Structural Concrete (ACI 301-05) with Selected ACI and ASTM References
CRSI MSP-2-01	Manual of Standard Practice, 27th Edition, Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants

1.3.3 *Field references*—Keep in Contractor's field office a copy of the following reference:

ACI SP-15	Field Reference Manual: Specifications for Structural Concrete (ACI 301-05) with Selected ACI and ASTM References.

1.4—Standards-producing organizations

Abbreviations for and complete names and addresses of organizations issuing documents referred to in this Specification are listed:

American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428

American Welding Society (AWS)
550 Northwest 42nd Avenue
Miami, FL 33126

Concrete Reinforcing Steel Institute (CRSI)
933 N. Plum Grove Road
Schaumburg, IL 60173

U.S. Army Corps of Engineers [COE(CRD)]
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180

National Ready Mixed Concrete Association (NRMCA)
900 Spring Street
Silver Spring, MD 20910

1.5—Submittals

1.5.1 *General*—Unless otherwise specified, submittals required in this Specification shall be submitted for review and acceptance.

1.5.2 *Testing agency reports*—Testing agencies will report results of concrete and concrete materials tests and inspections performed during the course of the Work to the Owner, Architect/Engineer, Contractor, and the concrete supplier. Strength test reports will include location in the Work where the batch represented by test was deposited and the batch ticket number. Reports of strength tests will include detailed information of storage and curing of specimens before testing. Final reports will be provided within seven days of test completion.

1.6—Quality assurance

1.6.1 *General*—Concrete materials and operations may be tested and inspected by the Owner as work progresses. Failure to detect defective work or material will not prevent rejection if a defect is discovered later nor shall it obligate the Architect/Engineer for final acceptance.

1.6.2 *Testing agencies*—Agencies that test concrete materials shall meet the requirements of ASTM C 1077. Testing agencies that test reinforcing steel shall meet the requirements of ASTM E 329. Testing agencies shall be accepted by the Architect/Engineer before performing any work. Field tests of concrete required in 1.6.3 and 1.6.4 shall be made by an ACI Concrete Field Testing Technician Grade 1 certified in accordance with ACI CP1 or equivalent. Equivalent certification programs shall include requirements for written and performance examinations as stipulated in ACI publication CP1.

1.6.3 *Testing responsibilities of Contractor*

1.6.3.1 Submit data on qualifications of proposed testing agency for acceptance. Use of testing services will not relieve the Contractor of the responsibility to furnish materials and construction in compliance with the Contract Documents.

1.6.3.2 *Duties and responsibilities*—Unless otherwise specified in the Contract Documents, the Contractor shall assume the duties and responsibilities given in 1.6.3.2.a through 1.6.3.2.g:

1.6.3.2.a Qualify proposed materials and establish mixture proportions.

1.6.3.2.b Allow access to the project site or to the source of materials and assist Owner's testing agency in obtaining and handling samples at the project site or at the source of materials.

1.6.3.2.c Advise Owner's testing agency at least 24 h in advance of operations to allow for completion of quality tests and for assignment of personnel.

1.6.3.2.d Provide and maintain adequate facilities on the project site for safe storage and initial curing of concrete test specimens as required by ASTM C 31/C 31M for the sole use of the testing agency.

1.6.3.2.e Submit test data and documentation on concrete ingredient materials and mixture proportions.

1.6.3.2.f Submit quality-control program of the concrete supplier and provide copies of test reports pertaining to the Work.

1.6.3.2.g When specified or permitted to base concrete acceptance on accelerated strength testing, submit correlation data for the standard 28-day compressive strength based on at least 15 sets of test data in accordance with 1.6.4.2.e with concrete made with the same materials encompassing a range of at least the required average strength f'_{cr}, plus or minus 1000 psi.

1.6.3.3 *Tests required of Contractor's testing agency*—Unless otherwise specified in the Contract Documents, the

Contractor shall provide, at no cost to the Owner, the necessary testing services given in 1.6.3.3.a and 1.6.3.3.b:

1.6.3.3.a Qualification of proposed materials and establishment of concrete mixtures.

1.6.3.3.b Other testing services needed or required by Contractor.

1.6.4 *Testing responsibilities of Owner's testing agency*

1.6.4.1 Unless otherwise specified in the Contract Documents, the Owner's testing agency will provide the necessary services given in 1.6.4.1.a through 1.6.4.1.c:

1.6.4.1.a Representatives of the Owner's testing agency will inspect, sample, and test materials and production of concrete as required by the Architect/Engineer. When it appears that material furnished or work performed by the Contractor fails to conform to Contract Documents, the testing agency will immediately report such deficiency to the Architect/Engineer, Contractor, and concrete supplier.

1.6.4.1.b The testing agency and its representatives are not authorized to revoke, alter, relax, enlarge, or release any requirement of the Contract Documents, nor to accept or reject any portion of the Work.

1.6.4.1.c The testing agency will report test and inspection results that pertain to the Work to the Architect/Engineer, Contractor, and concrete supplier within seven days after tests and inspections are performed.

1.6.4.2 *Testing services*—When required by the Owner or the Architect/Engineer, the Owner's testing agency will perform the following testing services given in 1.6.4.2.a through 1.6.4.2.i at no cost to the Contractor:

1.6.4.2.a Review and check-test proposed materials for compliance with Contract Documents.

1.6.4.2.b Review and check-test proposed concrete mixture as required by the Architect/Engineer.

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

1.6.4.2.d Obtain samples in accordance with ASTM C 172. Select the truckloads or batches of concrete to be tested on a random basis, using random numbers selected before commencement of concrete placement.

Obtain at least one composite sample for each 100 yd^3, or fraction thereof, of each concrete mixture placed in any one day. When the total quantity of a given concrete mixture is less than 50 yd^3, the strength tests may be waived by the Architect/Engineer.

1.6.4.2.e Conduct concrete strength tests during construction in accordance with the following procedures:

- Mold and cure a minimum of three cylinders from each sample in accordance with ASTM C 31/C 31M. Record any deviations from the ASTM requirements in the test report.
- Test cylinders in accordance with ASTM C 39/C39M. Test one specimen at seven days for information, and test a minimum of two specimens at 28 days for acceptance, unless otherwise specified. The compressive strength test results for acceptance shall be the average of the compressive strengths from the specimens tested at 28 days. If a specimen in a test shows evidence of improper sampling, molding, or testing, discard the specimen and consider the strength of the remaining cylinder or cylinders to be the test result. If all specimens in a test show defects, discard the entire test.
- When accelerated testing of concrete is specified or permitted as an alternative to standard testing, mold and cure two specimens from each composite sample in accordance with ASTM C 684, following the procedure specified by the Architect/Engineer. Make at least one accelerated strength test from each composite sample in 1.6.4.2.d and one standard cured 28-day compressive-strength test for at least every other accelerated strength test in accordance with ASTM C 31/C 31M. Use these test results to maintain and update the correlation between accelerated and standard 28-day compressive-strength tests.

1.6.4.2.f Determine slump of each composite sample taken in accordance with 1.6.4.2.d and whenever consistency of concrete appears to vary, using ASTM C 143/C 143M.

1.6.4.2.g Determine the temperature of each composite sample taken in accordance with 1.6.4.2.d using ASTM C 1064/C1064M.

1.6.4.2.h Determine the air content of normalweight concrete using ASTM C 231, C 173, or C 138 for each composite sample taken in accordance with 1.6.4.2.d or as directed by the Architect/Engineer. Additional tests may be performed as necessary.

1.6.4.2.i When the Contract Documents indicate concrete will be exposed to deicing salts, air content tests will be made on samples from the first three batches in the placement and until three consecutive batches have air contents within the range specified in 4.2.2.4, at which time every fifth batch will be tested. This test frequency will be maintained until a batch is not within the range specified in 4.2.2.4, at which time testing of each batch will be resumed until three consecutive batches have air contents within the range specified in 4.2.2.4. Additional tests may be performed as necessary for control. These air content tests may be taken on composite samples in 1.6.4.2.d or on samples from the batch at any time after discharge of 2 ft^3 of concrete.

1.6.4.3 *Additional testing services*—When required by the Architect/Engineer, the Owner's testing agency will perform the following testing services at no cost to the Contractor:

- Inspect the concrete batching, mixing, and delivery operations;
- Inspect forms, foundation preparation, reinforcing steel, embedded items, reinforcing steel placement, and concrete placing, finishing, and curing operations;
- Sample concrete at point of placement and other locations as directed by the Architect/Engineer and perform required tests;
- Review the manufacturer's report for each shipment of cement, reinforcing steel, and prestressing tendons, and conduct laboratory tests or spot checks of the materials received for compliance with specifications; and
- Other testing or inspection services as required by the Architect/Engineer.

1.6.4.4 *Other testing services as needed*—The Contractor shall pay for the following testing services performed, when necessary, by the Owner's testing agency:

- Additional testing and inspection required because of changes in materials or mixture proportions requested by the Contractor; and
- Additional testing of materials or concrete occasioned by failure to meet specification requirements.

1.6.5 *Tests on hardened concrete in-place*

1.6.5.1 *General*—When needed, tests on hardened concrete will be performed by the Owner's testing agency. Testing shall be at the Contractor's expense when this Specification requires such tests to verify the strength of the structure. The Owner will pay costs if tests are at the Owner's request and not required by this Specification.

1.6.5.2 *Nondestructive tests*—Use of the rebound hammer in accordance with ASTM C 805, pulse-velocity method in accordance with ASTM C 597, or other nondestructive tests may be permitted by the Architect/Engineer for evaluating the uniformity and relative concrete strength in place, or for selecting areas to be cored.

1.6.5.3 *Core tests*

1.6.5.3.a Where required by the Architect/Engineer, obtain cores in accordance with ASTM C 42/C42 M. Wipe cores surface-dry immediately after coring and allow to dry in air for a period not exceeding one hour after drilling. Seal cores in plastic bags or nonabsorbent containers until testing. End preparation of cores shall be completed within 48 h after drilling. Test cores not earlier than 48 h after drilling or last wetting and not later than seven days after the cores were drilled from the structure.

1.6.5.3.b At least three representative cores shall be taken from each area of in-place concrete that is considered potentially deficient. The location of cores shall be determined by the Architect/Engineer to impair the strength of the structure as little as possible. If, before testing, cores show evidence of having been damaged subsequent to or during removal from the structure, replacement cores shall be taken.

1.6.5.3.c Fill core holes with low-slump concrete or mortar of a strength equal to or greater than the original concrete.

1.6.6 *Evaluation of concrete strength tests*

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

1.6.6.2 *Nondestructive tests*—Test results will be evaluated by the Architect/Engineer and will be valid only if tests have been conducted using properly calibrated equipment in accordance with recognized standard procedures and an acceptable correlation between test results and concrete compressive strength has been established and is submitted.

1.6.6.3 *Core tests*—Core test results will be evaluated by the Architect/Engineer and will be valid only if tests have been conducted in accordance with specified procedures.

1.6.7 *Acceptance of concrete strength*

1.6.7.1 *Standard molded and cured strength specimens*—The strength level of concrete will be considered satisfactory when: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of ASTM C 31/C 31M equal or exceed f'_c; and no individual strength test result falls below f'_c by more than 500 psi when f'_c is 5000 psi or less, or by more than $0.10f'_c$ when f'_c is more than 5000 psi. These criteria also apply to accelerated strength testing unless another basis for acceptance is specified in the Contract Documents.

1.6.7.2 *Nondestructive tests*—Nondestructive tests shall not be used as the sole basis for accepting or rejecting concrete, but may be used, when permitted, to evaluate concrete where standard molded and cured cylinders have yielded results not meeting the criteria in 1.6.7.1.

1.6.7.3 *Core tests*—Strength level of concrete in the area represented by core tests will be considered adequate when the average compressive strength of the cores is equal to at least 85% of f'_c, and if no single core is less than 75% of the specified compressive strength f'_c.

1.6.8 *Field acceptance of concrete*

1.6.8.1 *Air content*—Concrete not within the limits of air-entrainment indicated in 4.2.2.4 and tested in accordance with 1.6.4.2.h shall not be used in the Work.

1.6.8.2 *Slump*—Concrete not within the slump limits of 4.2.2.2 shall not be used in the Work.

1.6.8.3 *Temperature*—Concrete not within temperature limits of 4.2.2.8 shall not be used in the Work.

1.7—Acceptance of structure

1.7.1 *General*—Completed concrete work shall conform to applicable requirements of this Specification and the Contract Documents.

1.7.1.1 Concrete work that fails to meet one or more requirements of the Contract Documents but subsequently is repaired to bring the concrete into compliance will be accepted.

1.7.1.2 Concrete work that fails to meet one or more requirements of the Contract Documents and cannot be brought into compliance may be rejected.

1.7.1.3 Repair rejected concrete work by removing and replacing or by reinforcing with additional construction as required by the Architect/Engineer. To bring rejected work into compliance, use repair methods that will maintain specified strength and meet applicable requirements for function, durability, dimensional tolerances, and appearance as determined by the Architect/Engineer.

1.7.1.4 Submit for acceptance the proposed repair methods, materials, and modifications needed to repair the concrete work to meet the requirements of Contract Documents.

1.7.1.5 Contractor shall pay all costs to bring concrete work into compliance with requirements of Project Specification.

1.7.1.6 Concrete members cast in the wrong location may be rejected.

1.7.2 *Dimensional tolerances*

1.7.2.1 Formed surfaces resulting in concrete outlines smaller than permitted by the tolerances of ACI 117 may be

considered deficient in strength and subject to the provisions of 1.7.4.

1.7.2.2 Formed surfaces resulting in concrete outlines larger than permitted by ACI 117 may be rejected. Remove excess materials when required by the Architect/Engineer.

1.7.2.3 Inaccurately formed concrete surfaces that exceed ACI 117 tolerances may be rejected.

1.7.2.4 Finished slabs exceeding the tolerances in 5.3.4.3 may be corrected provided they are brought into compliance with 1.7.3, 1.7.4, and 1.7.5.

1.7.2.5 Concrete with tolerances and defects exceeding the limitations of 2.2.2.4 may be rejected.

1.7.3 *Appearance*

1.7.3.1 Concrete not meeting the requirements of 5.3.3 or 5.3.4 shall be brought into compliance in accordance with 1.7.1.

1.7.4 *Strength of structure*

1.7.4.1 *Criteria for determining potential strength deficiency*—Strength will be considered deficient and concrete work will be rejected when the work fails to comply with requirements that control the strength of the structure including, but not limited to, the conditions given in 1.7.4.1.a through 1.7.4.1.f:

1.7.4.1.a Concrete strength failing to comply with requirements of 1.6.7.

1.7.4.1.b Reinforcing steel size, quantity, grade, position, or arrangement at variance with the requirements of Section 3 or other Contract Documents.

1.7.4.1.c Concrete elements that differ from the required dimensions or location.

1.7.4.1.d Curing not performed in accordance with Contract Documents.

1.7.4.1.e Inadequate protection of concrete from extreme temperature and other adverse environmental conditions during early stages of hardening and strength development.

1.7.4.1.f Mechanical injury, construction fires, or premature removal of formwork resulting in deficient strength.

1.7.4.2 *Action required when strength is potentially deficient*—When strength of the structure is considered potentially deficient, the actions given in 1.7.4.2.a through 1.7.4.2.e may be required by the Architect/Engineer:

1.7.4.2.a Structural analysis or additional testing, or both.

1.7.4.2.b Core tests.

1.7.4.2.c If testing is inconclusive or impractical or if structural analysis does not confirm the safety of the structure, load tests may be required and their results evaluated in accordance with ACI 318.

1.7.4.2.d Concrete work rejected by structural analysis or by results of a load test shall be strengthened with additional construction when required by the Architect/Engineer, or replaced.

1.7.4.2.e Document all repair work proposed to bring strength-deficient concrete work into compliance with Contract Documents, and submit the documentation to the Architect/Engineer for acceptance.

1.7.5 *Durability*

1.7.5.1 *Criteria for determining potential durability deficiency*—Durability of concrete work will be considered deficient and the concrete work will be rejected when it fails to comply with the requirements that control durability of the structure, including, but not limited to, the conditions given in 1.7.5.1a through 1.7.5.1.f:

1.7.5.1.a Strength failing to comply with 1.6.7.

1.7.5.1.b Materials for concrete not conforming to the requirements in 4.2.1.1, 4.2.1.2, 4.2.1.3, and 4.2.1.4.

1.7.5.1.c Concrete not conforming to the air-entrainment requirements in Contract Documents or the air content limits of Table 4.2.2.4.

1.7.5.1.d Curing not in accordance with Contract Documents.

1.7.5.1.e Inadequate protection of concrete from detrimental temperature and other detrimental environmental conditions during early stages of hardening and strength development.

1.7.5.1.f Concrete exceeding the maximum allowable chloride-ion content requirements in Table 4.2.2.6.

1.7.5.2 *Action required when durability is potentially deficient*—When durability of the structure is considered to be potentially deficient, the actions given in 1.7.5.2.a through 1.7.5.2.e may be required by the Architect/Engineer:

1.7.5.2.a Obtain and test samples of the ingredient materials used in the concrete.

1.7.5.2.b Obtain samples of concrete from the structure by coring, sawing, or other acceptable means.

1.7.5.2.c Laboratory evaluation of concrete and concrete materials to assess the ability of concrete to resist weathering action, chemical attack, abrasion, or other deterioration, and to protect reinforcement and embedments from corrosion.

1.7.5.2.d Repair or replace concrete rejected for durability deficiency as directed by the Architect/Engineer.

1.7.5.2.e Document repair work to bring concrete work into compliance with Contract Documents and submit the documentation to the Architect/Engineer for acceptance.

1.8—Protection of in-place concrete

1.8.1 *Loading and support of concrete*—Do not allow construction loads to exceed the superimposed load that the structural member, with necessary supplemental support, is capable of supporting safely and without damage or unacceptable deflections.

1.8.2 *Protection from mechanical injury*—During the curing period, protect concrete from damaging mechanical disturbances, including load-induced stresses, shock, and harmful vibration. Protect concrete surfaces from damage by construction traffic, equipment, materials, rain or running water, and other adverse weather conditions.

SECTION 2—FORMWORK AND FORMWORK ACCESSORIES

2.1—General

2.1.1 *Description*—This section covers design, construction, and treatment of formwork to confine and shape concrete to the required dimensions.

2.1.2 *Submittals*

2.1.2.1 Submit the data required in 2.1.2.1.a through 2.1.2.1.f unless otherwise specified:

2.1.2.1.a *Formwork facing materials*—Data on form-facing materials proposed for smooth-form finish if different from that specified in 2.2.1.1.

2.1.2.1.b *Construction and contraction joints*—Location of construction and contraction joints proposed if different from those indicated in the Contract Documents.

2.1.2.1.c *Testing for formwork removal*—Data on method for determining strength of concrete for removal of formwork in accordance with 2.3.4.2 when a method other than field-cured cylinders is proposed.

2.1.2.1.d *Formwork removal plans*—Detail plans for formwork removal operations when removal of forms at concrete strengths lower than that specified in 2.3.2.5 is proposed.

2.1.2.1.e *Reshoring and backshoring plans*—When reshoring or backshoring is required or permitted, submit procedures and plans of operations, before use, sealed by a professional Engineer licensed in the state where work will be performed. Indicate on shop drawings the magnitude of construction loads permitted during reshoring or backshoring.

2.1.2.1.f Data on formwork release agent or form liner proposed for use with each formed surface.

2.1.2.2 Submit data required in 2.1.2.2.a through 2.1.2.2.e when required by the Contract Documents:

2.1.2.2.a Shop drawings for formwork sealed by a professional Engineer licensed in the state where the work will be done.

2.1.2.2.b Calculations for formwork, reshoring and backshoring, sealed by a professional Engineer licensed in the state where the work will be done.

2.1.2.2.c Manufacturer's data and samples of form ties.

2.1.2.2.d Manufacturer's data and samples of expansion joint materials.

2.1.2.2.e Manufacturer's data and samples of waterstops.

2.2—Products

2.2.1 *Materials*

2.2.1.1 *Form-facing materials*—Materials for form faces in contact with concrete shall meet 5.3.3.5 and the following requirements unless otherwise specified in Contract Documents.

- For rough-form finish—No form-facing material is specified.
- For smooth-form finish—Use plywood, tempered concrete-form-grade hardboard, metal, plastic, paper, or other acceptable materials capable of producing the desired finish for form-facing materials. Form-facing materials shall produce a smooth, uniform texture on the concrete. Do not use form-facing materials with raised grain, torn surfaces, worn edges, dents, or other defects that will impair the texture of concrete surfaces.

2.2.1.2 *Formwork accessories*—Use commercially manufactured accessories for formwork accessories that are partially or wholly embedded in concrete, including ties and hangers. Do not use nonfabricated wire form ties. Where indicated in the Contract Documents, use form ties with integral water barrier plates in walls or other acceptable positive water barriers.

2.2.1.3 *Formwork release agents*—Use commercially manufactured formwork release agents that prevent formwork absorption of moisture, prevent bond with concrete, and do not stain the concrete surfaces.

2.2.1.4 *Expansion joint filler*—Premolded expansion joint filler shall conform to ASTM D 994, D 1751, or D 1752.

2.2.1.5 *Other embedded items*—Use waterstops, sleeves, inserts, anchors, and other embedded items of the material and design indicated in the Contract Documents. Waterstop materials shall meet requirements of CRD C 513 for rubber waterstop, or CRD C 572 for polyvinyl chloride waterstop. Splice the waterstops and use molded pieces as recommended by the manufacturer.

2.2.2 *Performance and design requirements*

2.2.2.1 Design and engineering of formwork shall be the responsibility of the Contractor. When required by the Contract Documents, design calculations for formwork and formwork drawings shall be sealed by a professional Engineer licensed in the state where the Work will be done.

2.2.2.2 Design formwork, shores, reshores, and backshores to support all loads transmitted to them and to comply with the requirements of the applicable building code. Design formwork to withstand the pressure resulting from placement and vibration of concrete and to maintain specified tolerances.

2.2.2.3 Do not use earth cuts as forms for vertical or sloping surfaces unless required or permitted by Contract Documents.

2.2.2.4 Maximum deflection of facing materials reflected on concrete surfaces exposed to public view shall be 1/240 of the span between structural members of the formwork. For architectural concrete, see 6.2.2.1.a.

2.2.2.5 *Formed construction and contraction joints*

2.2.2.5.a Locate and form construction joints that least impair strength of the structure and meet the requirements of 5.3.2.6.

2.2.2.5.b Unless otherwise specified or permitted, locate and detail formed construction joints to the following requirements:

- Locate construction joints within the middle third of the spans of slabs, beams, and girders. When a beam intersects a girder within this region, offset the joint in the girder a distance equal to or greater than twice the width of the beam;
- Locate joints in walls and columns at the underside of slabs, beams, or girders and at the tops of footings or slabs; and
- Make joints perpendicular to the main reinforcement.

2.2.2.5.c Provide keyways where indicated on Contract Documents. Unless otherwise specified, longitudinal keyways indicated on the Contract Documents, shall be a minimum of 1-1/2 in. deep in joints in walls and between walls and slabs or footings.

