301M-10

(metric)

Specifications for Structural Concrete

An ACI Standard

Reported by ACI Committee 301

American Concrete Institute®

First Printing
January 2011

American Concrete Institute®
Advancing concrete knowledge

Specifications for Structural Concrete

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI. Proper use of this document includes periodically checking for errata at **www.concrete.org/committees/errata.asp** for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided "as is" without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised *ACI Manual of Concrete Practice* (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

ISBN 978-0-87031-411-7

An in.-lb version of this document (ACI 301-10) is available at **www.concrete.org**

ACI 301M-10

Specifications for Structural Concrete

An ACI Standard

Reported by ACI Committee 301

W. Calvin McCall*
Chair

Colin L. Lobo
Secretary

James Edward Anderson
Jon B. Ardahl
Nicholas J. Carino*
Ramon J. Carrasquillo
Domingo J. Carreira
Mark F. Chrzanowski
Steven R. Close
James N. Cornell II*
Juan Pablo Covarrubias
Marwan A. Daye
Mario R. Diaz
Daniel P. Dorfmueller
Barry E. Foreman
Sidney Freedman*
John W. Gajda
David P. Gustafson
Charles S. Hanskat
Jerry S. Haught
Kenneth C. Hover*
Steven C. Jaycox
Larry B. Krauser
James A. Lee
Frank Stephen Malits
Theodore L. Neff*
Jerry Parnes
Aimee Pergalsky*
Henry B. Prenger
G. Michael Robinson
Bruce A. Suprenant
Wahid A. Tadros
Scott M. Tarr*
Arthur T. Weiss, Jr.
Michael A. Whisonant
Michelle L. Wilson*
Dennis M. Wittry
Bryan T. Wood

*Subcommittee Chairs.

Voting Subcommittee Members

Scott Michael Anderson
Roger J. Becker
Julie K. Buffenbarger
Anthony R. DeCarlo, Jr.
Darryl E. Dixon
Greg K. Fricks
Thomas M. Greene
Gardner P. Horst
Robert S. Jenkins
Larry P. Jorn
Alfred L. Kaufman, Jr.
Roy H. Keck
Donald P. Kline
Jason J. Krohn
Lionel A. Lemay
Kevin A. MacDonald
Thomas O. Malerk
Arthur W. McKinney
Andrew S. McPherson
Donald F. Meinheit
Dennis W. Phillips
Robert C. Richardson†
John R. Ries
Edward D. Russell
Gregory M. Scurto
Larbi M. Sennour
William C. Sherman
Joseph J. Steinbicker
Gregory R. Wagner

†Deceased.

ACI 301M-10 supersedes ACI 301M-05, was adopted June 22, 2010, and published January 2011.

This is a Reference Specification that the Architect/Engineer can apply to any construction project involving structural concrete by citing it in the Project Specifications. Checklists are provided to assist the Architect/Engineer in supplementing the provisions of this Reference Specification as needed by designating or specifying individual project requirements.

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

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

CONTENTS

(mandatory portion follows)

SECTION 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 *Work specified*—This Specification governs the construction of cast-in-place and precast structural concrete and industrial floor slabs cast on ground.

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

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

- Precast concrete products covered by ASTM specifications;
- Heavyweight shielding concrete;
- Slipformed paving concrete;
- Terrazzo;
- Insulating concrete;
- Refractory concrete;
- Shotcrete; and
- Slipformed concrete walls.

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

1.2—Definitions

acceptable or **accepted**—determined to be satisfactory by Architect/Engineer.

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

ACI Concrete Field Testing Technician Grade I—a person who has demonstrated knowledge and ability to perform and record the results of ASTM standard tests on freshly mixed concrete and to make and cure test specimens. 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**—Architect, Engineer, architectural firm, engineering firm, or architectural and engineering firm issuing Contract Documents or administering the Work under Contract Documents, or both.

architectural concrete—concrete that is typically exposed to view, is indicated as architectural concrete in Contract Documents, and therefore requires special care in 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.

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

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

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.

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

duct—the material creating a conduit in a concrete member to accommodate the prestressing steel of a post-tensioning tendon.

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

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

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

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

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

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

lightweight concrete—structural concrete containing lightweight aggregate conforming to ASTM C330 and having an equilibrium density, as determined by ASTM C567, between 1440 and 1840 kg/m^3.

mass concrete—any volume of structural concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration.

normalweight concrete—structural concrete containing aggregate that conforms to ASTM C33 and that typically has a density between 2160 and 2560 kg/m^3.

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

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

post-tensioning—a method of prestressing reinforced concrete in which tendons are tensioned after the concrete has attained a specified minimum in-place strength or a specified minimum age.

precast concrete—concrete cast elsewhere than its final position.

prestressed concrete—structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from loads (see **post-tensioning** and **pretensioning**).

prestressing sheathing—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.

prestressing steel—high-strength steel element, such as strand, bars, or wire, used to impart prestress forces to concrete.

pretensioning—method of prestressing in which prestressing steel is tensioned before the concrete is placed.

Project Drawings—graphic presentation of project requirements.

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

pull-on method—method of seating fixed-end anchorage by tensioning prestressing steel.

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

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

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

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

required—required in this Specification or 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.

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

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

shrinkage-compensating concrete—a concrete that increases in volume after setting, designed to induce compressive stresses in concrete restrained by reinforcement or other means, to offset tensile stresses resulting from shrinkage.

strength test—standard test conducted for evaluation and acceptance of concrete determined as the average of the compressive strengths of at least two 150 by 300 mm cylinders or at least three 100 by 200 mm cylinders made from the same sample of concrete, transported, and standard cured in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M at 28 days or at test age designated for f'_c.

structural concrete—concrete used in a member to resist loads and having a specified compressive strength of at least 17 MPa.

submit—provide to Architect/Engineer for review.

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

surface defects—imperfection in concrete surfaces defined in Contract Documents that must be repaired.

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

tilt-up—a construction technique for casting concrete members in a horizontal position at the project site and then erecting them to their final upright position in a structure.

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

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

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

1.3—Referenced standards and cited publications

1.3.1 *Referenced standards*—Standards referred to in this Specification are listed with serial designation including year of adoption or revision.