2.2.2.5.d Provide construction and contraction joints where indicated on the Contract Documents. Submit for

acceptance the location of construction and contraction joints differing from those indicated on the Contract Documents.

2.2.2.6 For a smooth-form finish, set the facing materials in an orderly and symmetrical arrangement, and keep the number of seams to a practical minimum. Facing materials shall be supported with studs or other backing capable of maintaining deflections within the tolerances specified in 2.2.2.4.

2.2.3 *Fabrication and manufacture*

2.2.3.1 Formwork shall be tight to prevent loss of mortar from concrete.

2.2.3.2 Place 3/4 in. minimum chamfer strips in the corners of formwork to produce beveled edges on permanently exposed surfaces unless otherwise specified. Do not bevel reentrant corners or edges of formed joints of concrete unless specified in the Contract Documents.

2.2.3.3 Inspect formwork and remove deleterious material immediately before concrete is placed. Provide temporary openings where needed at the base of column and wall formwork to facilitate cleaning and inspection.

2.2.3.4 Fabricate form ties so ends or end fasteners can be removed with minimum spalling at the faces of concrete. After the ends or end fasteners of form ties have been removed, terminate the embedded portion of ties not less than two diameters, or twice the minimum cross-sectional dimension of the tie, from the formed concrete surface. This distance shall be a minimum of 3/4 in. Repair tie holes in accordance with 5.3.7.2.

2.2.3.5 Locate waterstops in joints where indicated on Contract Documents. Use pieces of premolded waterstop with a maximum practicable length to create the minimum number of end joints. Make joints in waterstops in accordance with the manufacturer's recommendations. Ensure that joints develop effective watertightness equal to the continuous waterstop material, permanently develop not less than 50% of the strength of the parent section and permanently retain flexibility.

2.3—Execution

2.3.1 *Construction and erection of formwork*

2.3.1.1 At construction joints, lap contact surface of the form sheathing for flush surfaces exposed to view over the hardened concrete in the previous placement. Ensure formwork is sealed against hardened concrete to prevent offsets or loss of mortar at construction joints and to maintain a true surface.

2.3.1.2 Unless otherwise specified in the Contract Documents, construct formwork so concrete surfaces conform to the tolerance limits of ACI 117. The class of surface for offset between adjacent pieces of formwork facing material shall be Class B for surfaces permanently exposed to public view and Class D for surfaces that will be permanently concealed, unless otherwise specified.

2.3.1.3 Provide positive means of adjustment (such as wedges or jacks) of shores and struts. Do not make adjustments in the formwork after concrete has reached its time of initial setting. Brace formwork securely against lateral deflection and lateral instability.

2.3.1.4 To maintain specified tolerances, camber formwork to compensate for anticipated deflections in formwork during concrete placement. Set formwork and intermediate screed strips for slabs accurately to produce designated elevations and contours of the finished surface before removal of formwork. Ensure that edge forms and screed strips are strong enough to support vibrating screeds or roller pipe screeds when the finish specified requires the use of such equipment.

2.3.1.5 When formwork is cambered, set screeds to the same camber to maintain specified concrete thickness.

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

2.3.1.7 Anchor formwork to shores, supporting surfaces, or members to prevent upward or lateral movement of the formwork system during concrete placement.

2.3.1.8 Construct formwork for wall openings to facilitate removal and to counteract swelling of wood formwork.

2.3.1.9 Provide runways for moving equipment and support runways directly on the formwork or structural member without resting on the reinforcing steel.

2.3.1.10 Place sleeves, inserts, anchors, and embedded items required for adjoining work or for support of adjoining work before concrete placement.

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

2.3.1.12 Clean surfaces of formwork and embedded materials of mortar, grout, and foreign materials before concrete is placed.

2.3.1.13 Cover surfaces of formwork with an acceptable material that will prevent bond with the concrete. A field-applied formwork release agent or a factory-applied liner may be used. If a formwork release agent is used, apply to the surfaces of the formwork in accordance with the manufacturer's recommendations before placing reinforcing steel. Do not allow formwork release agent to puddle in the forms. Do not allow formwork release agent to contact reinforcing steel or hardened concrete against which fresh concrete is to be placed.

2.3.2 *Removal of formwork*

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

2.3.2.2 Remove top forms on sloping surfaces of concrete as soon as removal will not allow concrete to sag. Perform needed repairs or treatment required at once and follow immediately with specified curing.

2.3.2.3 Loosen wood formwork for wall openings as soon as loosening operations will not damage concrete.

2.3.2.4 Do not damage concrete during removal of formwork for columns, walls, sides of beams, and other parts not supporting the weight of the concrete. Perform needed repair and treatment required on vertical surfaces at once and follow immediately with specified curing.

2.3.2.5 Unless otherwise specified, leave formwork and shoring in place to support the weight of concrete in beams,

slabs, and in-place structural members until concrete has reached f_c', in accordance with 2.3.4. If a lower compressive strength is proposed for removal of formwork and shoring, submit detailed plans for review and acceptance. When shores and other vertical supports are arranged to allow the form-facing material to be removed without loosening or disturbing the shores and supports, the facing material may be removed at an earlier age unless otherwise specified.

2.3.2.6 Construct formwork to permit easy removal.

2.3.3 *Reshoring and backshoring*

2.3.3.1 Submittals for reshoring and backshoring operations shall comply with 2.1.2.1.e and 2.1.2.2.b.

2.3.3.2 During reshoring and backshoring, do not allow concrete in beam, slab, column, or any structural member to be loaded with combined dead and construction loads in excess of the loads permitted by the Architect/Engineer for the concrete compressive strength at the time of reshoring and backshoring.

2.3.3.3 Place reshores and backshores in sequence with stripping operations.

2.3.3.4 Tighten reshores and backshores to carry the required loads without overstressing the concrete members. Leave them in place until tests required by 2.3.4 indicate that the concrete compressive strength has attained the minimum value specified in 2.3.2.5.

2.3.3.5 For floors supporting shores under newly placed concrete, either leave the original supporting shores in place, or install reshores or backshores. The shoring system and the supporting slabs shall resist the anticipated loads. Locate reshores and backshores directly under a shore position or as indicated on formwork shop drawings.

2.3.3.6 In multistory buildings, place reshoring or backshoring over a sufficient number of stories to distribute the weight of newly placed concrete, forms, and construction live loads such that the design loads of the floors supporting the shores, reshores or backshores are not exceeded.

2.3.4 *Strength of concrete required for removal of formwork*

2.3.4.1 When removal of formwork or reshoring is based on concrete reaching a specified compressive strength, concrete will be presumed to have reached this strength when test cylinders, field cured the same as the concrete they represent, have reached the compressive strength specified for removal of formwork or reshoring. Mold cylinders in accordance with ASTM C 31/C 31M, and cure them under the same conditions for moisture and temperature as used for the concrete they represent. Test cylinders in accordance with ASTM C 39/C 39M.

2.3.4.2 Alternatively, when specified or permitted, use methods in 2.3.4.2 b through 2.3.4.2.d to evaluate concrete strength for formwork removal. Before using methods in 2.3.4.2.b through 2.3.4.2.d, submit data using project materials to demonstrate correlation of measurements on the structure with the compressive strength of laboratory-cured molded cylinders or drilled cores. Submit correlation data on the proposed alternative method for determining strength to the Architect/Engineer.

2.3.4.2.a Tests of cast-in-place cylinders in accordance with ASTM C 873. This is limited to slabs with concrete depths from 5 to 12 in.

2.3.4.2.b Penetration resistance in accordance with ASTM C 803/C 803M.

2.3.4.2.c Pullout strength in accordance with ASTM C 900.

2.3.4.2.d Maturity method in accordance with ASTM C 1074.

2.3.5 *Field quality control*

2.3.5.1 Establish and maintain survey controls and benchmarks in an undisturbed condition until final completion and acceptance of the project.

2.3.5.2 Variations from plumb and designated building lines shall not exceed the tolerances specified in ACI 117.

SECTION 3—REINFORCEMENT AND REINFORCEMENT SUPPORTS

3.1—General

This section covers materials, fabrication, placement, and tolerances of reinforcement and reinforcement accessories.

3.1.1 *Submittals, data, and drawings*—Unless otherwise required by Contract Documents, submit data and drawings specified in 3.1.1.1 through 3.1.1.3 for review and acceptance before fabrication and execution:

3.1.1.1 Submit the data specified in 3.1.1.1.a through 3.1.1.1g unless otherwise specified:

3.1.1.1.a *Reinforcement*—Submit manufacturer's certified test report.

3.1.1.1.b *Placing drawings*—Submit placing drawings showing fabrication dimensions and placement locations of reinforcement and reinforcement supports.

3.1.1.1.c *Splices*—Submit a list of splices and request to use splices not indicated in Contract Documents.

3.1.1.1.d *Mechanical splices*—Submit request to use mechanical splices not shown on the project drawings.

3.1.1.1.e *Column dowels*—Submit request to place column dowels without the use of templates.

3.1.1.1.f *Field bending*—Submit request and procedure to field bend or straighten reinforcement partially embedded in concrete.

3.1.1.1.g *Certification*—Submit copy of current CRSI Plant Certification Manual.

3.1.1.2 Submit the data specified in 3.1.1.2.a through 3.1.1.2.b when required:

3.1.1.2.a *Welding*—Submit description of reinforcement weld locations, welding procedures, and welder certification when welding is permitted in accordance with 3.2.2.2.

3.1.1.2.b *Supports*—If coated reinforcement is required, submit description of reinforcement supports and materials for fastening coated reinforcement not described in 3.3.2.4.

3.1.1.3 Submit the data specified in 3.1.1.3.a through 3.1.1.3.b when alternatives are proposed:

3.1.1.3.a *Reinforcement relocation*—Submit a request to relocate any reinforcement that exceeds specified placement tolerances.

3.1.1.3.b Inspection and quality-control program of plants applying epoxy coating if proposed plant is not certified in accordance with the CRSI Certification Program.

3.1.2 *Materials delivery, storage, and handling*

3.1.2.1 Prevent bending, coating with earth, oil, or other material, or otherwise damaging the reinforcement.

3.1.2.2 When handling coated reinforcement, use equipment having contact areas padded to avoid damaging the coating. Lift bundles of coated reinforcement at multiple pickup points to prevent bar-to-bar abrasion from sags in the bundles. Do not drop or drag coated reinforcement. Store coated reinforcement on cribbing that will not damage the coating.

3.2—Products

3.2.1 *Materials*

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

- ASTM A 615/A 615M;
- ASTM A 706/A 706M;
- ASTM A 970/A 970M; or
- ASTM A 996/A 996M, rail-steel bars shall be Type R.

3.2.1.2 *Coated reinforcing bars*—Use zinc or epoxy-coated reinforcing bars as specified in the Contract Documents.

3.2.1.2.a Zinc-coated (galvanized) reinforcing bars shall conform to ASTM A 767/A 767M. Repair coating damage due to shipping, handling, and placing in accordance with ASTM A 780. The maximum total damaged areas shall not exceed 2% of the surface area in each linear foot of each bar.

3.2.1.2.b Epoxy-coated reinforcing bars shall conform to ASTM A 775/A 775M or ASTM A 934/A 934M as specified in the Contract Documents.

Coatings shall be applied in plants that are certified in accordance with the Concrete Reinforcing Steel Institute (CRSI) Certification Program or an equivalent program acceptable to the Architect/Engineer.

Repair damaged areas with patching material conforming to ASTM A 775/A 775M or ASTM A 934/A 934M as applicable and in accordance with the material manufacturer's written recommendations. Repair coating damage due to shipping, handling, and placing. The maximum total damaged areas shall not exceed 2% of the surface area in each linear foot of each bar. Fading of the coating color will not be cause for rejection of epoxy-coated reinforcing bars.

3.2.1.3 *Stainless steel bars*—Stainless steel bars shall conform to ASTM A 955/A 955M.

3.2.1.4 *Bar mats*—Bar mats shall conform to ASTM A 184/A 184M:

3.2.1.5 *Wire*—Use plain or deformed wire as indicated on Contract Documents. Plain wire may be used for spirals.

3.2.1.5.a Plain wire shall conform to ASTM A 82.

3.2.1.5.b Deformed wire size D4 and larger shall conform to ASTM A 496.

3.2.1.5.c Epoxy-coated wire shall conform to ASTM A 884/A 884M. The maximum total damaged areas, including areas repaired at the manufacturing facility, shall not exceed 2% of the surface area in each linear foot of each wire. Repair all damaged areas.

3.2.1.5.d For wire with f_y exceeding 60,000 psi, f_y shall correspond to a strain of 0.35%.

3.2.1.6 *Welded wire reinforcement*—Use welded wire reinforcement specified in Contract Documents and conforming to one of the specifications given in 3.2.1.6.a through 3.2.1.6.c.

3.2.1.6.a *Plain welded wire reinforcement*—ASTM A 185, with welded intersections spaced not farther apart than 12 in. in the direction of principal reinforcement.

3.2.1.6.b *Deformed welded wire reinforcement*—ASTM A 497/A497M, with welded intersections spaced not farther apart than 16 in. in the direction of principal reinforcement.

3.2.1.6.c *Epoxy-coated welded wire reinforcement*—ASTM A 884/A 884M, the maximum total damaged areas, including areas repaired at the manufacturing facility, shall not exceed 2% of the surface area in each linear foot of each wire. Repair all damaged areas.

3.2.1.6.d For welded wire reinforcement with f_y exceeding 60,000 psi, f_y shall correspond to a strain of 0.35%.

3.2.1.7 *Wire-reinforcement supports*—Unless otherwise specified or permitted, use wire-reinforcement supports complying with Class 1, maximum protection, or Class 2, moderate protection, as indicated in Chapter 3 of the CRSI Manual of Standard Practice.

3.2.1.8 *Coated wire-reinforcement supports*

3.2.1.8.a For epoxy-coated reinforcement—Use wire-reinforcement supports coated with dielectric material, including epoxy or another polymer for a minimum distance of 2 in. from the point of contact with epoxy-coated reinforcement.

3.2.1.8.b For zinc-coated reinforcement—Use galvanized wire-reinforcement supports or wire-reinforcement supports coated with dielectric material.

3.2.1.9 *Precast concrete reinforcement supports*—Use concrete supports that have a surface area of not less than 4 in.^{2} and have a compressive strength equal to or greater than the specified compressive strength of the concrete being placed.

3.2.2 *Fabrication*

3.2.2.1 *Reinforcement*—Bend reinforcement cold unless heating is permitted. Fabricate reinforcement in accordance with fabricating tolerances of ACI 117.

3.2.2.2 *Welding*

3.2.2.2.a When welding of reinforcement is specified or permitted, comply with the requirements of ANSI/AWS D1.4. Do not weld crossing bars (tack welding) for assembly of reinforcement, supports, or embedded items.

3.2.2.2.b After completing welds on zinc-coated (galvanized) or epoxy-coated reinforcement, repair coating damage in accordance with requirements in 3.2.1.2.a or 3.2.1.2.b, respectively. Coat welds and steel splice devices used to splice reinforcement with the same material used for repair of coating damage.

3.3—Execution

3.3.1 *Preparation*

3.3.1.1 When concrete is placed, reinforcement shall be free of materials deleterious to bond. Reinforcement with

rust, mill scale, or a combination of both will be considered satisfactory, provided the minimum nominal dimensions, nominal weight, and the minimum average height of deformations of a hand-wire-brushed test specimen are not less than the applicable ASTM specification requirements.

3.3.2 *Placement*

3.3.2.1 *Tolerances*—Place, support, and fasten reinforcement as shown on the project drawings. Do not exceed the placing tolerances specified in ACI 117 before concrete is placed. Placing tolerances shall not reduce cover requirements except as specified in ACI 117.

3.3.2.2 *Reinforcement relocation*—When it is necessary to move reinforcement beyond the specified placing tolerances to avoid interference with other reinforcement, conduits, or embedded items, submit the resulting reinforcement arrangement for acceptance.

3.3.2.3 *Concrete cover*—Unless otherwise specified, minimum concrete cover for reinforcement shall be as indicated in Table 3.3.2.3.

For bundled bars, minimum concrete cover shall be equal to the equivalent diameter of the bundle but need not be greater than 2 in.; except the minimum cover shall not be less than specified in Table 3.3.2.3. The equivalent diameter of the bundle shall be computed based on the total area of the bundle. Tolerances on minimum concrete cover shall meet the requirements of ACI 117.

3.3.2.4 *Reinforcement supports*—Unless otherwise permitted, use the reinforcement supports given in 3.3.2.4.a through 3.3.2.4.i:

3.3.2.4.a Use precast concrete reinforcement supports to support reinforcement from the ground or a mud mat.

3.3.2.4.b Use reinforcement supports made of concrete, metal, or plastic to support uncoated reinforcement.

3.3.2.4.c Use wire reinforcement supports that are galvanized, coated with dielectric material, or made of dielectric material to support zinc-coated (galvanized) reinforcement.

3.3.2.4.d Reinforcement and embedded steel items used with zinc-coated (galvanized) reinforcement shall be zinc-coated (galvanized) or coated with nonmetallic materials.

3.3.2.4.e Support epoxy-coated reinforcement on coated wire reinforcement supports or on reinforcement supports made of dielectric material. Use coatings or materials compatible with concrete.

3.3.2.4.f When precast concrete reinforcement supports with embedded tie wires or dowels are used with epoxy-coated reinforcement, use wires or dowels coated with dielectric material.

3.3.2.4.g Reinforcement used as supports with epoxy-coated reinforcement shall be epoxy coated.

3.3.2.4.h In walls reinforced with epoxy-coated reinforcement, use spreader bars that are epoxy coated. Proprietary combination bar clips and spreaders used in walls with epoxy-coated reinforcement shall be made of corrosion-resistant material or coated with dielectric material.

3.3.2.4.i Fasten epoxy-coated reinforcement with tie wires coated with epoxy or other polymer.

3.3.2.5 *Welded wire reinforcement*—For slabs on ground, extend welded wire reinforcement to within 2 in. of the concrete edge. Lap splice edges and ends of welded wire reinforcement sheets as shown on the project drawings. Unless otherwise specified or permitted, do not extend welded wire reinforcement through contraction joints. Support welded wire reinforcement during placing of concrete to maintain positioning in the slab. Do not place welded wire reinforcement on grade and subsequently raise into position in concrete.

3.3.2.6 *Column dowels*—Furnish and use templates for placement of column dowels unless otherwise permitted.

3.3.2.7 *Splices*—Make splices as indicated on the project drawings unless otherwise permitted. Mechanical splices for reinforcement not shown on the project drawings shall not be used unless accepted by the Architect/Engineer. Remove reinforcement coating in the area of the mechanical splice if required by the splice manufacturer. After installing mechanical splices on zinc-coated (galvanized) or epoxy-coated reinforcement, repair coating damage and areas of removed coating in accordance with 3.2.1.2.a or 3.2.1.2.b. Coat exposed parts of mechanical splices used on coated bars with the same material used to repair coating damage.

3.3.2.8 *Field bending or straightening*—When permitted, bend or straighten reinforcement partially embedded in

Table 3.3.2.3—Minimum concrete cover for reinforcement

Minimum concrete cover for reinforcement, except for extremely corrosive atmospheres, other severe exposures, or additional fire protection, shall be as follows:	
	Minimum cover, in.
Slabs and joists	
Top and bottom bars for dry conditions	
No. 11 bars and smaller	3/4 in.
No. 14 and 18 bars	1-1/2 in.
Formed concrete surfaces exposed to earth, water, or weather, and over or in contact with sewage and for bottoms bearing on work mat, or slabs supporting earth cover	
No. 5 bars and smaller, W31 or D31 wire and smaller	1-1/2 in.
No. 6 through 18 bars, W45 or D45 wire	2 in.
Beams and columns, formed	
For dry conditions	
Stirrups, spirals, and ties	1-1/2 in.
Principal reinforcement	2 in.
Exposed to earth, water, sewage, or weather	
Stirrups and ties	2 in.
Principal reinforcement	2-1/2 in.
Walls	
For dry conditions	
No. 11 bars and smaller	3/4 in.
No. 14 and 18 bars	1-1/2 in.
Formed concrete surfaces exposed to earth, water, sewage, weather, or in contact with ground	2 in.
Footings and base slabs	
At formed surfaces and bottoms bearing on concrete work mat	2 in.
At unformed surfaces and bottoms in contact with earth	3 in.
Top of footings	Same as slabs
Over top of piles	2 in.

Table 3.3.2.8—Minimum diameter of bend

Bar size	Minimum inside bend diameter
No. 3 through 8	Six bar diameters
No. 9, 10, and 11	Eight bar diameters
No. 14 and 18	Ten bar diameters

concrete in accordance with procedures 3.3.2.8.a through 3.3.2.8.c. Reinforcing bar sizes No. 3 through 5 may be bent cold the first time, provided reinforcing bar temperature is above 32 °F. For other bar sizes, preheat reinforcing bars before bending.

3.3.2.8.a *Preheating*—Apply heat by any method that does not harm the reinforcing bar material or cause damage to the concrete. Preheat a length of reinforcing bar equal to at least five bar diameters in each direction from the center of the bend but do not extend preheating below the surface of the concrete. Do not allow the temperature of the reinforcing bar at the concrete interface to exceed 500 °F. The preheat temperature of the reinforcing bar shall be between 1100 and 1200 °F. Maintain the preheat temperature until bending or straightening is complete. Measure the preheat temperature by temperature measurement crayons, contact pyrometer, or other acceptable methods. Do not artificially cool heated reinforcing bars until the temperature of the bar is less than 600 °F.

3.3.2.8.b *Bend diameters*—Minimum inside bend diameters shall conform to the requirements of Table 3.3.2.8. In addition, beginning of the bend shall not be closer to the concrete surface than the minimum diameter of bend.

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

3.3.2.9 *Field cutting of reinforcement*—Field cut reinforcement only when specifically permitted using cutting methods specified by or acceptable to the Architect/Engineer. Do not flame cut epoxy-coated reinforcement.

3.3.2.9.a When zinc-coated (galvanized) reinforcing bars are cut in the field, coat the ends of the bars with a zinc-rich formulation used in accordance with the manufacturer's recommendations, and repair any coating damage in accordance with 3.2.1.2.a.

3.3.2.9.b When epoxy-coated reinforcing bars are cut in the field, coat the ends of the bars with the same material used for repair of coating damage, and repair any coating damage in accordance with 3.2.1.2.b.

3.3.2.10 *Reinforcement through expansion joint*—Do not continue reinforcement or other embedded metal items bonded to concrete through expansion joints. Dowels bonded on only one side of a joint and waterstops shall extend through the joint.

SECTION 4—CONCRETE MIXTURES

4.1—General

4.1.1 *Description*—This section covers the requirements for materials, proportioning, production, and delivery of concrete.

4.1.2 *Submittals*

4.1.2.1 *Mixture proportions*—Submit concrete mixture proportions and characteristics.

4.1.2.2 *Mixture proportion data*—Submit field test records used to establish the required average strength in accordance with 4.2.3.3. Submit test data used to establish the average compressive strength of the mixture in accordance with 4.2.3.4.

4.1.2.3 *Concrete materials*—Submit the following information for concrete materials, along with evidence demonstrating compliance with 4.2.1:

- For cementitious materials: types, manufacturing locations, shipping locations, and certificates showing compliance with ASTM C 150, ASTM C 595, ASTM C 618, ASTM C 845, ASTM C 989, or ASTM C 1157.
- For aggregates: types, pit or quarry locations, producers' names, gradings, specific gravities, and evidence not more than 90 days old demonstrating compliance with 4.2.1;
- For admixtures: types, brand names, producers, manufacturer's technical data sheets, and certification data; and
- For water and ice: source of supply.

4.1.2.4 *Field test data basis*—When field test records are used as the basis for selecting proportions for a concrete mixture, submit data on materials and mixture proportions with supporting test results confirming conformance with specified requirements.

4.1.2.5 *Mixture proportion adjustments*—Submit any adjustments to mixture proportions or changes in materials, along with supporting documentation, made during the course of the Work.

4.1.2.6 *Concrete for floors*—Submit evaluations and test results verifying adequacy of concrete to be placed in floors when the cementitious materials content is less than that specified in Table 4.2.2.1.

4.1.2.7 *Calcium chloride*—When it is desired to use calcium chloride, submit a request including data demonstrating compliance with 4.2.2.5.

4.1.2.8 *Volumetric batching*—When it is desired to produce concrete by the volumetric batching method, submit request along with description of proposed method.

4.1.2.9 *Time of discharge*—When it is desired to exceed the maximum time for discharge of concrete permitted by ASTM C 94/C 94M, submit a request along with a description of the precautions to be taken.

4.1.3 *Quality control*

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

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

4.1.3.3 Ensure that the concrete produced has the specified characteristics in the freshly mixed state and that these characteristics are maintained during transport and delivery.

4.1.4 *Materials storage and handling*

4.1.4.1 *Cementitious materials*—Store cementitious materials in dry, weathertight buildings, bins, or silos that will exclude contaminants.

4.1.4.2 *Aggregates*—Store and handle aggregate in a manner that will avoid segregation and prevent contamination with other materials or other sizes of aggregates. Store aggregates in locations that will 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. Provide agitating equipment for admixtures used in the form of suspensions or nonstable solutions to ensure uniform distribution of the ingredients. 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*—Use ASTM C 150 Type I or Type II cement unless one or a combination of the cementitious materials given in 4.2.1.1.a through 4.2.1.1.f are specified or permitted:

4.2.1.1.a Portland cement conforming to ASTM C 150.

4.2.1.1.b Blended hydraulic cement conforming to ASTM C 595 or C 1157. For the sections of the structure that are designated as subject to deicing chemicals, submit certification on the composition of the cement verifying that the concrete mixture meets the requirements of Table 4.2.2.9.

4.2.1.1.c Hydraulic cement conforming to ASTM C 1157. For sections of the structure that will be subjected to deicing chemicals, submit certification on the composition of the cement verifying that the concrete mixture meets the requirements of Table 4.2.2.9.

4.2.1.1.d Pozzolanic mineral admixture conforming to ASTM C 618. When fly ash is used, the minimum amount shall be 15% by weight of the total cementitious materials unless otherwise specified.

4.2.1.1.e Ground-granulated blast-furnace slag conforming to ASTM C 989.

4.2.1.1.f Silica fume conforming to ASTM C 1240.

4.2.1.1.g Use cementitious materials that are of the same brand and type and from the same plant of manufacture as the cementitious materials used in the concrete represented by the submitted field test records or used in the trial mixtures.

4.2.1.2 *Aggregates*—Aggregates shall conform to ASTM C 33 unless otherwise specified. When a single size or a combination of two or more sizes of coarse aggregates are used, the final grading shall conform to the grading requirements of ASTM C 33 unless otherwise specified or permitted. Aggregates used in concrete shall be obtained from the same sources and have the same size ranges as the aggregates used in the concrete represented by submitted historical data or used in trial mixtures.

4.2.1.3 *Water and ice*—Mixing water for concrete and water used to make ice shall meet the requirements of ASTM C 1602/C 1602M. Use potable water unless alternative sources of water complying with ASTM 1602/C 1602M are permitted.

4.2.1.4 *Admixtures*—When required or permitted, admixtures shall meet the requirements of the following:

- Air-entraining admixtures—ASTM C 260;
- Chemical admixtures—ASTM C 494;
- Chemical admixtures for use in producing flowing concrete—ASTM C 1017/C 1017M; and
- Calcium chloride—ASTM D 98.

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

4.2.1.5 *Change of materials*—When changes in brand, type, size, or source of cementitious materials, aggregates, water, ice, or admixtures are proposed, submit new field data, data from new trial mixtures, or other evidence that the change will not adversely affect the relevant properties of the concrete. Data shall be submitted for acceptance before changes are made.

4.2.2 *Performance and design requirements*

4.2.2.1 *Cementitious-material content*—The cementitious-material content shall be adequate for concrete to satisfy the specified requirements for strength, water-cementitious material ratio, durability, and finishing ability. For concrete used in floors, cementitious-material content shall not be less than indicated in Table 4.2.2.1 unless otherwise accepted. Acceptance of a lower cementitious-material content will be contingent upon verification that concrete mixtures with the lower cementitious-material content will meet the specified strength requirements and will produce concrete with equal finish quality, appearance, durability, and surface hardness. When a history of finishing quality is not available, evaluate the proposed mixture by placing concrete in a slab at the project site using project materials, equipment, and personnel. The slab shall be at least 8 x 8 ft and have an acceptable thickness. Slump shall not exceed the specified slump. Submit evaluation results for acceptance.

4.2.2.2 *Slump*—Unless otherwise specified or permitted, concrete shall have, at the point of delivery, a slump of 4 in. Determine the slump by ASTM C 143/C 143M. Slump tolerances shall meet the requirements of ACI 117. When use of a Type I or II plasticizing admixture conforming to ASTM C 1017/C 1017M or when a Type F or G high-range water-reducing admixture conforming to ASTM C 494 is permitted to increase the slump of concrete, concrete shall have a slump of 2 to 4 in. before the admixture is added and a maximum slump of 8 in. at the point of delivery after the admixture is added unless otherwise specified.

4.2.2.3 *Size of coarse aggregate*—Unless otherwise specified or permitted, nominal maximum size of coarse aggregate shall not exceed three-fourths of the minimum clear spacing between reinforcing bars, 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*—Unless otherwise specified, concrete shall be air-entrained and the air content at the point of delivery shall conform to the requirements of Table 4.2.2.4 for severe exposure. For specified compressive strengths above 5000 psi, the air contents indicated in Table

Table 4.2.2.1—Minimum cementitious-materials content requirements for floors

Nominal maximum size of aggregate, in.	Minimum cementitious material content, lb/yd^3
1-1/2	470
1	520
3/4	540
3/8	610

Note: When fly ash is used, quantity shall not be less than 15% nor more than 25% by weight of total cementitious material.

Table 4.2.2.4—Air content* of concrete for various sizes of coarse aggregate

Nominal maximum size of aggregate, in.	Air content,† %		
	Severe exposure	Moderate exposure	Mild exposure
Less than 3/8	9	7	5
3/8	7.5	6	4.5
1/2	7	5.5	4
3/4	6	5	3.5
1	6	4.5	3
1-1/2	5.5	4.5	2.5
2	5	4	2
3	4.5	3.5	1.5
6	4	3	1.5

*Measured in accordance with ASTM C 138, C 173, or C 231.
†Air-content tolerance is ±1-1/2%.

4.2.2.4 may be reduced by 1%. Measure air content in accordance with either ASTM C 138, C 173, or C 231.

4.2.2.5 *Admixtures*—When admixtures are specified in Contract Documents for particular parts of the Work, use the types specified. Use of calcium chloride or other admixtures containing chloride ions shall be subject to the limitations in 4.2.2.6. When accepted, add calcium chloride into the concrete mixture in solution form only.

4.2.2.6 *Chloride-ion concentration*—Unless otherwise specified, maximum water-soluble chloride-ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall not exceed the limits of Table 4.2.2.6. Measure water-soluble chloride-ion content in accordance with ASTM C 1218/C 1218M. The type of member described in Table 4.2.2.6 shall apply to the Work as indicated in the Contract Documents.

4.2.2.7 *Sulfate resistance*—For those portions of the structure designated as requiring sulfate resistance, provide concrete meeting the requirements specified in the Contract Documents. Submit documentation verifying compliance with specified requirements. Do not use calcium chloride admixture in sulfate-resistant concrete.

4.2.2.8 *Concrete temperature*—When the average of the highest and lowest temperature during the period from midnight to midnight is expected to drop below 40 °F for more than three successive days, deliver concrete to meet the following minimum temperatures immediately after placement:

- 55 °F for sections less than 12 in. in the least dimension;
- 50 °F for sections 12 to 36 in. in the least dimension;
- 45 °F for sections 36 to 72 in. in the least dimension; and
- 40 °F for sections greater than 72 in. in the least dimension.

Table 4.2.2.6—Maximum allowable chloride-ion content

Type of member	Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

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

Unless otherwise specified or permitted, the temperature of concrete as delivered shall not exceed 90 °F.

4.2.2.9 *Strength and water-cementitious material ratio*—The compressive strength and, when required, the water-cement or water-cementitious material ratio of the concrete for each portion of the Work shall be as specified in the Contract Documents.

4.2.2.9.a When required for concrete exposed to deicing chemicals, the maximum weight of fly ash, natural pozzolans, silica fume, or ground-granulated blast-furnace slag that is included in the concrete shall not exceed the percentages of the total weight of cementitious materials given in Table 4.2.2.9.

4.2.2.9.b Unless otherwise specified, strength requirements shall be based on a 28-day compressive strength determined on 6 x 12 in. cylindrical specimens made and tested in accordance with ASTM C 31/C 31M and C 39/C 39M, respectively.

4.2.3 *Proportioning*

4.2.3.1 Proportion concrete to comply with 4.2.2 to provide workability and consistency so concrete can be worked readily into forms and around reinforcement without segregation or bleeding, and to provide an average compressive strength adequate to meet acceptance requirements of 1.6.7.1. If the production facility has records of field tests performed within the past 12 months and spanning a period of not less than 60 calendar days for a class of concrete within 1000 psi of that specified for the Work, calculate a standard deviation and establish the required average compressive strength f'_{cr} in accordance with 4.2.3.2 and 4.2.3.3.a. If field test records are not available, select f'_{cr} from Table 4.2.3.3.b.

4.2.3.2 *Standard deviation*

4.2.3.2.a *Field test data*—Field test records used to calculate standard deviation shall represent materials, quality-control procedures, and climatic conditions similar to those expected in the Work. Changes in materials and proportions in concrete represented by the test records shall not have been more closely restricted than those in the proposed Work. Test records shall comply with one of the following:

- Data from a single group of at least 15 consecutive com-

Table 4.2.2.9—Maximum cementitious material requirements for concrete exposed to deicing chemicals

Cementitious material	Maximum percent of total cementitious material by weight*
Fly ash or other pozzolans conforming to ASTM C 618	25
Slag conforming to ASTM C 989	50
Silica fume conforming to ASTM C 1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50†
Total of fly ash or other pozzolans and silica fume	35†

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

pressive-strength tests with the same mixture proportions.

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

4.2.3.2.b *Standard deviation*—Calculate the standard deviation s of the strength test records as follows:

- For a single group of consecutive test results:

$$s = \left[\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{(n-1)}\right]^{1/2} \quad (4\text{-}1)$$

where

s = standard deviation;
n = number of test results considered;
X = average of n test results considered; and
$\overline{X}_i$ = individual test result.

- For two groups of consecutive test results:

$$s = \left[\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1+n_2-2)}\right]^{1/2} \quad (4\text{-}2)$$

where

s = standard deviation for the two groups combined;
s_1, s_2 = standard deviations for Groups 1 and 2, respectively, calculated in accordance with Eq. (4-1); and
n_1, n_2 = number of test results in Groups 1 and 2, respectively.

4.2.3.3 *Required average compressive strength*—Calculate f'_{cr} for the 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 standard deviation calculated in accordance with 4.2.3.2 to establish f'_{cr} in accordance with Table 4.2.3.3.a. Use the larger of the two values of f'_{cr} calculated.

4.2.3.3.b When field test records are not available to establish a standard deviation, select the required average compressive strength f'_{cr} from Table 4.2.3.3.c.

Table 4.2.3.3.a—Required average compressive strength f'_{cr}, when data are available to establish a standard deviation, psi

f'_c, psi	f'_{cr}, psi	
	Use the larger of:	Equation
5000 or less	$f'_{cr} = f'_c + 1.34ks$	(4-3)
	$f'_{cr} = f'_c + 2.33ks - 500$	(4-4)
Over 5000	$f'_{cr} = f'_c + 1.34ks$	(4-3)
	$f'_{cr} = 0.90f'_c + 2.33ks$	(4-5)

Notes: f'_{cr} = required average compressive strength; f'_c = specified concrete strength; k = factor from Table 4.2.3.3.b to adjust standard deviation if total number of tests is less then 30; and s = standard deviation calculated in accordance with 4.2.3.2

Table 4.2.3.3.b—*k*-factor for increasing standard deviation for number of tests considered

Total no. of tests considered	*k*-factor for increasing 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.

Table 4.2.3.3.c—Required average compressive strength f'_{cr}*

f'_c, psi	f'_{cr}, psi
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$1.1f'_c + 700$

*When data are not available to establish standard deviation.

4.2.3.4 *Documentation of required average compressive strength*—Documentation indicating the proposed concrete proportions will produce an average compressive strength equal to or greater than the required average compressive strength, and shall consist of field strength records or trial mixture.

4.2.3.4.a *Field test data*—If field test data are available and represent a single group of at least 10 consecutive strength tests for one mixture, using the same materials, under the same conditions, and encompassing a period of not less than 60 days, verify that the average of the field test results equals or exceeds f'_{cr}. Submit for acceptance the mixture proportions along with the field test data.

If the field test data represent two groups of compressive strength tests for two mixtures, plot the average strength $\overline{X}_1$ and $\overline{X}_2$ of each group versus the water-cementitious material ratio of the corresponding mixture proportions and interpolate between them to establish the required water-cementitious material ratio. Establish mixture proportions for f'_{cr} based on the required water-cementitious material ratio.

4.2.3.4.b *Trial mixtures*—Establish mixture proportions based on trial mixtures in accordance with the following requirements:

- Use materials and material combinations listed in 4.2.1.1 through 4.2.1.4 proposed for the Work.
- Determine f'_{cr} according to 4.2.3.3.a if suitable field test data are available, or use Table 4.2.3.3.b.

- Make at least three trial mixtures complying with 4.2.2. Each trial mixture shall have a different cementitious material content. Select water-cementitious material ratios that will produce a range of compressive strengths encompassing f'_{cr}.
- Proportion trial mixtures to produce a slump within 3/4 in. of the maximum specified, and for air-entrained concrete, an air content within 0.5% of the required air content indicated in Table 4.2.2.4. The temperature of the freshly mixed concrete shall be recorded and shall be within 10 °F of the intended maximum temperature of the concrete as mixed and delivered.
- For each trial mixture, make and cure three compressive strength cylinders for each test age in accordance with ASTM C 192/C 192M. Test for compressive strength in accordance with ASTM C 39/C 39M at 28 days or at the test age specified in the Contract Documents.
- From results of these tests, plot a curve showing the relationship between water-cementitious material ratio and compressive strength.
- From the curve of water-cementitious material ratio versus compressive strength, select the water-cementitious material ratio corresponding to f'_{cr}. This is the maximum water-cementitious material ratio that may be used to establish mixture proportions, unless a lower water-cementitious material ratio is specified in 4.2.2.8.
- Establish mixture proportions so that the maximum water-cementitious material ratio is not exceeded when slump is at the maximum specified.

4.2.3.5 *Field verification of adequacy of selected mixture proportions*—Using materials and mixture proportions accepted for use in the Work, verify that the concrete can be adequately placed using the intended placing method. Place the concrete mixture using project equipment and personnel. Verify that the slump and air content obtained at the form are acceptable. Make suitable corrections to the placing methods or to the mixture proportions, if needed. Submit any adjustments to the mixture proportions to the Architect/Engineer for review and acceptance.

4.2.3.6 *Revisions to concrete mixtures*—When 15 consecutive compressive strength test results become available from the field, calculate the actual average compressive strength and standard deviation. Calculate a revised value for f'_{cr} in accordance with 4.2.3.3.a. Verify that both of the requirements of 1.6.7.1 are met.

4.2.3.6.a When the actual average compressive strength X exceeds the revised value of f'_{cr} and requirements of 1.6.7.1 are met, f'_{cr} may be decreased. The revised mixture shall meet the requirements of 4.2.2.

4.2.3.6.b If the actual average compressive strength $\overline{X}$ is less than the revised value of f'_{cr}, or if either of the two requirements in 1.6.7.1 are 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 in the Work.

4.3—Execution

4.3.1 *Measuring, batching, and mixing*—Production facilities shall produce concrete of the 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 with ASTM C 94/C 94M.

4.3.1.2 *Concrete produced by volumetric batching and continuous mixing*—When concrete made by volumetric batching and continuous mixing is acceptable, it shall conform to the requirements of ASTM C 685/C 685M and shall satisfy the requirements of this Specification.

4.3.1.3 *Prepackaged dry materials used in concrete*—If packaged dry-combined materials are used, they shall conform to the requirements of ASTM C 387 and shall satisfy the requirements of this Specification.

4.3.2 *Delivery*—Concrete shall possess the specified characteristics in the freshly mixed state at the point of placing. Transport and deliver concrete in equipment conforming to the requirements of ASTM C 94/C 94M.

4.3.2.1 *Slump adjustment*—When concrete arrives at the point of delivery with a slump below that which will result in the specified slump at the point of placement and is unsuitable for placing at that slump, the slump may be adjusted to the required value by adding water up to the amount allowed in the accepted mixture proportions unless otherwise specified by the Architect/Engineer. Addition of water shall be in accordance with ASTM C 94/C 94M. Do not exceed the specified water-cementitious material ratio or slump. Do not add water to concrete delivered in equipment not acceptable for mixing. After plasticizing or high-range water-reducing admixtures are added to the concrete at the site to achieve flowable concrete, do not add water to the concrete. Measure slump and air content of air-entrained concrete after slump adjustment to verify compliance with specified requirements.

4.3.2.2 *Time of discharge*—Time for completion of discharge shall comply with ASTM C 94/C 94M unless otherwise permitted. When discharge is permitted after more than 90 min have elapsed since batching or after the drum has revolved 300 revolutions, 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 *Description*—This section covers the production of cast-in-place structural concrete. Included are methods and procedures for obtaining quality concrete through proper handling, placing, finishing, curing, and repair of surface defects.

5.1.2 *Submittals*

5.1.2.1 Submit the following data unless otherwise specified:

5.1.2.1.a *Field control test reports*—Maintain and submit accurate records of test and inspection reports.

5.1.2.1.b *Conveying equipment*—Submit description of conveying equipment.

5.1.2.1.c *Temperature measurement*—Submit proposed method of measuring concrete surface temperature changes.

5.1.2.1.d *Repair methods*—When stains, rust, efflorescence, and surface deposits must be removed as described in 5.3.7.7, submit the proposed method of removal.

5.1.2.1.e *Qualifications of finishers*—Submit qualifications of the finishing contractor and of flatwork finishers who will perform the Work as stipulated in 5.3.4.1.

5.1.2.2 Submit the data specified in 5.1.2.2.a through 5.1.2.2.g when required:

5.1.2.2.a *Drawings and data*—Submit shop drawings and data for review as required by the Contract Documents.

5.1.2.2.b *Placement notification*—When Contract Documents require advance notification of concrete placement, submit notification at least 24 h in advance.

5.1.2.2.c *Preplacement requirements*—Submit, when required, request for acceptance of preplacement activities.

5.1.2.2.d *Wet-weather placement*—When placement is scheduled during wet weather, submit, when required, request for acceptance of protection.

5.1.2.2.e *Hot-weather placement*—When placement of concrete exceeding 90 °F is desired as described in 5.3.2.1.c, submit, when required, request for placement along with proposed precautions.

5.1.2.2.f *Matching sample finish*—When required by Contract Documents, submit sample finish as described in 5.3.3.

5.1.2.2.g *Exposed-aggregate surface*—When an exposed-aggregate surface is specified and a surface retarder is proposed to be used, submit specification and manufacturer's data for the retarder and the proposed method of using retarder.

5.1.2.3 When alternatives are proposed, submit the data specified in 5.1.2.3.a through 5.1.2.3.g:

5.1.2.3.a *Construction joints*—Submit information for acceptance of proposed location and treatment of construction joints not indicated on the project drawings.

5.1.2.3.b *Two-course slabs*—When a bonding agent other than cement grout is proposed, submit specification and manufacturer's data for bonding agent.

5.1.2.3.c *Underwater placement*—When underwater placement is planned, submit request for acceptance of proposed method.

5.1.2.3.d *Contraction joints*—When contraction joints other than those indicated on the Contract Documents are proposed, submit request of location.

5.1.2.3.e *Moisture-preserving method*—When a moisture-preserving method other than specified in 5.3.6.4. is proposed, submit request of the proposed method.

5.1.2.3.f *Coated ties*—When coated form ties described in 5.3.7.2 are proposed to preclude the requirement to patch tie holes, submit proposed coated tie description.

5.1.2.3.g *Repair materials*—When a repair material described in 5.2.1.3 is proposed, submit the repair material specification, manufacturer's data on the proposed patching material, and the proposed preparation and application procedure.

5.1.3 *Delivery, storage, and handling*

5.1.3.1 *Delivery*—Place concrete within the time limits required in 4.3.2.2.

5.1.3.2 *Storage and handling*—Store and handle products to retain original quality. Do not use products stored beyond the manufacturer's recommended shelf life.

5.2—Products

5.2.1 *Materials*

5.2.1.1 *Curing compounds*—Use curing compounds that conform to ASTM C 309 or ASTM C 1315.

5.2.1.2 *Waterproof sheet materials*—Use waterproof sheet materials that conform to ASTM C 171.

5.2.1.3 *Proprietary patching materials*—Use acceptable proprietary patching materials complying with 5.3.7.6.

5.2.1.4 *Bonding grout*—Use bonding grout in accordance with 5.3.7.4.

5.2.1.5 *Site-mixed portland-cement repair mortar*—Use repair mortar in accordance with 5.3.7.5.

5.2.2 *Performance and design requirements*

5.2.2.1 *Construction and contraction joints*—Make and locate construction and contraction joints that are proposed, but not indicated on the project drawings, in accordance with 2.2.2.5. Do not impair strength of the structure with joints.

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 the inner surfaces of conveying equipment.