1.3.1.1 *ACI standards*

117M-10	Specifications for Tolerances for Concrete Construction and Materials
423.7-07	Specification for Unbonded Single-Strand Tendon Materials and Commentary
423.9M-10	Test Method for Bleed Stability of Cementitious Post-Tensioning Tendon Grout
ITG-7M-09	Specification for Tolerances for Precast Concrete

1.3.1.2 *ASTM standards*

A82/A82M-07	Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
A184/A184M-06	Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement
A185/A185M-07	Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete
A416/A416M-06	Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A421/A421M-05	Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete
A496/496M-07	Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
A497/A497M-07	Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
A615/A615M-07	Standard Specification for Deformed and Carbon-Steel Bars for Concrete Reinforcement
A666-03	Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar

A706/A706M-06a	Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A722/A722M-07	Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete
A767/A767M-06	Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
A775/A775M-07a	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A779/A779M-00	Standard Specification for Steel Strand, Seven-Wire, Uncoated, Compacted, Stress-Relieved for Prestressed Concrete
A780-01	Standard Practice for Repair of Damaged Hot-Dip Galvanized Coatings
A820/A820M	Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
A882/A882M-04a	Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand
A884/A884M-04	Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Reinforcement
A886/A886M-05	Standard Specification for Steel Strand, Indented, Seven-Wire, Stress-Relieved for Prestressed Concrete
A910/A910M-05	Standard Specification for Uncoated, Weldless, 2- and 3-Wire Steel Strand for Prestressed Concrete
A934/A934M-07	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
A955/A955M-07a	Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement
A970/A970M-06	Standard Specification for Welded or Forged Headed Bars for Concrete Reinforcement
A996/A996M-06a	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
A1022/A1022M-07	Standard Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement
A1035/A1035M-07	Standard Specification for Deformed and Plain, Low-carbon, Chromium, Steel Bars for Concrete Reinforcement
A1044/A1044M-05	Standard Specification for Steel Stud Assemblies for Shear Reinforcement of Concrete
C31/C31M-06	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33-03	Standard Specification for Concrete Aggregates
C39/C39M-05$^{\varepsilon 1}$	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C42/C42M-04	Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C67-09	Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile
C78-09	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C94/C94M-06	Standard Specification for Ready-Mixed Concrete
C109/C109M-08	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C126-09	Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units
C138/C138M-09	Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C143/C143M-09	Standard Test Method for Slump of Hydraulic-Cement Concrete
C144-04	Standard Specification for Aggregate for Masonry Mortar
C150-05	Standard Specification for Portland Cement
C157/C157M-08	Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
C171-07	Standard Specification for Sheet Materials for Curing Concrete
C172-04	Standard Practice for Sampling Freshly Mixed Concrete
C173/C173M-09	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C192/C192M-06	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C216-01a	Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)
C231-04	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C260-06	Standard Specification for Air-Entraining Admixtures for Concrete
C309-07	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C330-05	Standard Specification for Lightweight Aggregates for Structural Concrete
C373-88	Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products

C387-09	Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete
C403/C403M-08	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C404-07	Standard Specification for Aggregates for Masonry Grout
C494/C494M-05a	Standard Specification for Chemical Admixtures for Concrete
C567-05a	Standard Test Method for Determining Density of Structural Lightweight Concrete
C578-09$^{\varepsilon 1}$	Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation
C591-08a	Standard Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation
C595-07	Standard Specification for Blended Hydraulic Cements
C597-02	Standard Test Method for Pulse Velocity Through Concrete
C618-05	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C642-06	Standard Test Method for Density, Absorption, and Voids in Hardened Concrete
C650-04	Standard Test Method for Resistance of Ceramic Tile to Chemical Substances
C666/C666M-03	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C684-99 (2003)	Standard Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens
C685/C685M-01	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C803/C803M-03	Standard Test Method for Penetration Resistance of Hardened Concrete
C805/C805M-08	Standard Test Method for Rebound Number of Hardened Concrete
C834-05	Standard Specification for Latex Sealants
C845-04	Standard Specification for Expansive Hydraulic Cement
C873/C873M-04^{e1}	Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C878/C878M-09	Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete
C881/C881M-02	Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
C900-06	Standard Test Method for Pullout Strength of Hardened Concrete
C920-08	Standard Specification for Elastomeric Joint Sealants
C928/C928M-08	Standard Specification for Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs
C939-02	Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
C940-98a	Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory
C942-99	Standard Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory
C953-06	Standard Test Method for Time of Setting of Grouts for Preplaced-Aggregate Concrete in the Laboratory
C979-05	Standard Specification for Pigments for Integrally Colored Concrete
C989-06	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C1012-04	Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
C1017/C1017M-03	Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C1059-99	Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete
C1064/C1064M-08	Standard Test Methods for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C1074-04	Standard Practice for Estimating Concrete Strength by the Maturity Method
C1077-09b	Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C1088-09	Standard Specification for Thin Veneer Brick Units Made from Clay or Shale
C1107/C1107M-08	Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)
C1157-03	Standard Performance Specification for Hydraulic Cement
C1218/C1218M-99	Standard Test Method for Water-Soluble Chloride in Mortar and Concrete
C1240-05	Standard Specification for Silica Fume Used in Cementitious Mixtures
C1289-08	Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board
C1315-08	Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete

C1354/C1354M-09	Standard Test Method for Strength of Individual Stone Anchorages in Dimension Stone
C1602/C1602M-06	Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
D98-05	Standard Specification for Calcium Chloride
D412-06a^{e2}	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
D638-08	Standard Test Method for Tensile Properties of Plastics
D698-07^{e1}	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort [12 400 ft-lbf/ft^3 (600 kN-m/m^3)]
D994-98 (2003)	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
D1621-04a	Standard Test Methods for Compressive Properties of Rigid Cellular Plastics
D1751-04	Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Non-extruding and Resilient Bituminous Types)
D1752-04a	Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
D2240-05	Standard Test Method for Rubber Property—Durometer Hardness
D2940/D2940M-09	Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports
D3575-08	Standard Test Methods for Flexible Cellular Materials Made from Olefin Polymers
D4397-09	Standard Specification for Polyethylene Sheeting for Construction, Industrial, and Agricultural Applications
E165-09	Standard Practice for Liquid Penetrant Examination for General Industry
E329-08	Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction
E488-96 (2003)	Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements
E543-09	Standard Specification for Agencies Performing Nondestructive Testing
E1155-96 (2008)	Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers
E1444-05	Standard Practice for Magnetic Particle Testing
E1643-09	Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs
E1745-09	Standard Specification for Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs

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

AASHTO HB-17(02)	Standard Specification for Highway Bridges
AASHTO-07	LRFD Bridge Design Specifications
AASHTO M 251-06	Standard Specification for Plain and Laminated Elastomeric Bridge Bearings
ANSI A108/ A118/A136.1-09	American National Standards for the Installation of Ceramic Tile
ANSI/API RP 13B-1-09	Recommended Practice for Field Testing Water-Based Drilling Fluids, fourth edition
ASHRAE 90.1-99	Energy Standard for Buildings Except Low-Rise Residential Buildings
AWS C5.4-93	Recommended Practices for Stud Welding
AWS D1.1/D1.1M-08	Structural Welding Code—Steel
AWS D1.4/D1.4M-98	Structural Welding Code—Reinforcing Steel
CRD-C513-74	Specifications for Rubber Waterstops
CRD-C572-74	Specifications for Polyvinylchloride Waterstop
NAVY MIL-C-882E-89	Cloth, Duck, Cotton or Cotton-Polyester Blend, Synthetic Rubber, Impregnated, and Laminated, Oil Resistant