5.3.1.3 Before placing concrete in forms, complete the following:

- Comply with formwork requirements specified in Section 2;
- Remove snow, ice, frost, water, and other foreign materials from surfaces, including reinforcement and embedded items, against which concrete will be placed;
- Comply with reinforcing steel placement requirements specified in Section 3;
- Position and secure in place expansion joint materials, anchors, and other embedded items; and
- Obtain acceptance of finished preparation.

5.3.1.4 Before placing a concrete slab on ground, remove foreign materials from the subgrade and complete the following:

- Subgrade shall be well drained and of uniform load-bearing nature;
- In-place density of subgrade soils shall be uniform throughout the area and at least the minimum required by Contract Documents;
- Subgrade shall be free from frost and ice; and
- Subgrade shall be moist with no free water and no muddy or soft spots.

5.3.1.5 When high evaporative conditions necessitate protection of concrete immediately after placing or finishing,

make provisions in advance of concrete placement for windbreaks, shading, fogging, sprinkling, ponding, or wet covering.

5.3.1.6 During ambient temperature conditions described in 4.2.2.8, make provisions in advance of concrete placement to maintain the temperature of the concrete as specified in 5.3.2.1.b. Use heating, covering, or other means adequate to maintain required temperature without overheating or drying of concrete due to concentration of heat. Do not use combustion heaters unless precautions are taken to prevent exposure of the concrete to exhaust gases containing carbon dioxide.

5.3.2 *Placement of concrete*

5.3.2.1 *Weather considerations*

5.3.2.1.a *Wet weather*—Do not begin to place concrete while rain, sleet, or snow is falling unless adequate protection is provided and, when required, acceptance of protection is obtained. Do not allow rain water to increase mixing water or to damage the surface of the concrete.

5.3.2.1.b *Cold weather*—Concrete temperatures and ambient temperatures shall meet minimum temperature requirements of 4.2.2.8.

5.3.2.1.c *Hot weather*—The temperature of concrete as placed shall not exceed 90 °F unless otherwise specified or permitted. Loss of slump, flash set, or cold joints due to temperature of concrete as placed will not be acceptable. When temperature of concrete exceeds 90 °F, obtain acceptance, when required, of proposed precautionary measures. When temperature of steel reinforcement, embedments, or forms is greater than 120 ºF, fog steel reinforcement, embedments, and forms with water immediately before placing concrete. Remove standing water before placing concrete.

5.3.2.2 *Conveying*—Rapidly convey concrete from mixer to the place of final deposit by methods that prevent segregation or loss of ingredients and ensure the required quality of concrete. Do not use aluminum pipes or chutes.

5.3.2.3 *Conveying equipment*—Use acceptable conveying equipment of a size and design that will prevent cold joints from occurring. Clean conveying equipment before each placement.

5.3.2.3.a Use belt conveyors that are horizontal or at a slope that will not cause excessive segregation or loss of ingredients. Protect concrete to minimize drying and effects of temperature rise. Use an acceptable discharge baffle or hopper at the discharge end to prevent segregation. Do not allow mortar to adhere to the return length of the belt.

5.3.2.3.b Use metal or metal-lined chutes having rounded bottoms, and sloped between one vertical to two horizontal and one vertical to three horizontal. Chutes longer than 20 ft long and chutes not meeting slope requirements may be used provided the discharge is into a hopper before distributing into the forms.

5.3.2.3.c Use pumping equipment that permits placement rates that avoid cold joints and prevents segregation in discharge of pumped concrete.

5.3.2.4 *Depositing*—Deposit concrete continuously in one layer or in layers to have fresh concrete deposited on in-place concrete that is still plastic. Do not deposit fresh concrete on concrete that has hardened sufficiently to cause formation of seams or planes of weakness within the section, unless construction joint requirements of 5.3.2.6 are met. Do not use concrete that has surface-dried, partially hardened, or contains foreign material. When temporary spreaders are used in the forms, remove the spreaders as their service becomes unnecessary. Spreaders made of metal or concrete may be left in place if prior acceptance is obtained. Do not place concrete over columns and walls until concrete in columns and walls is no longer plastic and has been in place at least 1 h. Do not subject concrete to any procedure that will cause segregation. Deposit concrete as near as practicable to the final position to avoid segregation. Place concrete for beams, girders, brackets, column capitals, haunches, and drop panels at the same time as concrete for slabs. When underwater placement is required or permitted, place concrete by an acceptable method. Deposit fresh concrete so concrete enters the mass of previously placed concrete from within, displacing water with a minimum disturbance to the surface of concrete.

5.3.2.5 *Consolidating*—Consolidate concrete by vibration. Thoroughly work concrete around reinforcement and embedded items and into corners of forms, eliminating air and stone pockets that may cause honeycombing, pitting, or planes of weakness. Use internal vibrators of the largest size and power that can properly be used in the Work as described in Table 5.3.2.5. Use immersion-type vibrators with nonmetallic heads when consolidating concrete around epoxy-coated reinforcement. Workers shall be experienced in use of the vibrators. Do not use vibrators to move concrete within the forms.

5.3.2.6 *Construction joints and other bonded joints*—Locate construction joints as indicated on the project drawings or as accepted in accordance with 5.1.2.3.a. Formed construction joints shall meet requirements of 2.2.2.5. Remove laitance and thoroughly clean and dampen construction joints before placement of fresh concrete. When bond is required or permitted, use one of the following methods:

- Use an acceptable adhesive applied in accordance with the manufacturer's recommendations;
- Use an acceptable surface retarder in accordance with manufacturer's recommendations;
- Roughen the surface in an acceptable manner that exposes the aggregate uniformly and does not leave laitance, loosened particles of aggregate, or damaged concrete at the surface; or
- Use portland-cement grout of the same proportions as the mortar in the concrete in an acceptable manner.

5.3.3 *Finishing formed surfaces*

5.3.3.1 *General*—After removal of forms, give each formed surface one or more of the finishes described in 5.3.3.2, 5.3.3.3, or 5.3.3.4. When Contract Documents do not specify a finish, finish surfaces as required by 5.3.3.5.

5.3.3.2 *Matching sample finish*—When the finish is required by the Contract Documents to match a sample panel furnished to the Contractor, reproduce the sample finish on an area at least 100 ft^2 in a location designated by the Architect/Engineer. Obtain acceptance before proceeding with that finish in the specified locations.

Table 5.3.2.5—Range of characteristics, performance, and applications of internal vibrators

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Group	Diameter of head, in.	Frequency, vibrations per min.	Eccentric moment, in.-lb	Average amplitude, in.	Centrifugal force, lb	Radius of action, in.	Rate of concrete placement, yd^3/h per vibrator	Application
1	3/4 to 1-1/2	9000 to 15,000	0.03 to 0.10	0.015 to 0.03	100 to 400	3 to 6	1 to 5	Plastic and flowing concrete in very thin members and confined places
2	1-1/4 to 2-1/2	8500 to 12,500	0.08 to 0.25	0.02 to 0.04	300 to 900	5 to 10	3 to 10	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints
3	2 to 3-1/2	8000 to 12,000	0.20 to 0.70	0.025 to 0.05	700 to 2000	7 to 14	6 to 20	Stiff plastic concrete (<3 in. slump) in general construction such as walls, columns, beams, prestressed piles, and heavy slabs
4	3 to 6	7000 to 10,500	0.70 to 2.5	0.03 to 0.06	1500 to 4000	12 to 20	15 to 40	Mass and structural concrete of 0 to 2 in. slump deposited in quantities up to 4 yd^3 in relatively open forms of heavy construction
5	5 to 7	5500 to 8500	2.25 to 3.50	0.04 to 0.08	2500 to 6000	16 to 24	25 to 50	Mass concrete in gravity dams, large piers, massive walls, etc.

Column 3—While vibrator is operating in concrete.
Column 4—Computed eccentric moment ef, in.-lb, where e = distance from center of gravity of eccentric to its center of rotation, in., and f = force of gravity of eccentric, lb.
Column 5—Measured or computed peak amplitude while operating in air (deviating from point of rest), $a = ew/(W + w)$, in., where W = mass of shell and other nonmoving parts, lb, and w = mass of eccentric, lb.
Column 6—Computed centrifugal force of vibrator, $F = 4\pi^2 n^2 ew/g$, lb, where n = frequency of vibrator while operating in concrete, cycles/s, and g = acceleration due to gravity, 386.1 $in./s^2$.
Column 7—Radius over which concrete is fully consolidated.
Column 8—Assumes insertion spacing is 1-1/2 times radius of action, and that vibrator operates 2/3 of time concrete is being placed.
Column 7 and 8—These ranges reflect capacity of vibrator, mixture workability, degree of consolidation desired, and other construction conditions.

5.3.3.3 *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Unless otherwise specified, produce as-cast form finishes in accordance with the requirements given in 5.3.3.3.a through 5.3.3.3.c:

5.3.3.3.a *Rough-form finish*—Patch tie holes and defects. Chip or rub off fins exceeding 1/2 in. in height. Leave surfaces with the texture imparted by the forms.

5.3.3.3.b *Smooth-form finish*—Patch tie holes and defects. Remove fins exceeding 1/8 in. in height.

5.3.3.3.c *Architectural finishes*—Produce architectural finishes including special textured finishes, exposed-aggregate finish, and aggregate transfer finish in accordance with Section 6.

5.3.3.4 *Rubbed finishes*—Remove forms as early as permitted by 2.3.2. Produce one of the finishes given in 5.3.3.4.a through 5.3.3.4.c on concrete specified to have a smooth form finish:

5.3.3.4.a *Smooth-rubbed finish*—Remove forms as early as permitted by 2.3.2, and perform necessary patching. Produce finish on hardened concrete no later than the day following formwork removal. Wet the surface and rub it with carborundum brick or other abrasive until uniform color and texture are produced. Use no cement grout other than cement paste drawn from the concrete itself by the rubbing process.

5.3.3.4.b *Grout-cleaned finish*—Begin cleaning operations after contiguous surfaces to be cleaned are completed and accessible. Do not clean surfaces as work progresses. Wet the surface and apply grout consisting of one part portland cement and one and one-half parts fine sand with enough water to produce the consistency of thick paint. Match color of surrounding concrete. Scrub grout into voids, and remove excess grout. When grout whitens, rub the surface and keep the surface damp for 36 h afterward.

5.3.3.4.c *Cork-floated finish*—Perform necessary repairs. Remove ties, burrs, and fins. Wet the surface and apply stiff grout of one part portland cement and one part fine sand, filling voids. Match color of surrounding concrete. Use enough water to produce a stiff consistency. Compress grout into voids by grinding the surface with a slow-speed grinder. Produce the final finish with cork float, using a swirling motion.

5.3.3.5 *Unspecified finishes*—When a specific finish is not specified in Contract Documents for a concrete surface, apply the following finishes:

- Rough-form finish on concrete surfaces not exposed to public view; and
- Smooth-form finish on concrete surfaces exposed to public view.

5.3.4 *Finishing unformed surfaces*

5.3.4.1 *Placement*—Place concrete at a rate that allows spreading, straightedging, and darbying or bullfloating before bleed water appears. Strike smooth the top of walls, buttresses, horizontal offsets, and other similar unformed surfaces and float them to a texture consistent with finish of adjacent formed surface. Finish slab surfaces in accordance with one of the finishes in 5.3.4.2, as designated in the Contract Documents. Use qualified flatwork finishers acceptable to the Architect/Engineer. Unless otherwise permitted, a minimum of one finisher or finishing supervisor shall be a certified ACI Flatwork Concrete Finisher/Technician or a certified ACI Flatwork Technician as defined in ACI CP 10 or equivalent.

5.3.4.2 *Finishes and tolerances*

5.3.4.2.a *Scratch finish*—Place, consolidate, strikeoff, and level concrete, eliminating high spots and low spots. Roughen the surface with stiff brushes or rakes before the

final set. Produce a finish that will meet conventional bull-floated tolerance requirements of ACI 117.

5.3.4.2.b *Float finish*—Place, consolidate, strikeoff, and level concrete, eliminating high spots and low spots. Do not work concrete further until it is ready for floating. Begin floating with a hand float, a bladed power float equipped with float shoes, or a powered disk float when the bleedwater sheen has disappeared, and the surface has stiffened sufficiently to permit the operation. Produce a finish that will meet conventional straightedged tolerance requirements of ACI 117, then refloat the slab immediately to a uniform texture.

5.3.4.2.c *Trowel finish*—Float concrete surface, then power-trowel the surface. Hand-trowel the surface smooth and free of trowel marks. Continue hand-troweling until a ringing sound is produced as the floor is troweled. Tolerance for concrete floors shall be conventional straightedged tolerance in accordance with ACI 117 unless otherwise specified.

5.3.4.2.d *Broom or belt finish*—Immediately after concrete has received a floated finish, give the concrete surface a coarse transverse 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 specified in Contract Documents with portland cement in the proportions recommended by the aggregate manufacturer, or use bagged, premixed material specified in Contract Documents as recommended by the manufacturer. Float-finish the concrete surface. Apply approximately two-thirds of the blended material required for coverage to the surface by a method that ensures even coverage without segregation. Float-finish the surface after application of the first dry-shake. Apply the remaining dry-shake material at right angles to the first application and in locations necessary to provide the specified minimum thickness. Begin final floating and finishing immediately after application of the dry-shake. After selected material is embedded by the two floatings, complete operation with a broomed, floated, or troweled finish, as specified in the Contract Documents.

5.3.4.2.f *Heavy-duty topping for two-course slabs*—For heavy-duty topping mixture, use the materials and methods specified in Contract Documents. Place and consolidate concrete for the base slab, and screed concrete to the specified depth below the top of the finished surface. Topping placed the same day as the base slab shall be placed as soon as bleedwater in the base slab has disappeared and the surface will support a person without appreciable indentation. When topping placement is deferred, brush the surface with a coarse wire broom to remove laitance and scratch the surface when concrete is plastic. Wet-cure the base slab at least three days. Before placing the topping, clean the base slab surface thoroughly of contaminants and loose mortar or aggregate. Dampen the surface, leaving it free of standing water. Immediately before placing topping, scrub into the slab surface a coat of bonding grout consisting of equal parts of cement and fine sand with enough water to make a creamy mixture. Do not allow grout to set or dry before topping is placed. Bonding agents other than cement grout may be used with prior acceptance. Spread, compact, and float the topping mixture. Check for flatness of surface and complete operation with a floated, troweled, or broom finish as specified in the Contract Documents.

5.3.4.2.g *Topping for two-course slab not intended for heavy-duty service*—Preparation of base slab, selection of topping material, mixing, placing, consolidating, and finishing operations shall be as specified in Section 5.3.4.2.f, except that the aggregate need not be selected for special wear resistance.

5.3.4.2.h *Nonslip finish*—Where a nonslip finish is required, give the surface a broom or belt finish or a dry-shake application of crushed aluminum oxide or other abrasive particles, as specified in the Contract Documents. Rate of application shall be not less than 25 lb/100 ft^2.

5.3.4.2.i *Exposed-aggregate finish*—Immediately after surface of the concrete has been leveled to meet the conventional straightedged tolerance requirements of ACI 117 and the bleedwater sheen has disappeared, spread aggregate of the color and size specified in Contract Documents uniformly over the surface to provide complete coverage to a depth of one stone. Tamp the aggregate lightly to embed aggregate in the surface. Float the surface until the embedded stone is fully coated with mortar and the surface has been finished to meet the conventional straightedged tolerance requirements of ACI 117. After the matrix has hardened sufficiently to prevent dislodgment of the aggregate, apply water carefully and brush the surface with a fine-bristled brush to expose the aggregate without dislodging it. When specified or permitted, a surface retarder sprayed on freshly floated concrete surface may be used to extend the working time for the exposure of aggregate.

5.3.4.2.j *Nonspecified finish*—When the type of finish is not specified in Contract Documents, use one of the following appropriate finishes and accompanying tolerances.

- Scratch finish—For surfaces intended to receive bonded cementitious mixtures;
- Float finish—For walks, drives, steps, ramps, and for surfaces intended to receive waterproofing, roofing, insulation, or sand-bed terrazzo; or
- Trowel finish—For floors intended as walking surfaces, floors in manufacturing, storage, and warehousing areas, or for reception of floor coverings.

5.3.4.3 *Measuring tolerances for slabs*

5.3.4.3.a Measure slabs for suspended floors and slabs-on-ground to verify compliance with the tolerance requirements of ACI 117 as specified in 5.3.4.2.a through 5.3.4.2.c. Measure floor finish tolerances within 72 h after slab finishing and before removal of supporting formwork or shoring.

5.3.4.3.b Unless otherwise specified in the Contract Documents, for residential floors and nonresidential floor installations 10,000 ft^2 or less in total project area, measure floor finish tolerances in accordance with the "10-ft straight edge method" in ACI 117.

5.3.4.3.c Unless otherwise specified in the Contract Documents, for nonresidential floor installations exceeding 10,000 ft^2 in total project area, measure floor finish tolerances in accordance with ASTM E 1155 and the F-number system in ACI 117.

5.3.5 *Sawed contraction joints*—Where saw-cut joints are required or permitted, start cutting as soon as concrete has hardened sufficiently to prevent dislodgment of aggregates. Saw a continuous slot to a depth of one-fourth the thickness of the slab but not less than 1 in. Complete sawing within 12 h after placement. If an alternative method, timing, or depth is proposed for saw cutting, submit detailed procedure plans for review and acceptance.

5.3.6 *Curing and protection*

5.3.6.1 *Curing*—Cure concrete in accordance with 5.3.6.2 or 5.3.6.3 for a minimum of seven days after placement. Cure high-early-strength concrete for a minimum of three days after placement. Alternatively, moisture retention measures may be terminated when:

a. Tests made on at least two cylinders kept adjacent to the structure and cured by the same methods as the structure indicate that 70% of f_c', as determined in accordance with ASTM C 39/C 39M, has been attained;

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

c. Strength of concrete reaches f_c' as determined by accepted nondestructive test methods meeting the requirements of 2.3.4.2.

When one of the curing procedures in 5.3.6.4 is used initially, the curing procedure may be replaced by one of the other procedures when concrete is one day old, provided the concrete is not permitted to become surface-dry at any time. Use a curing procedure of 5.3.6.4 that supplies additional water during the entire curing period for concrete containing silica fume and when specified in the Contract Documents.

5.3.6.2 *Unformed concrete surfaces*—Apply one of the procedures in 5.3.6.4 after completion of placement and finishing of concrete surfaces that are not in contact with forms.

5.3.6.3 *Formed concrete surfaces*—Keep absorbent wood forms wet until they are removed. After formwork removal, cure concrete by one of the methods in 5.3.6.4.

5.3.6.4 *Preservation of moisture*—After placing and finishing, use one or more of the following methods to preserve moisture in concrete:

a. Ponding, continuous fogging, or continuous sprinkling;

b. Application of mats or fabric kept continuously wet;

c. Continuous application of steam (under 150 °F);

d. Application of sheet materials conforming to ASTM C 171;

e. Application of a curing compound conforming to ASTM C 309 or C 1315. Apply the compound in accordance with manufacturer's recommendation as soon as water sheen has disappeared from the concrete surface and after finishing operations. The application rate shall not be less than 1 gal./200 ft^2. For rough surfaces such as those specified in 5.3.4.2.a and 5.3.4.2.d, apply curing compound in two applications at right angles to each other. The material applied in each coat shall not be less than 1 gal./200 ft^2 of area. Do not use curing compound on any surface where concrete or other material will be bonded, unless the curing compound will not prevent bond or unless measures are to be taken to completely remove the curing compound from areas to receive bonded applications; or

f. Application of other accepted moisture-retaining method.

5.3.6.5 *Protection*—Immediately after placement, protect concrete from premature drying, excessively hot or cold temperatures, and mechanical injury. Protect concrete during the curing period such that the concrete temperature does not fall below the requirements of 4.2.2.8.

Maintain the concrete protection to prevent freezing of the concrete and to ensure the necessary strength development for structural safety. Remove protection in such a manner that the maximum decrease in temperature measured at the surface of the concrete in a 24 h period shall not exceed the following:

- 50 °F for sections less than 12 in. in the least dimension;
- 40 °F for sections from 12 to 36 in. in the least dimension;
- 30 ºF for sections 36 to 72 in. in the least dimension; or
- 20 ºF for sections greater than 72 in. in the least dimension.

Measure concrete temperature using a method acceptable to the Architect/Engineer, and record the concrete temperature. When the surface temperature of the concrete is within 20 °F of the ambient or surrounding temperature, protection measures may be removed.

5.3.7 *Repair of surface defects*

5.3.7.1 *General*—Repair tie holes and surface defects immediately after formwork removal. Where the concrete surface will be textured by sandblasting or bush-hammering, repair surface defects before texturing.

5.3.7.2 *Repair of tie holes*—Plug tie holes except where stainless steel ties, noncorroding ties, or acceptably coated ties are used. When portland-cement patching mortar conforming to 5.3.7.5 is used for plugging, clean and dampen tie holes before applying the mortar. When other materials are used, apply them in accordance with manufacturer's recommendations.

5.3.7.3 *Repair of surface defects other than tie holes*—Outline honeycombed or otherwise defective concrete with a 1/2 to 3/4 in. deep saw cut and remove such concrete down to sound concrete. When chipping is necessary, leave chipped edges perpendicular to the surface or slightly undercut. Do not feather edges. Dampen the area to be patched plus another 6 in. around the patch area perimeter. Prepare bonding grout according to 5.3.7.4. Thoroughly brush grout into the surface. When the bond coat begins to lose water sheen, apply patching mortar prepared in accordance with 5.3.7.5, and thoroughly consolidate mortar into place. Strikeoff mortar, leaving the patch slightly higher than the surrounding surface to compensate for shrinkage. Leave the patch undisturbed for 1 h before finishing. Keep the patch damp for seven days.

5.3.7.4 *Preparation of bonding grout*—For bonding grout, mix approximately one part cement and one part fine sand with water to the consistency of thick cream.

5.3.7.5 *Site-mixed portland-cement repair mortar*—Mix repair mortar using the same materials as concrete to be patched with no coarse aggregate. Do not use more than one

part cement to two and one-half parts sand by damp loose volume. For repairs in exposed concrete, make a trial batch and check color compatibility of repair material with surrounding concrete. When the repair is too dark, substitute white portland cement for a part of the gray cement to produce a color closely matching surrounding concrete. Use a repair mortar at a stiff consistency with no more mixing water than is necessary for handling and placing. Mix the repair mortar and manipulate the mortar frequently with a trowel without adding water.

5.3.7.6 *Repair materials other than site-mixed portland-cement mortar*—Acceptable repair materials other than site-mixed portland-cement mortar may be used for repair. Use repair materials in accordance with manufacturer's recommendations. Materials include, but are not limited to, 5.3.7.6.a and 5.3.7.6.b:

5.3.7.6.a Shotcrete;

5.3.7.6.b Commercial patching products, including:

- Portland-cement mortar modified with a latex bonding agent conforming to ASTM C 1059 Type II;
- Epoxy mortars and epoxy compounds that are moisture-insensitive during application and after curing, that embody an epoxy binder conforming to ASTM C 881/C 881M, Type III. The type, grade, and class shall be appropriate for the application as specified in ASTM C 881/C 881M;
- Shrinkage-compensating or nonshrink portland-cement grout conforming to ASTM C 1107; and
- Packaged, dry concrete repair materials conforming to ASTM C 928.

5.3.7.7 *Removal of stains, rust, efflorescence, and surface deposits*—Remove stains, rust, efflorescence, and surface deposits considered objectionable by the Architect/Engineer by acceptable methods.

SECTION 6—ARCHITECTURAL CONCRETE

6.1—General

6.1.1 *Description*

6.1.1.1 *Scope*—This section covers construction of architectural concrete as designated in Contract Documents.

6.1.1.2 *Coordination*—Provide coordination between this Work and work of other trades, and other concrete work on the structure. Integrate this Work into the structure. Prevent damage or defects that will lessen the quality of the surface.

6.1.1.3 *General requirements*—Architectural concrete shall comply with the requirements of Sections 1 through 5 unless otherwise indicated in Contract Documents and in this section.

6.1.2 *Submittals*

6.1.2.1 Submit the data specified in 6.1.2.1.a unless otherwise specified:

6.1.2.1.a *Drawings and data*—Submit shop drawings of forms for architectural concrete. Show jointing of facing panels; locations and details of form ties and recesses; and details of joints, anchorages, and other accessories.

6.1.2.2 Submit the data specified in 6.1.2.2.a through 6.1.2.2.c when required:

6.1.2.2.a *Mock-ups*—When Contract Documents require full-scale mock-ups of structural items, submit a request for acceptance of the proposed location at the project site.

6.1.2.2.b *Special finishes*—Submit, when required, mock-ups or sample panels of aggregate transfer and other special finishes.

6.1.2.2.c *Exposed-aggregate finishes*—Submit, when required, the proposed method of producing exposed-aggregate finishes.

6.1.2.3 *Review of submittals*—Do not construct forms until submittals have been accepted. Do not place concrete until submitted plans for batching, mixing, placing, and curing have been accepted.

6.1.3 *Quality assurance*

6.1.3.1 *Concrete construction technical specialists*—For architectural concrete operations listed in Project Specifications, provide a technical specialist trained or approved by the specialty item manufacturer. The specialist shall be on the project site during the first three days of construction operations using the specialty item and at other times required by the Project Specifications to provide technical assistance.

6.1.3.2 *Preconstruction conference*—A preconstruction conference shall be held for this phase of the Work. Organization and procedures shall be established and agreed to by all individuals involved with this phase of the Work.

6.1.3.3 *Samples and mock-up*—Make full-scale mock-ups of structural items when specified in Contract Documents. Use the same equipment, materials, and procedures that will be used in the final work. Make mock-ups at acceptable locations on the project site. Use mock-ups as samples of required quality of finished construction.

6.1.4 *Product delivery, storage, and handling*

6.1.4.1 *Aggregates*—Deliver each size of aggregate to the mixer at uniform moisture content throughout each day's concrete production.

6.1.5 *Project conditions*

6.1.5.1 *Environmental conditions*—Protect architectural concrete from damage, disfigurement, and discoloration from construction to acceptance.

6.2—Products

6.2.1 *Materials*

6.2.1.1 *Curing water and coverings*—Use curing water and coverings that will not stain the concrete.

6.2.1.2 *Reinforcement supports and spacers*—Use stainless steel, plastic, or plastic-coated reinforcement supports and spacers near exposed surfaces, except that plastic-coated products shall not be used near surfaces that are to be sandblasted.

6.2.1.3 *Formwork*—Use formwork that is watertight.

6.2.2 *Performance and design requirements*

6.2.2.1 *Formwork*

6.2.2.1.a Design forms to produce the required finish. Limit deflection of facing materials between studs and deflection of studs and walers to 0.0025 times the clear span (L/400).

6.2.2.1.b Where natural plywood form finish, grout-cleaned finish, smooth-rubbed finish, or other finish is required, form faces shall be smooth and forms shall be true

to line and grade. Surfaces produced shall require only minor dressing to arrive at true surfaces. Where an as-cast finish is required, construct and install the forms so that no dressing will be required in the finishing operation to match the accepted sample.

6.2.2.1.c Where as-cast surfaces, including natural plywood form finish, are specified, ensure that the panels are orderly in arrangement, with joints planned in an acceptable relation to openings, building corners, and other architectural features.

6.2.2.1.d Where panels for as-cast surfaces are separated by recessed or emphasized joints, provide in the structural design of the forms the locations of ties within the 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 lessen the quality of the surface. Thoroughly clean and properly coat forms before reuse.

6.3—Execution

6.3.1 *Preparation*—Thoroughly clean and inspect formwork and batching, mixing, conveying, and placing equipment before use. Do not use equipment for other concrete construction during architectural concrete operations.

6.3.2 *Proportioning concrete mixtures*—Maintain designated colors and uniformity of color, except when not required by Contract Documents. For a concrete mixture of a specified color, use the same materials and proportions throughout the project. Avoid changes in quantity of cementitious materials per unit volume of concrete. Use only one type and one brand of cement from one mill, only one source and one nominal maximum size of coarse aggregate, only one source of fine aggregate, and only one placing consistency. For architectural concrete with exterior exposure, use air-entrained concrete with a water-cementitious material ratio not exceeding 0.45 by weight. Air content shall comply with Table 4.2.2.4.

6.3.3 *Consolidation*—Do not allow vibrators to contact formwork for exposed concrete surfaces. Where a smooth-rubbed or similar finish is specified, work the coarse aggregate back from the forms by spading or form vibration, leaving a full surface of mortar but avoiding surface voids.

6.3.4 *Formwork monitoring*—During concrete placement, continuously observe formwork. If deviations from desired elevation, alignment, plumbness, or camber are observed, or if weakness develops and the falsework shows undue settlement or distortion, stop work, remove the affected construction if it is unacceptably damaged, and strengthen the falsework.

6.3.5 *Formwork removal*—Prevent damage to concrete from formwork removal. Do not pry against face of concrete. Use only wooden wedges to separate forms from concrete.

6.3.6 *Repair of tie holes and surface defects*

6.3.6.1 *Repair area*—Where as-cast finishes are specified, the total area requiring repair shall not exceed 2 ft^2 in each 1000 ft^2 of as-cast surface. This is in addition to tie-hole patches, if Contract Documents permit ties to fall within as-cast areas.

6.3.6.2 *Color match*—Repairs in as-cast architectural concrete shall match color and texture of surrounding surfaces. Determine by trial the mixture of repair mortar to obtain a color match with the concrete when both repair and concrete are cured and dry. After initial set, dress surfaces of repairs manually to obtain texture matching the surrounding surfaces.

6.3.6.3 *Exposed aggregate*—Any finishing process intended to expose aggregate on the surface shall show aggregate faces in patched areas. The outer 1 in. of patch shall contain the same aggregates as the surrounding concrete. In aggregate transfer finish, the patching mixture shall contain the same selected colored aggregates. After patches have been cured thoroughly, expose the aggregates together with the aggregates of adjoining surfaces by the same process of mortar removal.

6.3.6.4 *Curing of patches*—Cure patches in architectural concrete surfaces for seven days. Protect patches from premature drying.

6.3.7 *Finishing*—Finishes shall comply with one of the finishes specified in 6.3.7.1 through 6.3.7.4 or other finishes as indicated in the Contract Documents:

6.3.7.1 *Textured finishes*—Use textured forms or textured form liners of plastic, wood, or sheet metal. Secure liner panels in forms by cementing or stapling. Do not permit impressions of nail heads, screw heads, or washers to be imparted to the surface of the concrete. Seal edges of textured panels to each other or to divider strips to prevent bleeding of cement paste. Use a sealant that will not stain the concrete surface.

6.3.7.2 *Aggregate transfer finishes*—Produce aggregate transfer and special finishes that duplicate the mockups or sample panels that were prepared in advance and accepted.

6.3.7.3 *Exposed-aggregate finishes*—Expose aggregate by an acceptable method including blasting, bush-hammering, or a surface retarder. Provide a concrete surface that will duplicate the mockups or sample panels that were prepared in advance and accepted.

6.3.7.3.a *Scrubbed finish*—Provide a scrubbed finish on partially hardened concrete. Wet the concrete surface thoroughly and scrub with fiber or wire brushes, using water freely, until surface mortar is removed and aggregate is uniformly exposed. Then rinse with clear water. If portions of the surface have become too hard to permit uniform aggregate exposure, use dilute hydrochloric acid (1 part commercial muriatic acid diluted with four to 10 parts water) to remove the excess surface mortar after the concrete has been in place at least 14 days. Remove the acid from the finished surface with clean water within 15 min after application. To facilitate aggregate exposure, cast concrete against form faces coated with a surface retarder applied in accordance with the manufacturer's recommendations.

6.3.7.3.b *Blast finish*—Sandblast or waterblast the concrete surface to a degree sufficient to expose aggregates. Blast surfaces with the same specified blast finish at the same age of the concrete. Use stainless steel or plastic reinforcement supports and spacers near concrete surfaces to be blasted. Protect adjacent materials and inserts during abrasive blasting operations. Unless otherwise specified in the Contract Documents, degree of blasting shall be light and shall expose fine

aggregate with occasional exposure of coarse aggregate, to produce a uniform color, and not exceed a reveal of 1/16 in.

6.3.7.3.c *Tooled finish*—Dress the thoroughly cured concrete surface with electric, air, or hand tools to a uniform texture, as specified by Contract Documents.

6.3.7.3.d When blasted or tooled finishes are specified, remove surface mortar to the degree specified in Contract Documents.

6.3.7.4 *Applied finishes*—When finishes of stucco, cementitious coatings, or similar troweled materials are specified, prepare the surface of concrete to ensure permanent adhesion of the finish. When concrete is less than 24 h old, roughen it with a heavy wire brush or scoring tool. When concrete is older than 24 h, roughen the surface mechanically or by etching with acid. After roughening, wash the surface free of dust, acid, surface retarder, and other foreign material before final finish is applied.

SECTION 7—LIGHTWEIGHT CONCRETE

7.1—General

7.1.1 *Description*—This section covers requirements for structural lightweight concrete. Portions of structures to be lightweight concrete under the provisions of this section shall be designated in Contract Documents. Lightweight concrete shall comply with the requirements of Sections 1 through 5 unless otherwise specified in this section.

7.1.2 *Submittals*

7.1.2.1 *Review of submittals*—Obtain the Architect/Engineer's acceptance of required submittals before placing concrete.

7.1.3 *Product delivery, storage, and handling*

7.1.3.1 *Aggregate storage*—Unless otherwise specified or permitted, prewet dry lightweight aggregate and leave aggregates in the stockpile after prewetting for at least 12 h before using. Follow lightweight aggregate supplier's recommendations for storage, handling, prewetting, and draining, if applicable.

7.1.3.2 *Aggregate handling*—Do not allow machinery to run over lightweight aggregates.

7.2—Products

7.2.1 *Aggregates*—Fine and coarse lightweight aggregates for lightweight concrete shall conform to ASTM C 330. Normalweight aggregate used in lightweight concrete shall conform to 4.2.1.2.

7.2.2 *Performance and design requirements*

7.2.2.1 *Concrete exposed to weather*—When specified in the Contract Documents, entrain air in lightweight concrete subject to potentially destructive exposure (other than wear or loading), including exposure to freezing-and-thawing, severe weather, or deicer chemicals. Use 6 ± 1.5% air content when the nominal maximum size of aggregate is greater than 3/8 in. Use 7.5 ± 1.5% air content when the nominal maximum size is 3/8 in. or less. Determine the air content by the volumetric methods of ASTM C 173. Select concrete mixture proportions for air-entrained concrete to provide the specified compressive strength f'_c, specified in the Contract Documents.

7.2.2.2 *Floors*—For troweled floors, the slump of structural lightweight concrete placed by pump shall not exceed 5 in. at the point of placement. For other floors, slump of lightweight concrete shall not exceed 4 in. at the point of placement.

7.2.3 *Mixtures*

7.2.3.1 *Density*—Proportion lightweight concrete mixtures to meet the specified equilibrium density determined by the calculated equilibrium method in ASTM C 567 unless otherwise specified or permitted. Correlate equilibrium density with the fresh bulk density of concrete. Use the fresh bulk density as the basis for acceptance during construction. Submit test results and correlation for review.

7.2.3.2 *Proportioning*—Determine the quantity of cementitious materials needed to attain the specified strength for lightweight concrete in accordance with 4.2.3. Relate strength to cementitious materials content of the concrete.

7.2.4 *Batching and mixing*

7.2.4.1 *Procedure*—When batching and mixing procedures are at variance with this Specification, submit recommendations to the Architect/Engineer for acceptance.

7.2.4.2 *Low-absorption aggregate*—Batch and mix aggregate that has been shown to absorb less than 2% water by weight during the first hour after inundation, as required by 4.3.1. Test aggregate for water absorption with the minimum moisture content likely to occur on the project. Predampening may be used to achieve this condition.

7.2.4.3 *High-absorption aggregate*—Batch and mix concrete made with lightweight aggregates absorbing 2% or more water by weight as specified in 7.2.4.3.a and 7.2.4.3.b:

7.2.4.3.a First add aggregate to approximately 80% of the mixing water and mix for a minimum of 1-1/2 min in a stationary mixer or 15 revolutions at mixing speed in a transit mixer.

7.2.4.3.b Then add admixtures, cement, and the withheld portion of mixing water and complete the mixing in accordance with 4.3.1.

7.2.4.4 *Slump adjustment*—When permitted, add water or air-entraining admixture to the mixture to bring the mixture to the specified slump after transport. For pumped concrete, increase slump of concrete entering the pump to maintain the specified slump at point of placement, as long as the requirements of 4.3.2.1 are met.

Prewet lightweight aggregate in accordance with 7.1.3.1 unless otherwise specified. For pumped concrete, prewetting shall be sufficient to ensure that slump loss through the pump line does not exceed 4 in.

7.3—Execution

7.3.1 *Consolidation*—Do not vibrate lightweight concrete to the extent that large particles of aggregate float to the surface.

7.3.2 *Finishing*—Do not work lightweight concrete to the extent that mortar is driven down and lightweight aggregate appears at the surface.

7.3.3 *Field quality control*

7.3.3.1 *Additional testing*

7.3.3.1.a *Density*—Acceptance of lightweight concrete in the field will be based on fresh bulk density measured in

accordance with ASTM C 138. The fresh bulk density required in the field shall be that corresponding to the specified equilibrium density. When the fresh bulk density varies by more than plus or minus 3 lb/ft^3 from the required fresh bulk density, adjust the mixture as promptly as conditions permit to bring the density to the desired level. Do not use concrete for which fresh bulk density varies by more than plus or minus 4 lb/ft^3 from the required fresh bulk density.

7.3.3.1.b *Air content*—Determine the air content of the lightweight concrete sample for each strength test in accordance with ASTM C 173.

SECTION 8—MASS CONCRETE

8.1—General

8.1.1 *Description*

8.1.1.1 *Scope*—This section covers requirements for mass concrete as designated in Contract Documents.

8.1.1.2 *General requirements*—Mass concrete, either plain or reinforced, shall comply with the requirements of Sections 1 through 5 unless otherwise specified in this section.

8.1.2 *Submittals*—Comply with 4.1.2 and the following requirements:

8.1.2.1 *Cementitious materials*—Submit brand names, manufacturer's certifications, and test data on heat of hydration.

8.2—Products

8.2.1 *Materials*

8.2.1.1 *Cementitious materials*—Comply with 4.2.1.1, 8.2.1.1.a, and 8.2.1.1.b:

8.2.1.1.a Do not use ASTM C 150 Type III cement.

8.2.1.1.b Unless otherwise specified or permitted, use moderate heat of hydration portland cement, blended hydraulic cement with moderate or low heat of hydration properties, or portland cement with fly ash, pozzolan, or ground-granulated blast-furnace slag.

8.2.1.2 *Admixtures*—Comply with 4.2.1.4 and the following requirements:

8.2.1.2.a Do not use calcium chloride or other accelerating admixtures unless specifically permitted.

8.2.1.2.b Use an acceptable retarding admixture, pretested with project materials under project conditions, whenever prevailing temperature conditions make it necessary to prevent cold joints due to the quantity of concrete placed, to offset the effects of high concrete temperature, to permit revibration of the concrete, or to reduce the maximum temperature and rate of temperature rise.

8.2.2 *Performance and design requirements*

8.2.2.1 *Cementitious materials content*—Use the minimum cementitious material content required to attain f'_c, desired durability, and properties as specified in 4.2.2.

8.2.2.2 *Slump*—Unless otherwise permitted or specified, the slump of mass concrete shall conform to the following:

- For plain mass concrete, a maximum slump of 3 in.; and
- For reinforced mass concrete, the requirements of 4.2.2.2.

8.3—Execution

8.3.1 *Placement*

8.3.1.1 *Placing temperatures*—Unless otherwise permitted or specified, the temperature of concrete at the point of placement shall not exceed 70 °F or be less than 35 °F. Concrete placed in cold weather shall meet the requirements of 4.2.2.8.

8.3.1.2 *Slump*—Slump of the concrete when placed shall meet the tolerances of ACI 117.

8.3.1.3 *Consolidation*—Place concrete in layers not more than 18 in. thick. Extend vibrator heads into the previously placed layer of plastic concrete.

8.3.2 *Curing and protection*

8.3.2.1 *Preservation of moisture*

8.3.2.1.a Cure mass concrete for the minimum curing period specified in 5.3.6 unless Contract Documents require longer curing.

8.3.2.1.b When a specific curing method is not specified in the Contract Documents, preserve the moisture either by maintaining the forms in place or, for surfaces not in contact with forms, by applying one of the procedures specified in 5.3.6.4.

8.3.2.2 *Cold weather concrete placement*—Protect the concrete from freezing and moisture loss for the required curing period in accordance with 5.3.6.1. Do not use steam or other curing methods that will add heat to the concrete.

8.3.2.3 *Hot-weather concrete placement*—Keep forms and exposed concrete continuously wet during the curing period whenever the surrounding air temperature is above 90 °F.

8.3.2.4 *Control of concrete surface temperature*—Unless otherwise specified, cool the concrete gradually so that the drop in concrete surface temperature during and at the conclusion of the specified curing period does not exceed 20 °F in any 24 h period.

SECTION 9—PRESTRESSED CONCRETE

9.1—General

9.1.1 *Description*—This section covers requirements for site-cast, post-tensioned, and prestressed structural concrete members. Post-tensioned concrete shall comply with the requirements in Sections 1 through 5 unless otherwise specified.

9.1.2 *Submittals*

9.1.2.1 Required submittals before execution of the Work are specified in 9.1.2.1.a through 9.1.2.1.c:

9.1.2.1.a *Drawings*—Installation drawings of post-tensioned concrete construction providing the following information in addition to that required by Section 2 and Section 3:

- Sizes and heights of tendon supports, including bars, and chairs;
- The location of tendons throughout their length;
- Size, details, location, materials, and stress grade (where applicable) for tendons and accessories, including anchorages and couplers;
- Jacking procedures, stressing sequence, and tensioning forces;
- Values of the wobble and curvature coefficients and anchorage set assumed, and calculated tendon elongations; and
- Details of reinforcing steel to prevent bursting and spalling.

The installation drawings shall be sealed by a professional engineer licensed in the state where the Work will

be performed when specific tendon locations, stressing sequences, and elongations are not shown on the Contract Documents or when deviations from the tendon sizes or tendon locations shown on the Contract Documents are proposed.

9.1.2.1.b Gauge pressures and calibration curves for the specific jacks and gauges to be used. Calibrations shall be within 6 months of use.

9.1.2.1.c Grout mixture proportions and test data demonstrating compliance with 9.2.2.2.

9.1.2.2 *Optional submittals*—Submit the information specified in 9.1.2.2.a through 9.1.2.2.c when required by the Contract Documents:

9.1.2.2.a Test data substantiating the expected curvature and wobble coefficients and expected anchorage set.

9.1.2.2.b Results of tests required in 9.1.3.1, including demonstration of compliance with 9.2.1.5 through 9.2.1.7.

9.1.2.2.c Jack clearances.

9.1.2.3 Required submittals during the execution of the Work are specified in 9.1.2.3.a and 9.1.2.3.b.

9.1.2.3.a Certified mill test reports for a sample representing each production lot from which the prestressing steel was taken.

9.1.2.3.b Stressing records required in 9.3.4.3 for review before trimming extensions of tendons past anchorages.

9.1.3 *Quality control*

9.1.3.1 *Testing*—Test materials in accordance with the requirements of 9.1.3.1.a through 9.1.3.1.d. Include in the report a detailed description of test procedures and apparatus as well as test results.

9.1.3.1.a *Test assembly*—Test, in accordance with 9.1.3.1.b, two specimens of each tendon size at least 10 ft long and complete with standard production-quality anchorages. For unbonded tendons, test a third sample in accordance with 9.1.3.1.c.

9.1.3.1.b *Static test*—Test prestressed reinforcement specimens in accordance with the appropriate ASTM Specification of 9.2.1.1. Test tendon assembly with a method that will allow accurate determination of yield strength, breaking strength, and elongation of the specimen to ensure compliance with 9.2.1.5, or 9.2.1.6, and 9.2.1.7.

9.1.3.1.c *Cyclic test for unbonded tendons*—Perform a cyclic test on a representative tendon assembly that shall withstand, without failure, 500,000 cycles from 60 to 66% and back to 60% of its breaking strength. Test single element tendons using one strand, bar, or wire as a complete tendon assembly. Systems using multiple strands, wires, or bars may be tested using a prototype tendon provided the assembly has not less than 10% of the full-sized tendon.

9.1.3.1.d *Grout testing*—The Owner's testing agency will test the grout for strength and fluidity daily in accordance with ASTM C 1107.

9.1.3.2 *Tolerances*—Comply with the tolerances given in 9.1.3.2.a and 9.1.3.2.b.

9.1.3.2.a Bearing surface between anchorage and concrete shall be concentric with the tendon. The bearing plate or anchorage shall be perpendicular within plus or minus 1 degree to the direction of the tendon at the anchorage.

9.1.3.2.b Place tendons and anchorages within the tolerances of ACI 117 for reinforcement placement, distance between reinforcement, and concrete cover. These tolerances apply separately to both vertical and horizontal dimensions and may be different for each direction except that in slabs the horizontal tolerance shall not exceed 1 in. in 15 ft of tendon length.

9.1.4 *Product delivery, handling, and storage*—Deliver, handle, and store materials in a manner that prevents mechanical damage and corrosion. Store cement and premixed grout to prevent hydration during storage. Only use cement that has been properly stored for grouting.

9.2—Products

9.2.1 *Materials*—Use materials that comply with the requirements of 9.2.1.1 through 9.2.1.8:

9.2.1.1 *Prestressing tendons*—Prestressed reinforcement shall be of the type and strength required by the Contract Documents and shall conform to one of the following specifications:

- ASTM A 416/A 416M;
- ASTM A 421/A 421M;
- ASTM A 722/A 722M;
- ASTM A 779/A 779M; or
- ASTM A 882/A 882M.