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

ACI SP-15	Field Reference Manual: Specifications for Structural Concrete (ACI 301M-10) with Selected ACI and ASTM References
CRSI MSP-2-01	Manual of Standard Practice, 28th edition

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 301M-05) with Selected ACI and ASTM References

1.4—Standards-producing organizations

Names, abbreviations, and addresses of organizations issuing documents referenced in this Specification:

American National Standards Institute (ANSI)
1819 L Street, NW, 6th floor
Washington, DC 20036
www.ansi.org

American Association of State Highway & Transportation Officials (AASHTO)
444 North Capitol Street NW, Suite 249
Washington, DC 20001
www.transportation.org

American Concrete Institute (ACI)
38800 Country Club Drive
Farmington Hills, MI 48331
www.concrete.org

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428
www.astm.org

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE
Atlanta, GA 30329
www.ashrae.org

American Welding Society (AWS)
550 N.W. LeJeune Road
Miami, FL 33126
www.aws.org

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

U.S. Army Corps of Engineers (COE)
Engineering Research & Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180
www.usace.army.mil

Naval Facilities Engineering Command (NAFAC)
Engineering Service Center
1100 23rd Street
Port Hueneme, CA 93043
www.navy.mil

1.5—Submittals

1.5.1 *General*—Contractor shall provide to Architect/Engineer submittals required by this Specification in accordance with Contract Documents.

1.5.2 *Contractor's quality control*—When required, submit a quality control plan showing means and methods to control the purchase, use, and placement of materials. Provide information related to quality control in accordance with 1.6.2.

1.6—Quality assurance and quality control

1.6.1 *General*—Concrete materials and operations may be tested and inspected by 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 Architect/Engineer for final acceptance.

1.6.1.1 *Testing agencies*—Agencies that test concrete materials for quality assurance shall meet the requirements of ASTM C1077. Testing agencies that test or inspect placement of reinforcing steel shall meet the requirements of ASTM E329. Testing agencies shall be accepted by Architect/Engineer before performing Work.

1.6.1.2 *Field technicians*—Field tests of concrete required in 1.6.2 and 1.6.3.2 shall be made by an ACI Concrete Field Testing Technician Grade I or equivalent. Equivalent certification programs shall include acceptable requirements for written and performance examinations.

1.6.2 *Responsibilities of Contractor*

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

1.6.2.2 *Duties and responsibilities*—Unless otherwise specified in Contract Documents, Contractor assumes the duties and responsibilities given in 1.6.2.2.a through 1.6.2.2.g.

1.6.2.2.a Qualify proposed materials and establish mixture proportions with concrete supplier.

1.6.2.2.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.

1.6.2.2.c Advise Owner's testing agency at least 24 hours in advance of operations to allow for scheduling of quality assurance tests, review of project requirements, and for assignment of personnel.

1.6.2.2.d Provide space and source of electrical power on the project site for facilities to be used for initial curing of concrete test specimens as required by ASTM C31/C31M, for the sole use of Owner's quality assurance testing agency.

1.6.2.2.e Submit test data on materials used for concrete and mixture proportions.

1.6.2.2.f Submit concrete supplier's quality control program.

1.6.2.2.g When specified or permitted to use accelerated strength testing in accordance with ASTM C684, submit correlation data on the standard-cured 28-day compressive strength based on at least 15 sets of test data in accordance with 1.6.3.2.f with concrete made with the same materials encompassing a range of at least the required average strength f'_{cr}, plus or minus 7 MPa. Submit statistical procedure to estimate standard-cured 28-day compressive strength from measured accelerated strengths.

1.6.2.3 *Tests required of Contractor's testing agency*—Unless otherwise specified in Contract Documents, provide the necessary testing services given in 1.6.2.3.a and 1.6.2.3.b.

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

1.6.2.3.b Other testing services needed or required by Contractor to fulfill quality control plan.

1.6.3 *Responsibilities of Owner's testing agency*

1.6.3.1 Unless otherwise specified in Contract Documents, the Owner's testing agency will provide the necessary services given in 1.6.3.1.a through 1.6.3.1.c.

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

1.6.3.1.b The Owner's testing agency and its representatives are not authorized to revoke, alter, relax, enlarge, or release requirements of Contract Documents, nor to accept or reject any portion of Work.

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

1.6.3.2 *Testing services*—When required by Owner or Architect/Engineer, Owner's testing agency may perform testing services given in 1.6.3.2.a through 1.6.3.2g at no cost to Contractor.

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

1.6.3.2.b Review and test to verify Contractor's test results on proposed concrete mixture.

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

1.6.3.2.d For each concrete mixture on the project placed in any one day, obtain samples of fresh concrete in accordance with ASTM C172. Truckloads or batches of concrete will be sampled on a random basis. Unless otherwise specified, at least one composite sample will be obtained for each 110 m^3 of concrete or 460 m^2 of surface area of slabs or walls, or fractions thereof. When the total quantity of a given concrete mixture is less than 38 m^3, the strength tests may be waived by Architect/Engineer.

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

1.6.3.2.e Owner's testing agency will conduct concrete strength tests during construction by making and curing test specimens in accordance with ASTM C31/C31M and testing them according to ASTM C39/C39M. Unless otherwise specified, concrete strengths for acceptance shall be the average of at least two 150 by 300 mm or at least three 100 by 200 mm cylinders tested at 28 days.

1.6.3.2.f When accelerated testing of concrete is specified or permitted, specimens will be made and cured in accordance with ASTM C684. Companion specimens for standard-cured strength tests at 28 days may be required for every other accelerated strength test to maintain and update the correlation between accelerated and standard-cured 28-day strength tests.

1.6.3.2.g For concrete that may be exposed to deicing salts, Contract Documents may require air content tests at more frequent intervals than given in 1.6.3.2.d.

1.6.3.3 *Additional testing and inspection services*—When required, Owner's testing agency will perform the following testing and inspection services to verify conformance with Contract Documents.

- Inspect the concrete batching, mixing, and delivery operations;
- Inspect forms, foundation preparation, reinforcement, embedded items, reinforcement placement, and concrete placing, finishing, and curing operations;
- Sample concrete at point of placement and other locations as directed by Architect/Engineer and perform required tests;
- Review the manufacturer's report for each shipment of cement, reinforcement, 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 Architect/Engineer.