Tendons shall be fabricated in Post Tensioning Institute (PTI) certified plants.

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

9.2.1.2 *Protection of unbonded tendons*—Protect unbonded single-strand tendons against corrosion in accordance with ACI 423.6, "Specification for Unbonded Single-Strand Tendons." The protection shall be continuous over the entire length to be unbonded and shall prevent intrusion of cement paste or loss of coating materials during concrete placement.

9.2.1.3 *Ducts for bonded tendons*

9.2.1.3.a Duct-forming materials shall not react with alkalies in the cement, shall be strong enough to retain their shape and resist damage during construction, and shall prevent the intrusion of water from the cement paste. Duct-forming material left in place shall not directly or indirectly cause electrolytic action or deterioration. Ducts shall be corrugated or otherwise capable of transmitting forces from the grout to the surrounding concrete.

9.2.1.3.b The inside diameter of the duct shall be at least 1/4 in. larger than the wire, bar, or strand and shall have an inside cross-sectional area at least twice that of the net area of the prestressed reinforcement.

9.2.1.3.c Ducts shall have grout holes or vents at each end and at each intended high point. Provide drain holes at each intended low point if the tendon will be subjected to freezing after placing and before grouting.

9.2.1.4 *Sheathing for unbonded tendons*

9.2.1.4.a In accordance with ACI 423.6, sheathing for unbonded tendons shall have sufficient strength and water resistance to prevent damage or deterioration during transportation, storage at project site, installation, and concrete placement. The sheathing shall be continuous over the unbonded length of the tendons. The sheathing shall prevent

the intrusion of water from the cement paste and the escape of coating material.

9.2.1.4.b When specified in the Contract Documents and for applications in corrosive environments, the sheathing shall be connected to stressing, intermediate, and fixed anchorages to provide full encapsulation of the prestressing steel in accordance with ACI 423.6.

9.2.1.5 *Anchorages for bonded tendons*—Anchorages for bonded tendons tested in an unbonded state shall develop 95% of the actual breaking strength of the prestressed reinforcement, without exceeding anticipated set. The actual breaking strength of the prestressed reinforcement shall not be less than specified in Section 9.2.1.1, and shall be determined by tests on representative samples of the material in accordance with its ASTM standard. Anchorages that develop less than 100% of the actual breaking strength shall be used only where the bond length provided is equal to or greater than the bond length required to develop 100% of the actual breaking strength of the tendon. Provide the required bond length between the anchorage and the zone where the full prestressing force is required under service and factored loads.

9.2.1.6 *Anchorages for unbonded tendons*—Anchorages for unbonded tendons shall develop at least 95% of the actual breaking strength of the prestressed reinforcement without exceeding anticipated set. Total elongation of the tendon under ultimate load shall be not less than 2% when measured over a minimum gauge length of 10 ft.

9.2.1.7 *Couplers* —Use couplers only where indicated on the Contract Documents or as acceptable. All couplers shall develop strength in excess of the actual breaking strength of the prestressing steel without exceeding anticipated set of either the couplers or the prestressed reinforcement, and shall not reduce the ductility of the tendon below the minimum 2% elongation specified in 9.2.1.6. Enclose couplers in housings that permit necessary movements during stressing. For bonded tendons, provide fittings to allow complete grouting of all the couplers components.

9.2.1.8 *Sleeves and gaskets*—Connect sheathing at joints with leak tight sleeves or gaskets.

9.2.2 *Proportioning of concrete and grout mixtures*—Comply with 9.2.2.1 through 9.2.2.2.f for concrete and grout mixtures.

9.2.2.1 *Concrete*—Proportion concrete mixtures in compliance with Section 4.

9.2.2.2 *Grout*

9.2.2.2.a Unless otherwise permitted or specified, grout shall consist of a mixture of cement and water unless the gross inside cross-sectional area of the duct exceeds four times the tendon cross-sectional area, in which case fine aggregate may be added to the mixture. Fly ash or other pozzolans conforming to ASTM C 618 or ground granulated blast-furnace slag (GGBFS) conforming to ASTM C 989 may be added in accordance with the strength requirements of 9.2.2.2.e. The maximum water-soluble chloride ion concentration in the hardened grout shall be in accordance the prestressed concrete requirements of 4.2.2.6.

9.2.2.2.b When required by the Contract Documents, add an acceptable shrinkage-compensating or expanding admixture to produce an unrestrained expansion of the mixture of between 0 and 5% by volume of the grout.

9.2.2.2.c Do not use admixtures containing more than trace (from impurities, not as an intended ingredient) amounts of chlorides, fluorides, aluminum, zinc, or nitrates. Other admixtures may be used, provided acceptable tests or performance records show conclusively that the admixtures will have no harmful effects on the tendons, accessories, or grout.

9.2.2.2.d Use fine aggregate conforming to ASTM C 404, Size No. 2, except that all material shall pass the No. 16 sieve.

9.2.2.2.e Proportion grout to achieve a minimum compressive strength of 2500 psi at seven days and 5000 psi at 28 days when tested in accordance with Section 12.5 of ASTM C 1107, and have a consistency that will facilitate placement. When required by the Contract Documents, the consistency of the grout shall be verified in accordance with ASTM C 939, and the efflux time of the grout sample immediately after mixing shall be less than 25 s. Water content shall be the minimum necessary for proper placement, and the water-cementitious material ratio shall not exceed 0.45 by weight.

9.2.2.2.f Mix the grout in a mechanical mixer capable of continuous mixing that will produce a grout free of lumps and undispersed cement. Pass the grout through the No. 16 sieve into pumping equipment that has provisions for recirculation. Begin pumping grout as soon after mixing as possible. Continue pumping as long as the grout retains the required consistency. Discard grout that has partially set.

9.3—Execution

9.3.1 *Inspection*—Conduct a visual inspection to ensure that the requirements of this Specification and the Contract Documents are met. Inspection shall include, but not be limited to, the following:

- Cleanliness of material and formwork;
- Location of materials and formwork;
- Proper tensioning of prestressing tendons; and
- Proper grouting of grouted tendons.

9.3.2 *Preparation*

9.3.2.1 *Tendons and concrete*

9.3.2.1.a Keep tendons dry and water out of the ducts. Maintain concrete around grouted tendons at a temperature of 40 °F or higher for at least three days before grouting.

9.3.2.1.b Keep ducts free of grease, oil, paint, and other foreign matter. A light coat of rust on the prestressed reinforcement is permissible, provided loose rust has been removed and the surface is not pitted.

9.3.2.1.c Keep tendons for use in unbonded construction clean and undamaged, and protect them with a permanent, continuous coating specified in 9.2.1.2.

9.3.2.1.d When parts of the tendon extend beyond the ends of the member, or when tendons are outside the concrete of the post-tensioned element, cover the exposed or specified parts of the tendon with an additional coating. The coating may be shop or field-applied, and can be plastic, epoxy, or other acceptable material.

9.3.2.1.e Keep end anchorages that will be permanently protected with concrete free of loose rust, grease, oil, and other foreign matter.

9.3.2.1.f Protect grout fittings and ducts for bonded tendons from collapse, obstructions, and other damage before and during concrete placement. Before placing concrete, examine the duct and grout fittings for holes, and repair any holes located. If the tendon remains ungrouted for more than 28 days from the time of tendon placement, provide acceptable temporary corrosion protection.

9.3.2.2 *Grouting*—Provide a dependable high-pressure water supply of sufficient volume before beginning the grouting operation.

9.3.3 *Placement*

9.3.3.1 *Tendons and accessories*—Place tendons and anchorages within the tolerances of 9.1.3.2. Firmly support tendons to prevent displacement during concrete placement.

9.3.3.2 *Grout*

9.3.3.2.a For bonded-tendon construction, grout shall fill all voids between prestressed reinforcement, ducts, and anchorage fittings. Continue injection until grout of the same consistency as the grout injected flows from vent and drain openings without the presence of air bubbles. Close vent and drain openings progressively in the direction of the flow. After vent and drain openings have been closed, raise the grouting pressure to at least 50 psi and plug the injection hole.

9.3.3.2.b In the event of a blockage or an interruption of grouting, remove grout from the duct by flushing with water.

9.3.4 *Tensioning*

9.3.4.1 *Sequence*—Stress tendons in the sequence at the concrete compressive strength and at the construction stage indicated in the Contract Documents.

9.3.4.2 *Tensioning multiple-strand tendons*—Tension tendons composed of multiple strands in a common duct simultaneously unless the tendon is designed for the strands to be stressed individually.

9.3.4.3 *Prestressing force*—Tension the prestressed reinforcement using hydraulic jacks equipped with a pressure gauge calibrated to the jack within an accuracy of plus or minus 2%. Calibrate the gauge or dynamometer within six months before use. The pressure gauge shall have graduations no larger than 100 psi. Apply the jacking force required to produce the prestressing force shown on the Contract Documents or Installation Drawings and measure the tendon elongation. Verify that the prestressing force is adequate by comparing the measured elongations to the calculated elongations. If the measured elongations differ from the calculated elongations by more than 7%, determine and correct the cause of the discrepancy. Elongation calculations shall be based on average values of load-elongation curves for the prestressed reinforcement used. For each tendon, keep and submit a record of the measured elongations and the gauge pressure readings. Do not remove stressing tails, grout ducts, or grout stressing pockets until the Architect/Engineer has reviewed the elongation records.

9.3.4.4 *Prestress loss*—The total loss of prestressing force in any post-tensioned element due to unreplaced broken tendons shall not exceed 2% of the total prestressing force.

9.3.4.5 *Formwork*

9.3.4.5.a Ensure that formwork does not restrain elastic shortening, deflection, or camber resulting from application of the prestressing force, and is sufficiently rigid to prevent displacement of the tendons beyond the tolerances of 9.1.3.2. Anchor tendon supports to the formwork to maintain the tendon profile during concrete placement.

9.3.4.5.b Do not remove formwork supports until sufficient prestressing force has been applied to support the dead load, formwork, and anticipated construction loads. When a structure will be post-tensioned in two directions, formwork shall support the load that is redistributed by the partially completed stressing operation.

9.3.4.6 *Prevention of damage to tendons*—Do not expose tendons to mechanical damage, welding sparks, flame, or electric ground currents. Do not conduct burning and welding operations in the vicinity of tendons, except as permitted by 9.3.4.7.

9.3.4.7 *Trimming of tendons*—Surplus lengths of tendons beyond anchorages may be removed by either rapid oxyacetylene burning, abrasive wheel, or shears unless the procedure is contrary to the recommendations of the prestressed reinforcement or anchorage manufacturer.

SECTION 10—SHRINKAGE-COMPENSATING CONCRETE

10.1—General

10.1.1 *Scope*—This section covers shrinkage-compensating concrete using expansive cement conforming to ASTM C 845, Type E-1.

10.1.2 *General requirements*—Portions of structures to be constructed using shrinkage-compensating concrete under the provisions of this section shall be designated in the Contract Documents. Shrinkage-compensating concrete shall comply with the requirements of Sections 1 through 5 unless otherwise specified in this section.

10.1.3 *Submittals*

10.1.3.1 *Review of submittals*—Obtain the Architect/Engineer's acceptance of required submittals before placing concrete.

10.1.3.2 Submit expansion test results measured in accordance with ASTM C 878 for the concrete mixture proportions.

10.1.3.3 Submit placing sequence.

10.2—Products

10.2.1 Materials

10.2.1.1 *Cementitious materials*

10.2.1.1.a Unless otherwise specified, the cement shall comply with ASTM C 845, Type E-1 (K).

10.2.1.1.b When permitted, silica fume shall comply with ASTM C 1240.

10.2.1.1.c Unless otherwise specified, do not use fly ash or ground-granulated blast-furnace slag.

10.2.1.2 *Admixtures*

10.2.1.2.a Do not use accelerating admixtures or admixtures containing calcium chloride unless otherwise specified or permitted.

10.2.1.2.b Do not change type, brand, or dosage rate of admixtures without evaluating the revised concrete mixture for expansion as measured in accordance with ASTM C 878 unless permitted.

10.2.2 *Performance and design requirements*—Comply with 4.2.2 and 10.2.2.1 through 10.2.2.3:

10.2.2.1 *Minimum cement content*—Cement content shall not be less than 564 lb/yd^3.

10.2.2.2 *Expansion*—Unless otherwise specified, the concrete expansion shall be a minimum of 0.03% and a maximum of 0.10%, measured in accordance with ASTM C 878.

10.2.2.3 *Slump*—Unless otherwise specified or permitted, the slump shall not exceed 6 in. at the point of placement.

10.2.3 *Proportioning*—Comply with 4.2.3 and 10.2.3.1 through 10.2.3.3.

10.2.3.1 When laboratory trial mixtures are used, stop the mixer after the initial mixing cycle and cover the laboratory concrete mixer for 20 min unless otherwise specified. After this time period, add water, as necessary, to produce the maximum specified slump within 3/4 in. The concrete shall then be mixed for an additional 2 min.

10.2.3.2 For the proposed concrete mixture, provide laboratory test results for three expansion bars cast and tested in accordance with ASTM C 878. Record the expansion test results and submit for acceptance.

10.2.3.3 *Revisions to concrete mixtures*—When concrete mixture proportions are revised in accordance with 4.2.3.6, evaluate the effect on expansion by performing laboratory tests on three expansion bars cast with the revised concrete mixture in accordance with ASTM C 878. Submit test results along with the revised mixture proportions.

10.2.4 *Reinforcement*—Use deformed bars or deformed welded-wire reinforcement meeting the requirements of 3.2 at the amounts specified in the 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% strain when tested in accordance with ASTM D 1621 or D 3575.

10.3—Execution

10.3.1 *Reinforcement*

10.3.1.1 Place reinforcement on supports that are rigid and spaced adequately to ensure proper positioning of the reinforcement during placement.

10.3.1.2 Unless otherwise specified, position reinforcement 2 in. from the top surface for reinforced slabs on ground.

10.3.2 *Placing*

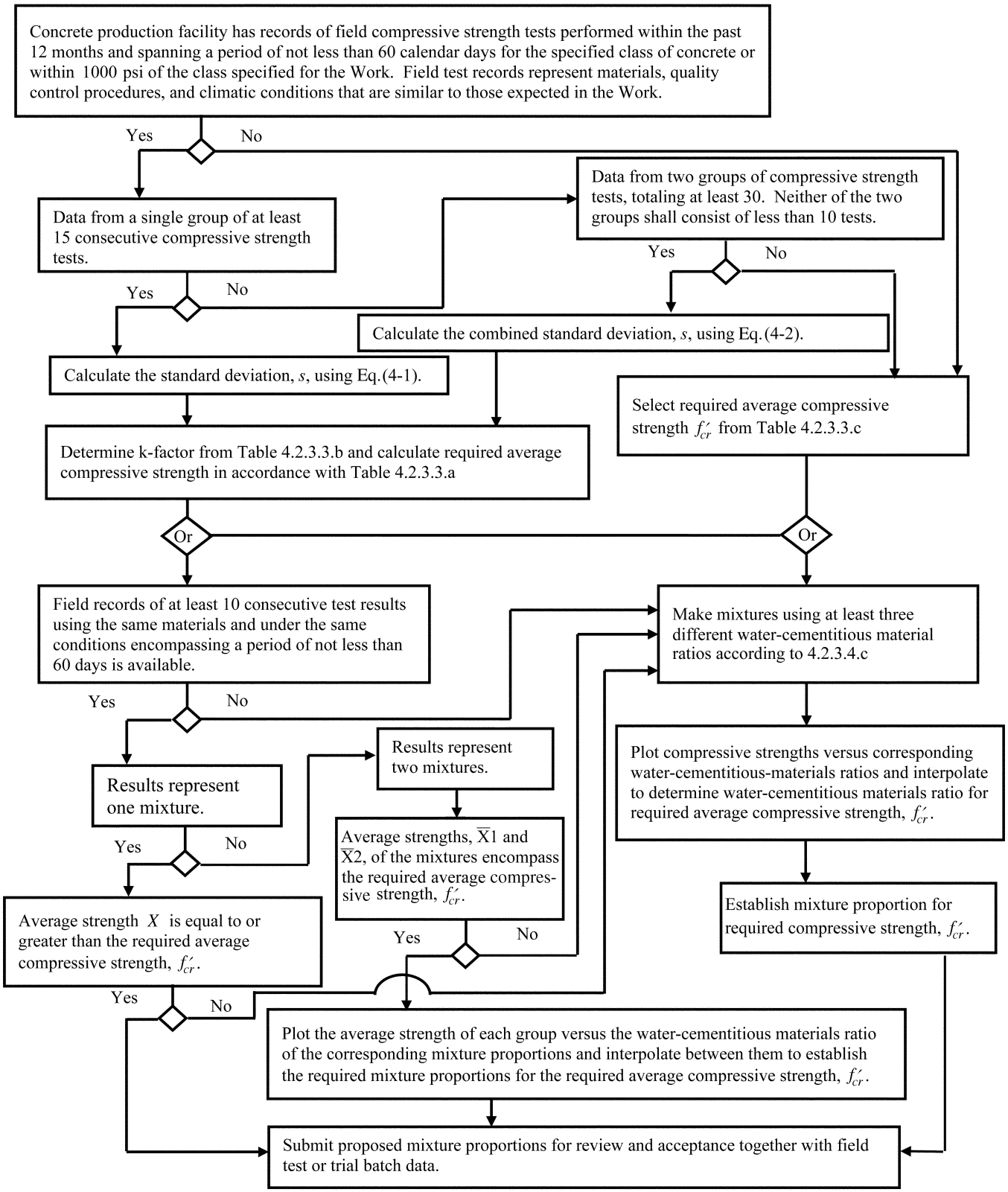
10.3.2.1 *Placing sequence*—Sequence of concrete placements shall permit the previous placements to have two adjacent edges free to expand.

10.3.2.2 Unless otherwise specified or permitted, the minimum time between casting adjoining sections shall be 72 h.

10.3.3 *Isolation joints*—Provide isolation joints at junctions with columns, walls, drains, or any other rigid obstruction in the structure, in accordance with the Contract Documents.

10.3.4 *Curing*—Unless otherwise specified, wet-cure shrinkage-compensating concrete for a minimum of seven days in accordance with 5.3.6.4 a or b.

Flowchart for Selection of Concrete Mixtures



NOTES TO SPECIFIER:

FOREWORD TO CHECKLISTS

F1. This Foreword is included for explanatory purposes only; it does not form a part of Specification ACI 301.

F2. ACI Specification 301 may be referenced by the Specifier in the Project Specification for any building project, together with supplementary requirements for the specific project. Responsibilities for project participants must be defined in the Project Specification. The ACI Specification cannot and does not address responsibilities for any project participant other than the Contractor.

F3. Checklists do not form a part of ACI Specification 301. Checklists assist the Specifier in selecting and specifying project requirements in the Project Specification.

F4. Building codes set minimum requirements necessary to protect the public. ACI Specification 301 may stipulate requirements more restrictive than the minimum. The Specifier shall make adjustments to the needs of a particular project by reviewing each of the items in the checklists and including those the Specifier selects as mandatory requirements in the Project Specification.

F5. The Mandatory Requirements Checklist indicates work requirements regarding specific qualities, procedures, materials, and performance criteria that are not defined in ACI Specification 301.

F6. The Optional Requirements Checklist identifies Specifier choices and alternatives. The checklists identify the Sections, Parts, and Articles of the reference specification and the action required or available to the Specifier.

F7. *Recommended References*—Documents and publications that are referenced in the Checklists of ACI Specification 301 are listed. These references provide guidance to the Specifier and are not considered to be part of ACI Specification 301.

American Concrete Institute (ACI)

ACI 117R	Commentary on Standard Specifications for Tolerances for Concrete Construction and Materials
ACI 201.2R	Guide to Durable Concrete
ACI 207.2R	Effect of Restraint, Volume Change, and Reinforcement on Cracking of Mass Concrete
ACI 211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 222R	Protection of Metals in Concrete Against Corrosion
ACI 223	Standard Practice for the Use of Shrinkage Compensating Concrete
ACI 225R	Guide to the Selection and Use of Hydraulic Cements
ACI 228.1R	In-Place Methods to Estimate Concrete Strength
ACI 302.1R	Guide for Concrete Floor and Slab Construction
ACI 303R	Guide to Cast-In-Place Architectural Concrete Practice
ACI 303.1	Standard Specification for Cast-In-Place Architectural Concrete
ACI 305R	Hot Weather Concreting
ACI 306.1	Standard Specification for Cold Weather Concreting
ACI 308.1	Standard Practice for Curing Concrete
ACI 311.1R	ACI Manual of Concrete Inspection—SP-2 (99)
ACI 311.4R	Guide for Concrete Inspection
ACI 311.5R	Guide for Plant Inspection and Field Testing of Ready-Mixed Concrete
ACI 318	Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (318R-05)
ACI 347	Guide to Formwork for Concrete
ACI CP 10	Craftsman Workbook for ACI Certification of Concrete Flat Work Technician/Finisher

ASTM International

ASTM C 441	Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
ASTM D 698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)]
ASTM D 1557	Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)]

National Ready Mixed Concrete Association (NRMCA)

Quality Control Manual, Section 3—Certification of Ready Mixed Concrete Production Facilities

Portland Cement Association (PCA)

PCA Design and Control of Concrete Mixtures, 14th Edition

Wire Reinforcement Institute (WRI)

WRI Manual of Standard Practice

Guidance for evaluating the degree of rusting on strand is given in "Evaluation of Degree of Rusting on Prestressed Concrete Strand," by A. S. Sason, *PCI Journal*, V. 37, No. 3, May-June 1992, pp. 25-30.

The above publications may be obtained from the following organizations (additional references can be found in Section 1.3 of the Specification):

American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

National Ready Mixed Concrete Association
90 Spring St.
Silver Spring, MD 20910

Prestressed Concrete Institute
209 W. Jackson Blvd Ste. 500
Chicago, IL 60606

Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60076

Wire Reinforcement Institute, Inc.
942 Main St., Suite 300
Hartford, CT 06103

MANDATORY REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Architect/Engineer
Reinforcement and reinforcement supports	
3.2.1.1	Specify required grades, types, and sizes of reinforcing steel.
3.3.2.7	Show splices on the project drawings.
Concrete mixtures	
4.2.2.6	Designate which portions of the structure are classified in accordance with Table 4.2.2.6 member types. Additional information on the effects of chlorides on corrosion of reinforcing steel is given in ACI 201.2R and ACI 222R. Test procedures must conform to those given in ASTM C 1218/C 1218M. An initial evaluation can be obtained by testing individual concrete ingredients for total chloride content. If total chloride-ion content, calculated on the basis of concrete proportions, exceeds that permitted in Table 4.2.2.6, it may be necessary to test samples of hardened concrete for water-soluble chloride-ion content as described in ASTM C 1218/C 1218M. Some of the total chloride ions present in the ingredients will either be insoluble or will react with the cement during hydration and become insoluble under the test procedure described. When concrete is tested for water-soluble chloride-ion content, the tests should be made at an age of 28 to 42 days. The limits in Table 4.2.2.6 are to be applied to chlorides contributed from the concrete ingredients, not those from the environment surrounding the concrete. The water-soluble chloride-ion limits in Table 4.2.2.6 differ from the acid-soluble chloride limits recommended in ACI 201.2R and ACI 222R. For reinforced concrete that will be dry in service, a limit of 1% has been included to control total soluble chlorides. Table 4.2.2.6 includes limits of 0.15 and 0.30% for reinforced concrete that will be exposed to chlorides or will be damp in service, respectively. These water-soluble chloride-ion limits compare with the recommended acid-soluble chloride-ion limits of 0.10 and 0.15 in ACI 201.2R while 222R recommends acid-soluble chloride-ion limits of 0.08 and 0.20% for prestressed and reinforced concrete, respectively.
4.2.2.7	Designate in the Contract Documents the portions of the structure requiring concrete resistant to sulfate attack. Specify requirements for concrete in these portions of the structure in accordance with Table 4.3.1 of ACI 318. Consult ACI 201.2R for guidance on establishing the degree of sulfate resistance needed. Criteria for evaluating effectiveness of materials against sulfate attack using test method ASTM C 1012 are provided: • in ASTM C 618 for fly ash and other pozzolans; • in ASTM C 1240 for silica fume; and • in ASTM C 989 for ground-granulated blast-furnace slag. Alternatively, consider accepting concrete mixtures that have shown a service record in excess of eight years in exposure at least as severe as that of the proposed structure.
4.2.2.9	Indicate the specified compressive strength of concrete f'_c for various portions of the Work. For most structural members, the requirements of the design will dictate the required strength. A higher compressive strength may be required for durability considerations. For floors, the specified compressive strength f'_c will generally depend upon the intended use and expected wear unless durability considerations dictate higher strengths. If the floor will be exposed to abrasive wear from early construction traffic, consider requiring a minimum compressive strength at three days of 1800 psi or higher. See ACI 302.1R for guidance on compressive strengths to specify for various classes of floors.
Handling, placing, and constructing	
5.3.1.4	Specify the required in-place density of subgrade soils for slabs-on-ground as a percentage of the maximum laboratory density. Specify the test methods to be used such as ASTM D 698 or ASTM D 1557.
Architectural concrete	
6.3.7	Specify which of the finishes from 6.3.7.1 through 6.3.7.3 (a through d) are required. Specify any special finishes that are required, but not covered by the above.
Prestressed concrete	
9.2.1.1	Specify type and minimum tensile strength of prestressed reinforcement.

OPTIONAL REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Architect/Engineer
General requirements	
1.6.3.2, 1.6.3.3, 1.6.4.1	Specify if other testing arrangements are required, such as Owner's testing agency establishing mixture proportions or any testing responsibilities of the Owner's testing agency that will be performed by the Contractor's testing agency.
1.6.3.2.g, 1.6.4.2.e	If accelerated testing of concrete is specified or permitted as an alternative to standard testing, specify the procedure from ASTM C 684 that is to be followed. Specify when compressive test specimens are to be tested if other than seven and 28 days.
1.6.4.3	Specify additional testing services desired for the Work, if applicable. Note that these additional testing services are to be performed by the Owner's testing laboratory; hence, the term "will" is used in place of "shall" in 1.6.4.3. Refer to ACI 311.1R (SP-2), ACI 311.4R, and 311.5R for specific inspection items that may be appropriate. When it is necessary or desirable to know properties of concrete at the point of placement or at locations other than the delivery point, specify that concrete is to be sampled at these other locations for testing. See the discussion under Optional Requirements in Section 4.2.2.2.
1.6.5.2	Specify if nondestructive tests will be permitted to evaluate uniformity or relative in-place strength of concrete. Refer to ACI 228.1R for guidance on nondestructive test methods.
1.6.7.1	If another basis for acceptance of concrete strength level is required for accelerated strength testing, specify the basis for acceptance.
Formwork and formwork accessories	
2.1.2.1	Review the list of submittal items and specify in Contract Documents the items that need not be submitted.
2.1.2.2	Review the list of submittal items and specify in Contract Documents the items to be submitted.
2.2.1.1	Specify other materials for form faces in contact with concrete.
2.2.1.2	Indicate where walls require form ties with a positive water-barrier.
2.2.2.1	Specify if calculations and drawings for formwork must be sealed by a licensed Engineer.
2.2.2.3	Specify if earth cuts will be permitted or required.
2.2.2.4	Specify more or less stringent limitations on deflection of facing materials when needed. Refer to ACI 347 for further guidance.
2.2.2.5.b	Specify or allow alternative locations for formed construction joints when necessary to facilitate formwork removal or accelerate construction, provided that the alternative joint locations do not adversely affect the strength of the structure.
2.2.2.5.c	Specify keyway depths other than 1-1/2 in. when required.
2.2.3.2	Specify if chamfer strips are not required on exterior corners of permanently exposed surfaces. Specify if bevels are required on re-entrant corners of concrete or on edges of formed concrete joints.
2.3.1.2	Specify tolerance limits required to be different than those of ACI 117. Specify when a more or less restrictive tolerance for abrupt offset is required. Refer to ACI 347 and the Commentary to ACI 117 for further guidance.
2.3.2.5	Specify the minimum compressive strength for removal of forms supporting the weight of concrete if different than f'_c. Specify if nonload-carrying form-facing material is not permitted to be removed at an earlier age than the load-carrying portion of the formwork.
2.3.4.2	Specify if the alternative methods for evaluating concrete strength for formwork removal are permitted.
Reinforcement and reinforcement supports	
3.1.1	Specify if the submittals listed in 3.1.1.1 through 3.1.1.3 are not required to be submitted. Otherwise, they will be required to be submitted.
3.2.1.1	For headed bars, specify type of steel for reinforcing bars: • Low-alloy steel (ASTM A 706/A 706M); • Carbon steel (ASTM A 615/A 615M). For carbon steel (ASTM A 615/A 615M) also specify grade; and • Rail steel or axle steel deformed bars (ASTM A 996/A 996M).
3.2.1.2	Specify if coated reinforcing bars are required and, if so, whether the coating is to be zinc or epoxy.
3.2.1.2.a	For zinc-coated reinforcing bars conforming to ASTM A 767/A 767M, specify the class of coating, whether galvanizing is to be performed before or after fabrication, and indicate which bars require special finished bend diameters (usually smaller sizes used for stirrup and ties). Avoid mixing galvanized and nongalvanized reinforcing steel or other embedded steel that could result in galvanic cells.
3.2.1.2.b	Specify the ASTM specification to which epoxy-coated reinforcing bars are to conform.
3.2.1.4	Specify which of the three combinations will apply.
3.2.1.5	Specify plain or deformed wire and, if required, epoxy-coated wire.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
3.2.1.6	Specify plain or deformed welded wire reinforcement and, if required, epoxy-coated wire reinforcement. Refer to "WRI Manual of Standard Practice" for additional guidance.
3.2.1.7	Specify if wire reinforcement supports are required or permitted.
3.2.2.2	Specify if bar welds are required or permitted. If required or permitted, specify any desired requirements for preparation for welding (such as removal of zinc or epoxy coating) more stringent than those in AWS D1.4. Specify desired requirements for chemical composition of reinforcing bars more stringent than those of the referenced ASTM specifications. Specify special heat treatment of welded assemblies, if required. Specify supplementary requirements for welding of wire to wire, and welding of wire or welded wire reinforcement to reinforcing bars or structural steels.
3.3.2.3	Specify special cover requirements for corrosive atmosphere, other severe exposures, or fire protection not covered in Table 3.3.2.3. Some concrete covers in Table 3.3.2.3 may exceed minimum concrete covers required by ACI 318. Concrete covers used for design must agree with the covers specified in Table 3.3.2.3.
3.3.2.4	Specify if the methods of support are to be other than those indicated in 3.3.2.4.a through 3.3.2.4.i.
3.3.2.5	Specify where reinforcement may extend through contraction joints, including saw-cut joints.
3.3.2.8	Specify if bending or straightening reinforcement partially embedded in concrete is permitted.
3.3.2.9	Specify if field cutting of reinforcement is permitted and specify cutting methods to be used.
Concrete mixtures	
4.2.1.1	Specify the other standards that the cementitious material may be required or permitted to conform to if cement other than ASTM C 150 Type I or Type II is required or permitted. Specify if ASTM C 150 cement with ASTM C 618 pozzolanic materials, ASTM C 989 ground-granulated blast-furnace slag, or ASTM C 1240 silica fume, is required. Specify the class of pozzolan or grade of slag that is required. Specify if ASTM C 595 blended hydraulic cement or C 1157 hydraulic cement are required or permitted. Use ACI 318 and 225R to determine what will be acceptable for the project conditions. ASTM C 1157 is a performance specification for hydraulic cement. Requirements for physical properties of the cement are specified in ASTM C 1157; however, there are no restrictions on the composition of the cement or its constituents. When using ASTM C 1157, the Architect/Engineer should consider whether any additional limits on physical properties or constituents should be specified. If it is suspected that concrete will be exposed to sulfates in service, evaluate the water-soluble sulfates in the soil and groundwater. Use the criteria of ACI 318, Section 4.3.1 and Table 4.3.1, to determine the cement type to use. Use any of the cements in ACI 318, Table 4.3.1 for concrete exposed to sea water. Verify the availability of the cement specified. Do not use ASTM C 595, Type S and SA. Specify if less than 15% fly ash is permitted. In some instances, using less than 15% fly ash can increase the concrete's susceptibility to excessive expansions caused by alkali-silica reactivity (ASR). If a smaller percentage of fly ash is proposed for use, the proposed project mixture of fly ash and portland cement from the same source should be tested and compared to a control mixture using only the portland cement in accordance with ASTM C 441. The project mixture should be considered acceptable, provided the average length increase of the project mixture does not exceed that of the control mixture. For projects where expansions due to ASR may be critical, consider requiring the test comparison at some frequency during the Work, such as every three months. If reactive aggregates are available and may be used, specify the use of natural pozzolan, fly ash, slag, or silica fume in an amount shown to be effective in mitigating harmful expansions due to alkali-silica reactivity. Alternatively, specify a low-alkali cement be used as described in the Optional Requirements Checklist for 4.2.1.2.
4.2.1.2	If aggregates are to conform to a specification other than ASTM C 33 for grading, deleterious substances, or soundness, specify the other requirements. Specify the test for determining conformance to requirements for cleanliness, and specify grading be performed on samples obtained from the aggregates at the point of batching. Specify any additional requirements for aggregate such as hardness, color, mineralogical composition, texture, or shape (crushed or gravel). If concrete will be exposed to wetting, extended exposure to humid atmosphere, or in contact with moist ground, specify the use of aggregates that do not contain materials deleteriously reactive with alkalies in the cement; however, such aggregates may be used with cement containing less than 0.60% alkalies such as (Na_2O + $0.658K_2O$) or with a material such as natural pozzolan, fly ash, slag, or silica fume in an amount shown to be effective in preventing harmful expansion due to alkali-aggregate reaction in accordance with ASTM C 441.
4.2.1.4	Specify the admixtures listed in 4.2.1.4 that are required. Indicate the parts of the Work in which each type of admixture should or may be used.
4.2.2.1	Specify if less than 15% or more than 25% fly ash is permitted in floors. If more than 25% is permitted, a history should be available demonstrating the finishing ability of the proposed concrete mixture.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
4.2.2.2	If slump is to be different than 4 in., specify the requirement. It might be necessary at times to specify that the slump of concrete be determined at the point of placement rather than at the point of delivery. For example, pumped concrete is often specified to have slump measured at the end of the pumpline to preclude problems encountered with varying slump loss during pumping. This would provide for a slump higher than 4 in. at the point of delivery to obtain 4 in. slump at the end of the pumpline. Once the slump loss during pumping can be determined, acceptance or rejection of concrete based on slump can then be determined at the delivery point. For example, if a 1-1/2 in. slump loss during pumping has been established and confirmed by comparative testing, a slump of 5-1/2 in. measured at the point of delivery will meet the 4 in. slump requirement at the end of the pumpline. Specify if a plasticizing or high-range water-reducing admixture is required or permitted to produce concrete with high slumps. If so, specify the required slump if different from those indicated in 4.2.2.2. For floors, refer to ACI 302.1R for guidance on slumps to specify for the various classes of floors. If a plasticizing or high-range water-reducing admixture is required or permitted to obtain high-strength concrete with a low water-cementitious material ratio, such as 0.25 to 0.30, modify the requirements accordingly for the slump before adding the admixture. Confer with concrete suppliers and admixture suppliers in the area where the project is located to determine their experience and input for such high-performance concrete.
4.2.2.3	If an aggregate size requirement differs from that specified by 4.2.2.3 (for example, smaller size in floor toppings), specify nominal maximum size of aggregate.
4.2.2.4	Specify if concrete is not required to be air-entrained. Intentionally entrained air should not be incorporated in normalweight concrete slabs that require a dense, polished, machine-troweled surface. Refer to ACI 302.1R for further guidance. For air-entrained concrete for other than severe exposure, specify the type of exposure as indicated in Table 4.2.2.4. Exposure is defined as follows: *Mild exposure*—Service in a climate where concrete will not be exposed to freezing, deicing agents, or other aggressive agents, but where air entrainment is desired for other beneficial effects, such as to improve workability or cohesion in concrete with a low cementitious material content. To improve strength, air contents lower than those needed for durability can be used. This exposure includes indoor or outdoor service. *Moderate exposure*—Service in a climate where freezing is expected, but where the concrete will not be continually exposed to moisture or free water for long periods before freezing and will not be exposed to deicing agents, other aggressive agents, or other aggressive chemicals. Examples include exterior beams, columns, walls, girders, and slabs that are not in contact with wet soil and are located so that they will not receive direct application of deicing salts. *Severe exposure*—Concrete that is exposed to deicing chemicals or other aggressive agents or that may become highly saturated by continual contact with moisture or free water before freezing. Examples include parking structures, pavements, bridge decks, curbs, gutters, sidewalks, canal linings, and exterior water tanks or sumps. Specify if a particular ASTM test method (ASTM C 231, C 138, or C 173) is required for measuring air content. For the same reasons as described in the Optional Requirements to 4.2.2.2, it may be necessary to specify that air content be measured at the point of placement to account for loss of air content during pumping. Once the loss of air content during pumping is established, acceptance limits at the point of placement can be determined.
4.2.2.5	Specify types of admixture required and indicate the parts of the Work in which each type should or may be used. Calcium chloride as an admixture shall not be used in concrete to be subjected to severe or very severe sulfate exposure as defined in Table 4.3.1 of ACI 318.
4.2.2.6	When epoxy- or zinc-coated bars are used, the limits in Table 4.2.2.6 may be more restrictive than necessary. Specify if higher limits are allowed. See the references given in the Mandatory Requirements Checklist for 4.2.2.6.
4.2.2.8	These requirements have been excerpted from ACI 306.1. For projects in cold climates, such as in northern winters, or in situations where it is prudent to require the Contractor to follow specific procedures to achieve the limits of 4.2.2.8, the temperature limits for cold weather may be deleted and ACI 306.1 can be referred to in its entirety. Options within ACI 306.1 must then be exercised. Also, see the Optional Requirements Checklist for 5.3.6.1. If concrete delivered in hot weather with a temperature higher than 90 °F has been used successfully in given climates or situations, the higher temperature may be specified in place of the 90 °F limit.
4.2.2.9	Concrete exposed to alternating cycles of freezing and thawing in a saturated condition; deicer salts; fresh, brackish, or seawater including the area in the splash or spray zone; sulfates; and concrete that is required to have low permeability to water should be specified to have a water-cementitious material ratio not exceeding the value in ACI 318 Tables 4.2.2 and 4.3.1, whichever is applicable.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
4.2.2.9.a	Specify those areas that will be exposed to deicing chemicals and must comply with the limitations in Table 4.2.2.9.
4.2.2.9.b	If the test specimen is to be other than a 6 x 12 in. cylindrical specimen, specify the size of the specimen. If age at test is to be other than 28 days, specify age at test. If a different test method is required, specify the test method.
4.2.3.4.b	Specify the test ages, if other than 28 days, for trial mixture proportioning.
4.3.1.1	If concrete materials are to be specified, measured, batched, or mixed other than in conformance with ASTM C 94/C 94M, specify how these procedures are to be accomplished. Specify if the ready-mixed concrete production facility must be certified by the NRMCA Program for Certification of Ready-Mixed Concrete Production Facilities or an equivalent program.
4.3.2.1	Specify when slump adjustment by addition of water at the project site is not permitted.
4.3.2.2	If shorter or longer time for completion of discharge is required or permitted, specify maximum time.
Handling, placing, and constructing	
5.1.2.1	Specify if submittals listed in 5.1.2.1.a through 5.1.2.1.e are not required to be submitted.
5.1.2.2.a	Specify if shop drawings must be submitted.
5.1.2.2.b	Specify if advance notification of concrete placement is required.
5.1.2.2.c	Specify if a request for acceptance of preplacement activities must be submitted. When necessary, specify a preconstruction conference be held before the start of construction activities.
5.1.2.2.d	Specify if a request for acceptance of wet-weather protection must be submitted.
5.1.2.2.e	Specify if a request for acceptance of hot-weather precautions must be submitted.
5.1.2.2.f	Specify if samples finished in accordance with 5.3.3.2 must be submitted.
5.1.2.2.g	Specify if an exposed-aggregate surface is required.
5.3.2.1.c	If concrete temperatures higher than 90 °F are acceptable, based on location, relative humidity, and past experience, specify a higher allowable concrete temperature in hot weather. Review the ACI 305R report for guidance to specify a higher temperature.
5.3.2.6	Specify if bond is required at construction joints.
5.3.3.2	Specify if the finish is required to match that of a sample panel to be furnished for comparison purposes. Specify the sample finish location and the in-place finish location.
5.3.3.3	Specify more restrictive tolerances for as-cast form finishes as needed based on importance of surface appearance. See Optional Requirements Checklist for 2.3.1.2 for additional guidance.
5.3.3.5	Specify if finishes other than those in 5.3.3.5 are required.
5.3.4.1	Specify which of the finishes or combination of finishes in 5.3.4.2 are required. If this is not done, the finishes will be as required in 5.3.4.2.j. Specify when more or less certified flatwork concrete finishers may be required or permitted. More stringent qualifications for the finishing contractor and finishers may be appropriate where floor serviceability is significant to the Owner and for large floor projects with specific requirements for flatness, heavy loading, frequent lift truck traffic, or automated warehouse truck traffic. For such projects, specify that the finishing contractors use qualified flatwork finishers who are skilled in the specific type of Work required.
5.3.4.2.c	Specify more restrictive tolerances if applicable. The conventional straightedged tolerance from ACI 117 applies to most general floor construction. For floors requiring tighter tolerances, such as in areas housing sensitive test or monitoring equipment, specify either “flat” or “very flat” floor tolerances from ACI 117. Refer to the commentary for ACI 117 and ACI 302.1R for more guidance. Specify tolerances that may be more or less restrictive when applicable.
5.3.4.2.e	For dry-shake finishes, specify the metallic or mineral aggregate, the final finishing method, and the location.
5.3.4.2.f	For heavy-duty topping for two-course slabs, specify the materials, the final finishing method, and the location.
5.3.4.2.h	For nonslip finishes, specify the location. Where abrasive particles other than crushed aluminum oxides are to be used, specify the other abrasive particles.
5.3.4.2.i	For exposed-aggregate finishes, specify the location, color, surface retarder, and size of aggregate. (Usually 3/8 to 5/8 in.)