Provide Owner's testing agency requested documentation and access to perform such testing and inspection activities.

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

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

1.6.4 *Tests on hardened concrete in place*

1.6.4.1 *General*—When needed, Owner's testing agency will perform tests on hardened concrete. Testing shall be at Contractor's expense when this Specification requires such tests to verify strength of the concrete in the structure because strength test specimens prepared and tested in accordance with Contract Documents fail to meet acceptance criteria. Owner will pay costs if tests are at the Owner's request and not required by this Specification.

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

1.6.4.3 *Core tests*

1.6.4.3.a If concrete strength is in doubt or when required by Contract Documents, cores will be obtained, moisture conditioned, prepared, and tested in accordance with ASTM C42/C42M, unless otherwise specified.

Cores will be tested no earlier than 48 hours after drilling or last wetting and no later than 7 days after the cores were drilled from the structure, unless otherwise specified.

1.6.4.3.b At least three representative cores will be taken from each area of in-place concrete that is considered potentially deficient. Architect/Engineer determines the location of cores to limit damage to the strength of the structure. If, before testing, cores show evidence of having been damaged subsequent to or during removal from the structure, replacement cores will be taken.

1.6.4.3.c Contractor shall fill core holes with no-slump concrete or mortar of strength equal to or greater than the original concrete. Unless otherwise specified, provide moist curing for at least 3 days.

1.6.5 *Evaluation of concrete strength tests*

1.6.5.1 *Standard molded and cured strength specimens*—Test results from standard molded and cured test cylinders will be evaluated separately for each specified concrete mixture. Evaluation is valid only if tests have been conducted in accordance with procedures specified. For evaluation, each specified mixture shall be represented by at least five strength tests. When strength test results do not meet the requirements of 1.6.6.1, take steps to increase the average of subsequent strength test results. Submit documentation of actions to increase strength test results.

1.6.5.2 *Core tests*—Core test results will be evaluated by Architect/Engineer and are valid only if tests are conducted in accordance with specified procedures. Do not use core tests in place of standard-cured specimens specified in 1.6.5.1 for initial acceptance testing of concrete.

1.6.5.3 *In-place strength tests*—Test results will be evaluated by Architect/Engineer and are valid only if tests are conducted using properly calibrated equipment in accordance with recognized standard procedures and an acceptable correlation between test results and concrete compressive strength is established and submitted.

1.6.6 *Acceptance of concrete strength*

1.6.6.1 *Standard molded and cured strength specimens*—The strength of concrete is satisfactory provided that the criteria of 1.6.6.1.a and 1.6.6.1.b are met.

1.6.6.1.a Every average of three consecutive strength tests equals or exceeds the specified compressive strength f'_c.

1.6.6.1.b No strength test result falls below f'_c by more than 3.5 MPa when f'_c is 35 MPa or less, or by more than $0.10f'_c$ when f'_c is more than 35 MPa. These criteria also apply to accelerated strength testing unless another basis for acceptance is specified in Contract Documents.

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

1.6.6.3 *In-place tests*—In-place tests shall not be used as the sole basis for accepting or rejecting concrete, but may be used, when specified, to evaluate concrete where strength test results of standard molded and cured cylinders fail to meet the criteria in 1.6.6.1.b.

1.6.7 *Field acceptance of concrete*

1.6.7.1 *Air content*—If the measured air content at delivery is greater than the upper limit of 4.2.2.7.b, a check test of air content will be performed immediately on a new sample from delivery unit. If the check test fails, the concrete has failed to meet the requirements of this Specification. If the measured air content is less than the lower limits of 4.2.2.7.b, adjustments will be permitted in accordance with ASTM C94/C94M, unless otherwise specified. If the check test of the adjusted mixture fails, the concrete has failed to meet the requirements of this Specification.

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

1.6.7.3 *Temperature*—If the measured concrete temperature at delivery is not within the limits of 4.2.2.6, or as otherwise specified, a check test will be performed immediately at a new location in the sample. If the check test fails, the concrete is considered to have failed to meet the requirements of this Specification.

1.7—Acceptance of structure

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

1.7.1.1 Concrete work that fails to meet one or more requirements of 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 Contract Documents and cannot be brought into compliance is subject to rejection.

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

1.7.1.4 Submit 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 be responsible to bring concrete work into compliance with requirements of Contract Documents.

1.7.2 *Dimensional tolerances*

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

1.7.2.2 Formed surfaces resulting in concrete members with dimensions smaller than permitted by the tolerances of ACI 117M may be considered deficient in strength and subject to the provisions of 1.7.4.

1.7.2.3 Formed surfaces resulting in concrete members with dimensions larger than permitted by ACI 117M are subject to rejection. Remove excess materials when required by Architect/Engineer.

1.7.2.4 Inaccurately formed concrete surfaces that exceed ACI 117M tolerances are subject to rejection.

1.7.2.5 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.

1.7.2.6 Concrete members placed against formwork surfaces exceeding the limitations of 2.2.2.4 are subject to rejection.

1.7.3 *Appearance*

1.7.3.1 Concrete surfaces 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 may be considered deficient and concrete work is subject to rejection 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 1.6.6.1.b.

1.7.4.1.b Reinforcement 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 Insufficient 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 structure strength is considered potentially deficient, the actions given in 1.7.4.2.a through 1.7.4.2.e may be required by 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 Load tests, which may be required if core testing is inconclusive or impractical or if structural analysis does not confirm the safety of the structure.

1.7.4.2.d Strengthening with additional construction or replacement for concrete work shown deficient by structural analysis or by results of a load test.

1.7.4.2.e Submittal of documentation for repair work proposed to bring strength-deficient concrete work into compliance with Contract Documents.

1.7.5 *Durability*

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

1.7.5.1.a Strength failing to comply with 1.6.6.1.b.

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, 4.2.1.4, and Contract Documents.

1.7.5.1.c Concrete not conforming to the air-entrainment requirements in Contract Documents or the air content limits of Table 4.2.2.7.b.1.

1.7.5.1.d Curing not in accordance with Contract Documents.

1.7.5.1.e Insufficient protection of concrete surfaces from detrimental environmental conditions as required by 5.3.6.5.

1.7.5.1.f Internal early-age concrete temperatures or temperature gradients greater than permitted by Sections 8 and 13 or by Contract Documents.

1.7.5.1.g Concrete exceeding the maximum allowable chloride-ion content requirements in Contract Documents.

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

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

1.7.5.2.b Obtain concrete samples 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 concrete's resistance to weathering, chemical attack, abrasion, or other deterioration, and to protect reinforcement and metallic embedments from corrosion.

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

1.7.5.2.e Document repair work to bring concrete work into compliance with Contract Documents and submit documentation 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 loads that the structural member is capable of supporting safely without damage. If construction loads are expected to exceed the safe load capacity of the member, provide supplemental support.

1.8.2 *Protection from mechanical injury*—During the curing period, protect concrete from damage by mechanical disturbances, including load-induced stresses, shock, and vibration. Protect concrete surfaces from damage by construction traffic, equipment, materials, running water, rain, 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 required dimensions.

2.1.2 *Submittals*

2.1.2.1 Unless otherwise specified, submit data required in 2.1.2.1.a through 2.1.2.1.e.

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

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

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

2.1.2.1.d *Reshoring and backshoring procedure*—Before using reshoring or backshoring that is required or permitted, submit procedure, including drawings signed and sealed by a licensed design engineer. Include on shop drawings formwork removal procedure and magnitude of construction loads permitted during reshoring or backshoring.

2.1.2.1.e Submit 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 Contract Documents.

2.1.2.2.a Submit shop drawings for formwork signed and sealed by a licensed design engineer as required by jurisdiction where Work will be done.

2.1.2.2.b Submit design calculations for formwork, shoring, reshoring and backshoring, signed and sealed by a licensed design engineer as required by jurisdiction where Work will be done.

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

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

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

2.2—Products

2.2.1 *Materials*

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

2.2.1.2 *Formwork accessories*—Use commercially manufactured and engineered formwork accessories, including ties and hangers. Where indicated in Contract Documents, use form ties in walls with integral water barrier plates or other acceptable positive water barriers. Unless otherwise specified or permitted for ferrous ties, the breakback distance of ties for Surface Finish-2.0 or Surface Finish-3.0 shall be at least 20 mm.

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

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

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

2.2.1.6 *Chamfer materials*—Unless otherwise specified or permitted, use lumber materials 20 mm x 20 mm.

2.2.2 *Performance and design requirements*

2.2.2.1 Contractor is responsible for design and engineering of formwork. When required by Contract Documents, design calculations for formwork and formwork drawings shall be signed and sealed by a licensed design engineer as required by state or jurisdiction where Work will be done.

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

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

2.2.2.4 Unless otherwise specified, maximum deflection of facing materials reflected on concrete surfaces exposed to view shall be 1/240 of span between structural members of formwork. For architectural concrete, refer to 6.2.2.1.a.

2.2.2.5 *Construction, expansion, and contraction joints*

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

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

2.2.2.5.b Provide keyways where indicated in Contract Documents. Unless otherwise specified, longitudinal keyways indicated in Contract Documents shall be a minimum of 40 mm deep in joints in walls and between walls and slabs or footings.

2.2.2.5.c Provide construction, expansion, and contraction joints where indicated in Contract Documents. Submit for acceptance details and locations of construction, expansion, and contraction joints differing from those indicated in Contract Documents.

2.2.2.5.d Design formwork to accommodate waterstop materials. Locate waterstop in construction joints where indicated in Contract Documents. Use waterstop with a maximum practical length to create minimum number of splices.

2.2.2.6 Provide form-facing materials to produce specified appearance and texture.

2.2.2.7 Design temporary openings where needed at base of vertical formwork to facilitate cleaning and inspection at construction joint and along form.

2.2.3 *Fabrication and manufacture*

2.2.3.1 Fabricate formwork joint tight to control loss of mortar from concrete.

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

2.2.3.3 Use manufactured form ties designed to be removed so that ends or end fasteners can be removed without damage to concrete. Unless otherwise specified or permitted for ferrous ties, the breakback distance of ties for Surface Finish-2.0 or Surface Finish-3.0 shall be at least 20 mm.

2.3—Execution

2.3.1 *Construction and erection of formwork*

2.3.1.1 Formwork shall be tight to control loss of mortar from concrete.

2.3.1.2 Unless otherwise specified, place 20 mm minimum chamfer strips in corners of formwork to produce beveled edges on permanently exposed surfaces. Unless otherwise specified, do not bevel reentrant corners or edges of formed joints of concrete.

2.3.1.3 Inspect formwork and remove deleterious material immediately before concrete is placed.

2.3.1.4 At construction joints exposed to view, lap form-facing materials over the concrete or previous placement. Ensure formwork is placed against hardened concrete so offsets at construction joints attain specified tolerances and minimize loss of mortar.

2.3.1.5 Unless otherwise specified, construct formwork so concrete surfaces conform to tolerances in ACI 117M. Unless otherwise specified, class of surface for offset between adjacent pieces of formwork facing material shall be Class B for surfaces permanently exposed to view and Class D for surfaces that will be permanently concealed, provided that concrete cover and cross section are within tolerance.

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

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

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

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

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

2.3.1.11 Provide runways for moving equipment and support runways directly on formwork or structural member without resting on reinforcement.

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

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

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

2.3.1.15 Cover formwork surfaces with an acceptable material that prevents bond with concrete. Field-applied formwork release agent or factory-applied liner may be used. If a formwork release agent is used, apply to formwork surfaces in accordance with manufacturer's recommendations before placing reinforcement. Do not allow formwork release agent to puddle on forms. Do not allow formwork release agent to contact reinforcement or hardened concrete against which fresh concrete is to be placed.

2.3.1.16 Erect form-facing materials to produce specified appearance and texture. Replace used form-facing materials that will impair specified appearance and texture of concrete surfaces.

2.3.1.17 Install formwork to accommodate waterstop materials. Locate waterstops in joints where indicated in Contract Documents. Use waterstop with a maximum practicable length. Splice waterstops in accordance with manufacturer's written instructions. Install factory-manufactured premolded mitered corners.

2.3.2 *Removal of formwork*

2.3.2.1 When vertical 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 treatments 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 vertical formwork for columns, walls, and sides of beams. Perform needed repair and treatment required on vertical surfaces that day and follow immediately with specified curing.

2.3.2.5 Unless otherwise specified or permitted, leave formwork and shoring in place to support construction loads and weight of concrete in beams, slabs, and other structural members until in-place strength of concrete determined in accordance with 2.3.4 is at least f'_c. Unless otherwise specified, when shores and other supports are arranged to allow removal of form-facing material without allowing structural slab or member to deflect, form-facing material and its horizontal supporting members may be removed at an earlier age.

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

2.3.3 *Reshoring and backshoring*

2.3.3.1 Submittals for reshoring and backshoring operations shall comply with 2.1.2.1.d 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 loads permitted by Architect/Engineer for concrete compressive strength at time of reshoring and backshoring.