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
5.3.4.3.b, 5.3.4.3.c	Alternative floor finish tolerances, types of floors, and floor areas may be specified where applicable. The 10 ft straightedge method of measuring tolerances from ACI 117 applies to many small general floor construction applications. The F-number measuring system specified in ACI 117 applies to many large specialized and general floor construction applications. For floors requiring tighter tolerances, such as in areas with frequent lift-truck traffic, automated warehouse forklifts, or housing sensitive test and monitoring equipment, specify either "flat" or "very flat" floor tolerances from ACI 117 using the F-number measuring system. When specifying the F-number measuring system for unshored floors, specify only the F_F value, not the F_L value. Note that the commentary for ACI 117 contains cautions (per ASTM E 1155) to not use the F-number measuring system within 2 ft of an imbed or construction joint. Caution should also be used in specifying the F-number measuring system in floor areas that slope, unless a specific constant slope has been specified so that the F_F value is appropriate. Refer to the commentary for ACI 117 and ACI 302.1R for further guidance.
5.3.5	Specify if saw-cut contraction joints are required.
5.3.6.1	For concrete surfaces that require enhanced durability, such as high wear resistance, low permeability, or minimal cracking, a longer duration of curing may be needed than is required to meet compressive strength criteria alone. When such enhanced properties are required, minimum curing periods of 7 days for high-early-strength concrete, 14 days for concrete incorporating Type I or Type II cements, and 14 to 21 days for concrete incorporating pozzolan as one of the cementitious materials are recommended. See ACI 308.1 for additional guidance. Specify if a curing procedure of 5.3.6.4 that supplies additional water is required.
5.3.6.5	Requirements for rate of temperature change have been excerpted from ACI 306.1. For optional cold-weather concreting requirements, see the Optional Requirements Checklist for 4.2.2.8 and specify ACI 306.1 in its entirety, if appropriate.
5.3.7.7	Where stains, rust, efflorescence, and surface deposits are to be limited, describe the degree to which they are unacceptable.
Architectural concrete	
6.1.1.1	Designate areas to be treated as architectural concrete. Describe special color requirements. If necessary, specify a symmetrical array of formwork panels of a specified size.
6.1.1.3	Review Sections 1 through 5 and specify requirements to be omitted or added for architectural concrete. Designate any special cementitious materials, aggregates, or admixtures required for architectural concrete.
6.1.2.1, 6.1.2.2	Specify which submittals are required.
6.1.3.1	If the importance of the Work warrants it, list operations for which a technical specialist, trained or approved by the specialty item manufacturer, is to be on the project site to provide technical assistance during the first three days of construction operations using the specialty item. Specify any other times when a technical specialist is to be on the project site to provide technical assistance.
6.1.3.3	Specify for which structural items the Contractor is to make full-scale mock-ups as samples of finished construction.
6.2.2.1.d	Specify if it is permissible for ties to be located within exposed areas of architectural concrete.
6.3.2	Specify areas where designated colors and uniformity of color need not be maintained. Specify areas where stucco or cementitious coating is required. If so, specify applicable requirements or refer to the applicable part of the Contract Documents for such requirements. If applicable, specify required color.
6.3.3	Specify areas where a smooth-rubbed or similar finish is required.
6.3.6.1	Specify areas where as-cast finishes are permitted or required. Specify if ties are permitted within as-cast areas.
6.3.7.3.a	When acid washing or surface retarders are to be used to obtain a scrubbed finish, review ACI 303R, "Guide to Cast-in-Place Architectural Concrete Practice," and specify the recommendations and appropriate safety precautions that should be followed.
6.3.7.3.b	For a blast finish, if the degree of blasting is to be other than light, specify what degree of blasting is to be used based on the following: Brush — Sufficient to dull surface sheen but not to have any reveal Light — Maximum 1/16 in. aggregate exposure Medium — Maximum 1/4 in. aggregate exposure Heavy — Maximum 1/3 in. of the large aggregate diameter Refer to ACI 303.1 for additional guidance.
6.3.7.3.c	Where a tooled finish surface texture is specified, such as a hand-tooled, rough- or fine-pointed, or bush-hammered surface texture, provide description of specified surface texture.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
6.3.7.3.d	If blasted or tooled finishes are specified, specify the degree to which surface mortar is to be removed (removal of surface mortar only, removal of sufficient mortar to expose the surface of some coarse aggregate in relief to a specified depth, or removal with tools of sufficient material to abrade the coarse aggregate).
6.3.7.4	Specify areas where designated colors and uniformity of color need not be maintained. Specify areas where stucco or cementitious coating is required. If so, specify applicable requirements or refer to the applicable part of the Contract Documents for such requirements. If applicable, specify required color.
Lightweight concrete	
7.1.1	Designate portions of the structure to be constructed of lightweight concrete. Review Sections 1 through 5 and specify requirements to be omitted or added for lightweight concrete.
7.1.3.1	Specify if prewetting lightweight aggregate is not required.
7.2.2.1	Where lightweight concrete is subject to potentially destructive exposure other than wear or loading, specify that it be air-entrained. Destructive exposures include freezing and thawing, severe weather, or deicer chemicals. Specify the required compressive strength based on the requirements of ACI 318 Section 4.2.2 and Table 4.2.2.
7.2.3.1	For lightweight concrete, specify the equilibrium density. Specify method of determining equilibrium density of other than the calculated method in ASTM C 567.
7.2.4.4	Specify if presoaking lightweight aggregate by means other than vacuum saturation, ponding, or sprinkling is required.
Mass concrete	
8.1.1.1	Designate portions of the structure to be treated as either plain mass concrete or reinforced mass concrete. Whether or not concrete should be designated as mass concrete depends on many factors such as weather conditions, the volume-surface ratio, rate of hydration, degree of restraint to volume change, temperature and mass of surrounding materials, and functional and aesthetic effect of cracking. In general, heat generation should be considered when the minimum cross-sectional dimension approaches or exceeds 2-1/2 ft or when cement contents above 600 lb/yd^3 are used. The requirements for each project, however, should be evaluated on their own merits.
8.1.1.2	Review Sections 1 through 5 and specify additional requirements or any requirements to be omitted for mass concrete.
8.2.1.1.b	For mass concrete sections, cements such as ASTM C 150, Type II moderate heat; ASTM C 150, Type IV; ASTM C 595 (MH or LH) cements; or cement combinations with fly ash, pozzolans, or ground granulated blast-furnace slag should be used for the low heat-of-hydration benefits. Because low heat-of-hydration cementitious materials generally have lower early strengths, the compatibility of the concrete using such materials should be considered with the other work on the project. If the lower early concrete strength obtained using such cementitious materials is not acceptable, specify appropriate procedures to be used. The availability of cementitious materials should also be considered when specifying a particular cement or cementitious material combination.
8.2.2.1	When 28-day strength is not required for service conditions, a reduction in cement content can be achieved by requiring that concrete mixtures be proportioned for a strength at ages other than 28 days, such as at 56 or 90 days. Use of fly ash or other acceptable pozzolan may also reduce the required cement content. The Contract Documents should specify the use of pozzolans and later-age design strengths when acceptable.
8.2.2.2	Specify the maximum permissible slump if it is to be other than 3 in. for plain mass concrete or that required by 4.2.2.2 for reinforced mass concrete.
8.3.1.1	If the limits on temperature of concrete when deposited are to be other than as given in 8.3.1.1, specify maximum and minimum placing temperatures.
8.3.2.1.a	A curing period of 7 days is sufficient for mass concrete proportioned for a 28-day specified strength. When concrete strength is based on 56- or 90-day compressive strength, the curing period should be extended to a minimum of 14 days. Specify the duration of curing if longer than 7 days is required.
8.3.2.1.b	Mass concrete is best cured with water for the additional cooling benefit in warm weather. When water curing is impractical, such as when the surrounding air temperature is less than 32 °F, other methods such as the use of liquid membrane-forming compounds may be used. Specify if a particular curing method is desired.
8.3.2.4	Specify additional or optional temperature controls as appropriate to minimize thermal cracking. For example, limitations on temperature differentials between the center and surface of the concrete may be desirable for large structurally reinforced placements, such as large mat foundations, if the entire concrete section can be cast in one continuous placement and the external restraint from adjacent concrete elements can be avoided. Complying with limitations on temperature differentials will normally require keeping concrete warm with insulation. Additional reinforcing steel may also be needed to minimize crack widths from base restraint and the higher peak concrete temperatures. See PCA publication, *Design and Control of Concrete Mixtures*, 14th edition, and ACI 207.2R for additional guidance.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Architect/Engineer
Prestressed concrete	
9.1.1	Review Sections 1 through 5 and specify additional requirements or requirements to be omitted for post-tensioned concrete.
9.1.2.2	If required, specify that the Contractor submit test data substantiating expected coefficients and anchorage set.
9.2.1.1	Guidance for evaluating the degree of rusting on strand is given in "Evaluation of Degree of Rusting on Prestressed Concrete Strand," by A. S. Sason, *PCI Journal*, V. 37, No. 3, May-June 1992, pp. 25-30.
9.2.1.4.b	Indicate areas that are considered to be corrosive environments where encapsulation of the prestressing steel at stressing, intermediate, and fixed anchorages is required.
9.2.1.7	Indicate areas where couplers may be used.
9.2.2.2.a	Specify specific grout mixture for the project, if desired.
9.2.2.2.b	If a shrinkage-compensating or expanding admixture is required for the grout, so specify in the Contract Documents.
9.2.2.2.e	Specify when verification of grout consistency is desired.
9.3.2.1.d	Indicate areas that require an additional coating on the exposed or specified parts of the tendon.
9.3.4.1	Specify the sequence, the concrete strength, and the stages at which tendons should be stressed.
Shrinkage-compensating concrete	
10.1.2	Designate areas to be constructed using shrinkage-compensating concrete. Specify requirements of Sections 1 to 5 that do not apply.
10.2.1.1.a	If an expansive cement other than ASTM C 845, Type E-1 (K) is acceptable or required, specify the cement type.
10.2.1.1.c	Fly ash or ground granulated blast-furnace slag will affect the expansion and should not be used without adequate testing.
10.2.1.2.a	Accelerating admixtures, specifically ones that contain calcium chloride, may reduce the expansion of the concrete and should not be permitted for use in shrinkage-compensating concrete.
10.2.1.2.b	Admixtures may have an effect on the expansion of the specific concrete mixture. Do not permit changes in admixture dosage or type without additional testing. See ACI 223 for additional information.
10.2.2.2	If different minimum and maximum limits for expansion are desired, specify the requirements. Minimum expansion needed is based on the projected shrinkage for the particular concrete mixture and the amount of reinforcement used. Consult ACI 223 for guidance.
10.2.2.3	If slump is to be different than 6 in. maximum at the point of placement, specify the requirement. Refer to Optional Requirements Checklist 4.2.2.2 for guidance on slump loss between delivery and placements points.
10.2.3.1	Due to the initial slump loss of shrinkage-compensating concrete, it is necessary to proportion the concrete mixture to consider initial slump loss. If the concrete mixture used in the Work has a delivery time longer than 20 min, specify a longer hold time to be used in the trial mixture proportioning procedure. Consult ACI 223 for guidance.
10.2.4	Specify the grade of reinforcing bar and the amounts of reinforcement required. Shrinkage-compensating concrete must always be reinforced. The reinforcement should be determined in accordance with ACI 318. See ACI 223 for additional guidance.
10.2.5	Specify alternative compressible isolation-joint filler material if desired.
10.3.1.2	Specify position of bars in reinforced slabs on ground if different from 2 in. from top surface.
10.3.2.2	If a longer time between casting of adjoining sections is needed, specify the time required. See ACI 223 for guidance.
10.3.4	If shrinkage-compensating concrete is cured by a method other than wet curing, the expansion will be reduced significantly. The structure or slab should be designed to compensate for this reduced expansion. See ACI 223 for guidance. If curing is to be continued for a period longer than 7 days, or if a method other than water curing is acceptable, specify the requirements in the Contract Documents.

SUBMITTALS CHECKLIST

NOTE: The items listed will be submitted by the Contractor and reviewed by the Architect/Engineer.

Notify the Contractor of acceptance or rejection after review of submittals. All submittals and responses should be retained in files for future reference during the Work. Some submittal requirements shown will apply only when optional requirements are selected and written into the Project Specifications. Once optional requirements have been selected, review the Section/Part/Article indicated for the submittal item to see if it applies.

Section/Part/Article	Submittal items and notes to Architect/Engineer
General requirements	
1.6.3.1	Proposed testing agency.
1.6.3.2.e	Test data and documentation on materials and concrete mixtures.
1.6.3.2.f	Quality-control program of the concrete supplier.
1.6.3.2.g	Request to use accelerated testing and correlation data.
1.6.4.1.c	Test and inspection results.
1.7.1.4	Proposed repair methods, materials, and modifications to the Work.
1.7.4.2.e	Description of repair work performed to bring strength-deficient concrete into compliance with the Contract Documents.
1.7.5.2.e	Description of repair performed to bring potentially nondurable concrete into compliance with the Contract Documents.
Formwork and formwork accessories	
2.1.2.1.a	Data on formwork facing materials if different from that specified in 2.2.1.1.
2.1.2.1.b	Data on proposed departure from location or detail of construction and contraction joints shown on the project drawings.
2.1.2.1.c	Correlation data for alternative methods of determining strength of concrete for formwork removal. Refer to ACI 228.1R for recommendations on developing suitable correlation data.
2.1.2.1.d	Detailed plan for formwork removal at a lower compressive strength than specified.
2.1.2.1.e	Plan and procedures for installation and removal of reshoring and backshoring. See ACI 347 for guidance on items to consider.
2.1.2.1.f	Data on formwork release agent or formwork liners.
2.1.2.2.a	Shop drawings for formwork.
2.1.2.2.b	Calculations for formwork, reshoring, and backshoring.
2.1.2.2.c	Data and samples of form ties.
2.1.2.2.d	Data and samples of expansion joint materials.
2.1.2.2.e	Data and samples of waterstops.
2.2.2.3	Request to use earth cuts as form surfaces.
2.2.2.5.b	Alternative location and details of construction joints.
2.2.2.5.d	Alternative locations and details for formed construction and contraction joints.
2.3.2.5	Detailed plan for formwork removal at a lower compressive strength than f_c'.
2.3.4.2	Data correlating alternative concrete strength-measuring methods for formwork removal. Refer to ACI 228.1R for recommendations on developing suitable correlation data.
Reinforcement and reinforcement supports	
3.1.1.1.a	Certified test reports on materials.
3.1.1.1.b	Placing drawings showing fabrication dimensions and locations for placement of reinforcement and supports.
3.1.1.1.c	List of splices and request to use splices not shown on the project drawings.
3.1.1.1.d	Request to use mechanical splices not shown on the project drawings.
3.1.1.1.e	Request for placement of column dowels without the use of templates.
3.1.1.1.f	Request and procedure to field bend or straighten partially embedded reinforcement.
3.1.1.1.g	Copy CRSI Plant Certification.
3.1.1.2.a	Description of reinforcement weld locations, weld procedures, and welder qualifications.
3.1.1.2.b	Proposed supports for coated reinforcement and materials for fastening coated reinforcement not covered in 3.3.2.4.
3.1.1.3.a, 3.3.2.2	When the Contractor finds it necessary to move reinforcement beyond the specified placing tolerances to avoid interference with other reinforcement, conduits, or embedded items, review a submittal showing the resulting arrangement of reinforcement.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and notes to Architect/Engineer
3.1.1.3.b	Inspection and quality-control program of plants that are not certified by the Concrete Reinforcing Steel Institute.
3.2.2.1	Request to heat and bend reinforcement.
3.3.2.6	Request to use alternate method for setting column dowels.
3.3.2.7	Request to use mechanical splices not shown on the project drawings.
3.3.2.8	Request and procedure to field bend or straighten partially embedded reinforcement.
3.3.2.9	Request to field cut reinforcement.
Concrete mixtures	
4.1.2.1	Mixture proportions and characteristics. Check that mixture proportions conform to the requirements of 4.2.2 for cementitious material content, water-cementitious material ratio, slump, nominal maximum size of coarse aggregate, air content, admixtures, and chloride-ion concentration, as well as compressive strength and yield.
4.1.2.2, 4.2.3.4.a	Method and test data used to establish mixture proportions. Several different methods can be used to select mixture proportions to produce the necessary placeability, density, strength, and durability of the concrete. Field experience of concrete mixtures previously used under similar conditions provides the best assurance that the proposed concrete mixture can be used satisfactorily and will have the specified properties. If there is no field experience, ACI 211.1 provides guidance for selection of the initial quantities of materials based on material properties and specified concrete properties. When a field test record is not available, ACI 211.1 recommends that mixture characteristics be checked by trial batches in the laboratory or in the field. Blending aggregates to meet criteria for a combined grading is another proportioning method that can be used. Listed below are some of the different procedures that have been used to determine proportions of blended aggregates: • Combined fineness modulus; • 8 to 18% retained on each of the standard sieves; • Coarseness factor chart; and • 0.45 power chart. When one of the above or other similar proportioning methods are used, the specific combined grading to which aggregate is to be blended, along with the tolerances for control, should be submitted. This proportioning method also requires concrete characteristics to be checked by trial batches.
4.1.2.3	Information on types, classes, producers' names, and plant locations for cementitious materials; types, pit or quarry locations, producers' names, gradings, and properties required by ASTM C 33 for aggregates; types, brand names, and producers' names for admixtures; and source of supply for water and ice. Except for admixtures and water, test results confirming conformance with applicable specifications shall not be more than 90 days old. Test results for aggregate soundness, abrasion, and reactivity may be older than 90 days, but not older than 1 year, provided test results for the other properties specified in ASTM C 33 indicate that the aggregate quality has not changed.
4.1.2.4	Materials, mixture proportions, and field strength-test data used for proportioning.
4.1.2.5, 4.2.3.5	Requests for adjustments to mixture proportions. Requests to adjust mixture proportions necessary for workability or consistency. If the Contractor desires to decrease the cementitious materials content of the concrete mixture after having satisfied the requirements of 4.2.3.6, review a request for acceptance of the proposed revised mixture with a lower cementitious materials content on a trial basis. If the Contractor finds it necessary to increase the cementitious materials content, review a request for acceptance of the proposed revised mixture with a higher cementitious materials content on a trial basis. Confirm adequacy of modified proportions has been verified from a set of new field test data.
4.1.2.6	Evaluation and test results required in 4.2.2.1 verifying the adequacy of concrete to be placed in floors if the cementitious materials content is less than the minimum specified in Table 4.2.2.1.
4.1.2.7	Request to use calcium chloride.
4.1.2.8, 4.3.1.1	Request to use the volumetric batching method.
4.1.2.9	Requests to exceed the ASTM C 94/C 94M required time of discharge.
4.2.1.1	Requests to use cementitious materials other than ASTM C 150 Type I or Type II. When ASTM C 595 or C 1157 cements are used in structures that will be subjected to deicing chemicals, verify compliance of the concrete with Table 4.2.2.9.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and notes to Architect/Engineer
4.2.1.3	Request to use alternative sources of water.
4.2.1.4	Request to use admixtures.
4.2.1.5	Request to change materials and data verifying that properties of the concrete mixture conform to the requirements of 4.2.2.
4.2.2.1	Request to use a lower cementitious material content.
4.2.2.2	Request to use a slump other than that specified.
4.2.2.7	Documentation indicating compliance with the specified requirements for sulfate resistance. Documentation may include test results on the cementitious material to be used in the proposed concrete mixture in accordance with ASTM C 1012. Alternatively, evidence of adequate sulfate resistance of at least 8-year old existing structures in exposures at least as severe as the proposed structure may be accepted. The level of sulfate ions in the soil or water of the existing structure should be comparable to the exposure of the proposed structure as provided by the Architect/Engineer.
4.2.3.6.c	Revised mixture proportions based on revised value of f'_{cr}.
Handling, placing, and constructing	
5.1.2.1.a	Test and inspection records.
5.1.2.1.b	Description of conveying equipment.
5.1.2.1.c	Proposed method of measuring concrete surface temperature changes.
5.1.2.1.d	Proposed method for removal of stains, rust, efflorescence, and surface deposits.
5.1.2.1.e	Qualifications of finishing contractor and flatwork finishers.
5.1.2.2.a	Shop drawings of placing, handling, and constructing methods.
5.1.2.2.b	Advance notification of forthcoming placement. Arrange for tests and inspection to be properly coordinated.
5.1.2.2.c	Request for acceptance of preplacement activities to ensure the preplacement activities are properly inspected, if necessary.
5.1.2.2.d, 5.3.2.1.a	Proposed wet-weather protection activities.
5.1.2.2.e	Proposed precautions for placement of concrete hotter than 90 °F.
5.1.2.2.f	Sample finish.
5.1.2.2.g, 5.3.4.2.i	Specification and manufacturer's data for surface retarder used in producing exposed-aggregate finish along with method of use.
5.1.2.3.a	Proposed location and treatment of construction joints not shown on the project drawings. Review proposed methods for preparing the surface and the use of portland-cement grout.
5.1.2.3.b	Bonding agents other than cement grout for two-course slabs.
5.1.2.3.c, 5.3.2.4	Proposed method for underwater placement.
5.1.2.3.d	Proposed location of contraction joints not indicated on the project drawings.
5.1.2.3.e	Proposed methods of curing other than those of 5.3.6.4.
5.1.2.3.f	Description of proposed coated form ties.
5.1.2.3.g, 5.2.1.3, 5.3.7.6	Specification and data and methods of use for any proposed repair material other than site-mixed portland-cement mortar described in 5.3.7.5 (see 5.3.7.6). For patches in exposed concrete, exercise caution when using the materials described in 5.3.7.6, particularly with regard to both possible color changes from weathering and delamination due to differing coefficients of thermal expansion. Ensure that the material, including ASTM type or class, is appropriate for the moisture and thermal conditions of exposure.
5.3.2.1.c	Request to exceed 90 °F concrete temperature, along with proposed precautionary measures and supporting data.
5.3.2.6	Proposed materials and methods to prepare the concrete surface to achieve bond.
5.3.4.2.f	Request to use bonding agents other than cement grout.
5.3.5	Detailed plan for alternative saw-cutting method, such as shallow-cut and dry-cut method. See ACI 302.1R for further guidance.
5.3.6.4	Proposed methods of curing other than those listed in 5.3.6.4.a through e.
5.3.6.5	Method of measuring concrete surface temperature.

SUBMITTALS CHECKLIST (cont.)

Architectural concrete	
6.1.2.1.a	Shop drawings and fabricating drawings of formwork for architectural concrete. These drawings should show jointing of facing panels; locations and details of form ties and recesses; details of joints, anchorages, and other accessories; and any necessary alignment bracing. Review drawings for condition of finished surface, jointing, location of form tie holes and their treatment, types of form ties, location and details of rustication strips, leak-tightness, assembly, and removal.
6.1.2.2.a	Request for the proposed location of full-scale mock-ups at the project site.
6.1.2.2.b	Mock-ups or sample panels of aggregate transfer and other special finishes.
6.1.2.2.c	When an exposed-aggregate finish is required, review a description of the method (such as blasting, bush-hammering, or use of a surface retarder) the Contractor desires to use to expose aggregate.
Lightweight concrete	
7.1.3.1	Request for alternate prewetting methods or times for lightweight aggregate.
7.2.3.1	Test results or calculations correlating equilibrium density to the required fresh bulk density.
7.2.4.1	Batching and mixing procedure that varies from the specified requirements in Section 4.
7.2.4.4	If the Contractor needs additional water or air entrainment to bring the concrete to the specified slump, review the request and quantities to be added.
Mass concrete	
8.1.2	Documentation and test data on cementitious material, aggregates, admixtures, and water. If the Contractor deems it necessary to use a retarding, accelerating, or other admixture in mass concrete, review manufacturer's data on the admixture and the Contractor's test results on the admixture with the other project materials.
8.2.1.2.a	Request to use an accelerating admixture. As a general rule, accelerating admixtures should not be used in mass concrete because they contributed to early undesirable heat development. On rare occasions, such as when early formwork removal is critical, accelerating admixtures may be needed to accelerate strength development in reinforced mass concrete during winter conditions. Calcium chloride, if used, should not be permitted in excess of 1% by weight of cement. The Architect/Engineer must accept the use of any accelerating admixture.
8.2.2.2	Requests to use a slump greater than 3 in. for plain mass concrete or a slump differing from the requirements of 4.2.2.2 for reinforced mass concrete.
8.3.1.1	Requests to allow limits on concrete temperature at placement to exceed 70 °F or to be less than 35 °F.
Prestresssed concrete	
9.1.2.1.a	Installation drawings and data on: • Sizes and heights of tendon support bars and chairs; • Tendon locations; • Size, details, location, materials, and stress grade (where applicable) for tendons and accessories; • Jacking procedures, stressing sequence, and tensioning forces; • Wobble and curvature coefficients and anchorage set data; and • Details of reinforcement to prevent busting and spalling.
9.1.2.1.b	Gauge pressures and calibration curves for the rams and gauges.
9.1.2.1.c	Grout mixture proportions and test data demonstrating compliance with 9.2.2.2.
9.1.2.2.a	Test data substantiating the expected coefficient and anchorage set.
9.1.2.2.b	Results of tests required in 9.1.3.1.
9.1.2.2.c	Jack clearances.
9.1.2.3.a	Certified mill tests for a sample taken from the production lot of the prestressing tendon that will be used in the Work.
9.1.2.3.b	Stressing and elongation records.
9.2.1.7	Proposed locations of couplers at locations other than as indicated on the Contract Documents.
9.2.2.2.a	Request to use different grout mixtures.
9.3.2.1.d	Data on coating material for tendons extending outside the concrete, or otherwise specified to receive an additional coating.
9.3.2.1.f	Data on corrosion protection material for tendons ungrouted for more than 28 days after tendon placement.
9.3.4.3	Records of measured elongation and gauge pressure readings for the prestressing force.

SUBMITTALS CHECKLIST (cont.)

Shrinkage-compensating concrete	
10.1.3.2	Expansion test results for the proposed concrete mixtures.
10.1.3.3	Proposed sequences of concrete placements. It is critical that the concrete be placed in such manner that will permit the placement to expand. Consult ACI 223 for guidance.
10.2.1.1.c	Request to use silica fume.
10.2.3.2	Expansion test results for the proposed concrete mixtures.
10.2.3.3	Proportions and expansion test results for revised mixture proportions.