2.3.3.3 Place reshores or backshores in sequence with stripping operations.

2.3.3.4 Tighten reshores or backshores to carry required loads without overstressing concrete members. Leave reshores or backshores in place until tests required by 2.3.4

indicate that concrete compressive strength has attained minimum value specified in 2.3.2.5.

2.3.3.5 For floors supporting shores under newly placed concrete, either leave original supporting shores in place, or install reshores or backshores. Shoring system and supporting slabs shall resist 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 weight of newly placed concrete, forms, and construction live loads such that design loads of floors supporting 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, reshoring, or backshoring is based on concrete reaching a specified compressive strength, concrete is presumed to have reached this strength when test cylinders, field cured the same as the concrete they represent, have reached compressive strength specified. Mold cylinders in accordance with ASTM C31/C31M, and cure them under same conditions for moisture and temperature as used for the concrete they represent. Test cylinders in accordance with ASTM C39/C39M.

2.3.4.2 Alternatively, when specified or permitted, use one or more of the methods listed in 2.3.4.2.a 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 results of in-place test with compressive strength of laboratory-cured molded cylinders or drilled cores. Submit correlation data on proposed alternative method for determining strength to Architect/Engineer.

2.3.4.2.a Tests of cast-in-place cylinders in accordance with ASTM C873/C873M. This is limited to slabs with concrete depths from 125 to 300 mm.

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

2.3.4.2.c Pullout strength in accordance with ASTM C900.

2.3.4.2.d Maturity method in accordance with ASTM C1074.

2.3.5 *Field quality control*

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

2.3.5.2 Before concrete is placed, inspect formwork for conformance to Contract Documents and then schedule Owner's quality assurance inspection, if specified.

SECTION 3—REINFORCEMENT AND REINFORCEMENT SUPPORTS

3.1—General

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

3.1.1 *Submittals*

3.1.1.1 Unless otherwise specified, submit data and drawings specified in 3.1.1.1.a through 3.1.1.1.g before fabrication and execution.

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 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 indicated in Contract Documents.

3.1.1.1.e *Column dowels*—Submit request to place column dowels without using templates.

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

3.1.1.1.g *Certification*—Submit copy of current Concrete Reinforcing Steel Institute (CRSI) Plant Certification.

3.1.1.2 Unless otherwise specified, submit the data specified in 3.1.1.2.a and 3.1.1.2.b before fabrication and execution.

3.1.1.2.a *Welding*—Submit description of reinforcing bar weld locations, welding procedure specifications, and AWS 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 if not described in 3.3.2.4.

3.1.1.3 Unless otherwise specified, submit data specified in 3.1.1.3.a and 3.1.1.3.b before fabrication and execution when alternatives are proposed.

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

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

3.1.2 *Material storage and handling*

3.1.2.1 Prevent bending and protect reinforcement surfaces from contact with soil, oil, or other materials that decrease bond to concrete.

3.1.2.2 When handling coated reinforcement, use equipment with 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 coating.

3.2—Products

3.2.1 *Materials*

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

- ASTM A615/A615M;
- ASTM A706/A706M;
- ASTM A970/A970M;
- ASTM A996/A996M, rail-steel bars shall be Type R; or
- ASTM A1035/A1035M.

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

3.2.1.2.a Zinc-coated (galvanized) reinforcing bars shall conform to ASTM A767/A767M. Coating damage incurred during shipment, handling, and placing of zinc-coated (galvanized) reinforcing bars shall be repaired in accordance with ASTM A780. The maximum damaged areas shall not exceed 2% of surface area in each 300 mm of each bar or the bar shall not be used. The 2% limit on maximum allowed damaged coating area shall include previously repaired areas damaged before shipment as required by ASTM A767/A767M.

3.2.1.2.b Epoxy-coated reinforcing bars shall conform to ASTM A775/A775M or ASTM A934/A934M as specified in Contract Documents.

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

Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated reinforcing bars shall be repaired. Repair damaged coating areas with patching material conforming to ASTM A775/A775M or ASTM A934/A934M as applicable and in accordance with material manufacturer's written recommendations. The maximum damaged coating area shall not exceed 2% of surface area in each 300 mm of each bar or bar shall not be used. The 2% limit on maximum damaged coating area shall include repaired areas damaged before shipment as required by ASTM A775/A775M or A934/A934M as applicable. Fading of coating color will not be cause for rejection of epoxy-coated reinforcing bars.

3.2.1.3 *Stainless steel reinforcing bars*—Stainless steel reinforcing bars shall conform to ASTM A955/A955M.

3.2.1.4 *Bar mats*—When specified, use bar mats conforming to ASTM A184/A184M. When welding bars, comply with requirements in 3.2.2.2. When coated bar mats are required, repair damaged coating in accordance with 3.2.2.2.b.

3.2.1.5 *Headed reinforcing bars*—Unless otherwise specified, headed reinforcing bars shall conform to ASTM A979/A970M.

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

3.2.1.6.a Plain wire shall conform to ASTM A82/A82M.

3.2.1.6.b Deformed wire size MD25 and larger shall conform to ASTM A496/A496M.

3.2.1.6.c Epoxy-coated wire shall conform to ASTM A884/A884M. Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated wires shall be repaired. Repair damaged coating areas with patching material in accordance with material manufacturer's written recommendations. The maximum damaged area shall not exceed 2% of surface area in each 300 mm of each wire or the wire shall not be used.

The 2% limit on maximum damaged coating area shall include repaired areas damaged before shipment as required by ASTM A884/A884M.

3.2.1.6.d Stainless steel wire shall conform to ASTM A1022/A1022M.

3.2.1.6.e For wire with f_y exceeding 420 MPa, f_y shall correspond to a strain of 0.35%.

3.2.1.7 *Welded wire reinforcement*—Use welded wire reinforcement specified in Contract Documents and conforming to one of the specifications given in 3.2.1.7.a through 3.2.1.7.e.

3.2.1.7.a Plain welded wire reinforcement shall conform to ASTM A185/A185M, with welded intersections spaced no greater than 300 mm apart in direction of principal reinforcement.

3.2.1.7.b Deformed welded wire reinforcement shall conform to ASTM A497/A497M, with welded intersections spaced no greater than 400 mm apart in direction of principal reinforcement.

3.2.1.7.c *Epoxy-coated welded wire reinforcement*—Epoxy-coated welded wire reinforcement shall conform to ASTM A884/884M. Coating damage incurred during shipment, storage, handling, and placing of epoxy-coated welded wire reinforcement shall be repaired in accordance with ASTM A884/A884M. Repair damaged coating areas with patching material in accordance with material manufacturer's written recommendations. The maximum damaged area shall not exceed 2% of surface area in each 300 mm of each wire or welded wire reinforcement shall not be used. The 2% limit on maximum damaged coating area shall include repaired areas damaged before shipment as required by ASTM A884/A884M.

3.2.1.7.d Stainless steel welded wire reinforcement shall conform to ASTM A1022/A1022M.

3.2.1.7.e For welded wire reinforcement with f_y exceeding 420 MPa, f_y shall correspond to a strain of 0.35%.

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

3.2.1.9 *Steel fiber reinforcement*—When required, steel fiber reinforcement shall be deformed and conform to ASTM A820/A820M. Length-diameter ratio of fibers shall be between 50 and 100.

3.2.1.10 *Reinforcement supports*—Provide reinforcement support types indicated within structure as required by Contract Documents. Unless otherwise permitted, reinforcement supports shall be of a type indicated in 3.2.1.10.a through 3.2.1.10.d as specified. Reinforcement supports shall secure and support the reinforcement within specified tolerances.

3.2.1.10.a Wire-reinforcement supports.

3.2.1.10.b Coated wire-reinforcement supports including epoxy, polymer, and galvanized coatings.

3.2.1.10.c Precast concrete reinforcement supports.

3.2.1.10.d All-plastic reinforcement supports.

3.2.1.11 *Coated wire-reinforcement supports*

3.2.1.11.a When specified, use wire-reinforcement supports coated with epoxy or another polymer a distance at least 50 mm from point of contact with epoxy-coated reinforcement.

3.2.1.11.b When specified, use galvanized wire-reinforcement supports or wire-reinforcement supports coated with epoxy or another polymer.

3.2.1.12 *Precast concrete reinforcement support*—When permitted, use precast concrete supports that have a surface area of not less than 2500 mm^2 and have a compressive strength equal to or greater than specified compressive strength of concrete being placed.

3.2.2 *Fabrication*

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

3.2.2.2 *Welding*

3.2.2.2.a When welding of reinforcing bars is specified or permitted, comply with requirements of AWS D1.4/D1.4M. 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 reinforcing bars, repair coating damage in accordance with requirements in 3.2.1.2.a or 3.2.1.2.b, respectively. Coat welds and mechanical splice devices used to splice reinforcing bars with 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 minimum nominal dimensions, nominal weight, and minimum average height of deformations of a hand-wire-brushed test specimen are not less than applicable ASTM specification requirements.

3.3.2 *Placing*

3.3.2.1 *Tolerances*—Place, support, and fasten reinforcement as indicated in Contract Documents. Do not exceed tolerances specified in ACI 117M before concrete is placed.

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

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

3.3.2.4 *Reinforcement supports*—Unless permitted otherwise, use reinforcement supports indicated 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 above 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 epoxy or another polymer, or made of plastic to support zinc-coated (galvanized) reinforcement.

3.3.2.4.d Reinforcement supports 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 plastic. 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 epoxy or another polymer.

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

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

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 50 mm of concrete edge. Lap splice edges and ends of welded wire reinforcement sheets as indicated in Contract Documents. Unless otherwise specified or permitted, do not extend welded wire reinforcement through control joints. Place, support, and secure welded wire reinforcement to maintain positioning in slab during concrete placement. Do not place welded wire reinforcement on grade and subsequently raise it into position during placement of concrete.

3.3.2.6 *Column dowels*—Unless otherwise permitted, furnish and use templates for placement of column dowels.

3.3.2.7 *Splices*—Unless otherwise permitted, make splices as indicated in Contract Documents. Mechanical splices for reinforcing bars not indicated in Contract Documents shall not be used unless accepted by Architect/Engineer. Remove coating on reinforcing bar in area of mechanical splice if required by splice manufacturer. After installing mechanical splices on zinc-coated (galvanized) or epoxy-coated reinforcing bars, 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 same material used to repair coating damage.

3.3.2.8 *Field bending or straightening*—When permitted, bend or straighten reinforcing bars partially embedded in concrete in accordance with procedures 3.3.2.8.a through 3.3.2.8.c. Reinforcing bar sizes No. 10 through 16 may be bent cold the first time, provided reinforcing bar temperature is above 0°C. For other bar sizes, preheat reinforcing bars before bending.

3.3.2.8.a *Preheating*—Apply heat by methods that do not harm reinforcing bar material or cause damage to concrete. Preheat length of reinforcing bar equal to at least five bar diameters in each direction from center of bend but do not extend preheating below concrete surface. Do not allow temperature of reinforcing bar at concrete interface to exceed 250°C. Preheat temperature of reinforcing bar shall be between 600 and 650°C. Maintain preheat temperature until bending or straightening is complete.

Unless otherwise permitted, measure preheat temperature by temperature measurement crayons or contact pyrometer.

Table 3.3.2.3—Concrete cover for reinforcement

		Concrete cover, mm
Cast-in-place concrete (nonprestressed)		
a.	**Concrete cast against and permanently in contact with ground**	75
b.	**Concrete in contact with ground or weather:**	
	No. 19 through No. 57 bars	50
	No. 16 bar, MW200 or MD200 wire, and smaller	40
c.	**Concrete not exposed to weather or in contact with ground:**	
	Slabs, walls, joists:	
	No. 43 and No. 57 bars	40
	No. 36 bar and smaller	20
	Beams, columns:	
	Primary reinforcement, ties, stirrups, spirals	40
	Shells, folded plate members:	
	No. 19 bar and larger	20
	No. 16 bar, MW200 or MD200 wire, and smaller	13
Cast-in-place concrete (prestressed) Concrete cover for prestressed and nonprestressed reinforcement, ducts, and end fittings.		
d.	**Concrete cast against and permanently in contact with ground**	75
e.	**Concrete in contact with ground or weather:**	
	Wall panels, slabs, joists	25
	Other members	40
f.	**Concrete not exposed to weather or in contact with ground:**	
	Slabs, walls, joists	20
	Beams, columns:	
	Primary reinforcement	40
	Ties, stirrups, spirals	25
	Shells, folded plate members:	
	No. 16 bar, MW200 or MD200 wire, and smaller	10
	Other reinforcement	Nominal diameter of reinforcement but not less than 20
Precast concrete (manufactured under plant control conditions) Concrete cover for prestressed and nonprestressed reinforcement, ducts, and end fittings.		
g.	**Concrete in contact with ground or weather:**	
	Wall panels:	
	No. 43 and No. 57 bars, prestressing tendons larger than 40 mm diameter	40
	No. 36 bar and smaller, prestressing tendons 40 mm diameter and smaller, MW200 and MD200 wire and smaller	20
	Other members:	
	No. 43 and No. 57 bars, prestressing tendons larger than 40 mm diameter	50
	No. 19 through No. 36 bars, prestressing tendons larger than 16 mm diameter through 40 mm diameter	40
	No. 16 bar and smaller, prestressing tendons 16 mm diameter and smaller, MW200 and MD200 wire, and smaller	30
h.	**Concrete not exposed to weather or in contact with ground:**	
	Slabs, walls, joists:	
	No. 43 and No. 57 bars, prestressing tendons larger than 40 mm diameter	30
	Prestressing tendons 40 mm diameter and smaller	20
	No. 36 bar and smaller, MW200 or MD200 wire, and smaller	16
	Beams, columns:	
	Primary reinforcement	Nominal diameter of reinforcement but not less than 16 and need not exceed 40
	Ties, stirrups, spirals	10
	Shells, folded plate members:	
	Prestressing tendons	20
	No. 19 bar and larger	16
	No. 16 bar and smaller, MW200 or MD200 wire, and smaller	10
i.	**Bundled bars**	
	Shall be the larger of: (1) equivalent diameter of bundle but not more than 50 mm; or (2) cover specified in Table 3.3.2.3 for equivalent diameter of bundle.	
j.	**Headed shear stud reinforcement and headed reinforcing bars**	In accordance with Contract Documents

Table 3.3.2.8—Minimum specified diameter of bend

Bar size	Minimum inside bend diameter
No. 10 through 25	Six bar diameters
No. 29, 32, and 36	Eight bar diameters
No. 43 and 57	Ten bar diameters

Do not artificially cool heated reinforcing bars until bar temperature is less than 320°C.

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

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

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

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

3.3.2.10 *Reinforcement through expansion joint*—Do not continue reinforcement or other embedded metal items bonded to concrete through expansion joints, except dowels, where specified, are bonded on only one side of a 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 C150, ASTM C595, ASTM C618, ASTM C845, ASTM C989, ASTM C1157, or ASTM C1240;
- 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' names, manufacturer's technical data sheets, and certificates showing compliance with ASTM C260, ASTM C494/C494M, ASTM C1017/C1017M, or ASTM D98; and
- For water and ice: source of supply.

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

4.1.2.5 *Trial mixture records*—When trial mixture records are used as a basis for confirming conformance with specified requirements, submit data on material and mixture proportions with supporting test results.

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

4.1.2.7 *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.

4.1.2.8 *Calcium chloride*—When Contractor wants to use calcium chloride, submit a request including data demonstrating compliance with 4.2.2.5.

4.1.2.9 *Volumetric batching*—When Contractor wants to produce concrete by the volumetric batching method, submit request along with description of proposed method.

4.1.2.10 *Time of discharge*—When Contractor wants to exceed the maximum time for discharge of concrete permitted by ASTM C94/C94M, 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 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 concrete produced has the specified characteristics in the freshly mixed state and that these characteristics are maintained during transport and delivery.

4.1.4 *Material storage and handling*

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

4.1.4.2 *Aggregates*—Store and handle aggregate in a manner that will avoid segregation and prevents contamination by 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. To ensure uniform distribution of the constituents, provide agitating equipment for admixtures used in the form of suspensions or unstable solutions. Protect liquid admixtures from freezing and from temperature changes that would adversely affect their characteristics.

4.2—Products

4.2.1 *Materials*

4.2.1.1 *Cementitious materials*—Use ASTM C150 Type I or Type II cement. Alternatively, use one or a combination of the cementitious materials given in 4.2.1.1.a through 4.2.1.1.f when specified or permitted or when required to meet the durability criteria of 4.2.2.7.

4.2.1.1.a Portland cement conforming to ASTM C150.

4.2.1.1.b Blended hydraulic cement, excluding Type IS (>70) conforming to ASTM C595. For the sections of the structure that are designated as subject to deicing chemicals, submit certification on the cement composition verifying that the concrete mixture meets the requirements of Table 4.2.2.7.b.2.

4.2.1.1.c Hydraulic cement conforming to ASTM C1157. For sections of the structure that will be subjected to deicing chemicals, submit certification on the cement composition verifying that the concrete mixture meets the requirements of Table 4.2.2.7.b.2.

4.2.1.1.d Pozzolans conforming to ASTM C618. 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 C989.

4.2.1.1.f Silica fume conforming to ASTM C1240.

4.2.1.1.g Use cementitious materials of the same brand and type and from the same manufacturing plant 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*—Unless otherwise specified, aggregates shall conform to ASTM C33. When a single size or combinations of two or more sizes of coarse aggregates are used, the final grading shall conform to the grading requirements of ASTM C33, unless otherwise specified or permitted. Aggregates used in concrete shall be obtained from the same sources and have the same size range as 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 be potable water unless alternative sources of water complying with ASTM C1602/C1602M are specified or permitted.

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

- Air-entraining admixtures—ASTM C260;
- Chemical admixtures—ASTM C494/C494M;
- Chemical admixtures for use in producing flowing concrete—ASTM C1017/C1017M; and
- Calcium chloride—ASTM D98.

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 to 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.

Table 4.2.2.1—Minimum cementitious material content requirements for floors

Nominal maximum size of aggregate, mm	Minimum cementitious material content, kg/m^3
37.5	280
25.0	310
19.0	320
9.5	360

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

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, *w/cm*, durability, and finishability. For concrete used in floors, cementitious material content shall not be less than indicated in Table 4.2.2.1, unless otherwise specified. Where permitted, acceptance of lower cementitious material content will be contingent upon verification that concrete mixtures with 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 2.5 x 2.5 m 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 100 mm. Determine the slump by ASTM C143/C143M. Slump tolerances shall meet the requirements of ACI 117M.

When a Type I or II plasticizing admixture conforming to ASTM C1017/C1017M or a Type F or G high-range water-reducing admixture conforming to ASTM C494/C494M is permitted to increase the slump of concrete, concrete shall have been a proportioned to a slump of 50 to 100 mm before the admixture is added and a maximum slump of 200 mm 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 in accordance with 4.2.2.7.b. Unless otherwise specified, measure air content at point of delivery in accordance with ASTM C173/C173M or ASTM C231.

4.2.2.5 *Admixtures*—When admixtures are specified in Contract Documents for particular parts of the Work, use the types specified. The use of calcium chloride or other admixtures containing chloride ions shall be subject to the limitations in 4.2.2.7. When accepted, add calcium chloride into the concrete mixture in solution form only.

Table 4.2.2.7.a—For Exposure Category S: sulfate exposure

Exposure class	Maximum *w/cm*	Minimum f'_c, MPa	Required cementitious materials*—types			Additional requirements
			ASTM C150	ASTM C595	ASTM C1157	
S0	NA	NA	NA	NA	NA	NA
S1	0.50	28	II†‡	IP(MS), IS(<70)(MS)	MS	NA
S2	0.45	31	V‡	IP(HS), IS(<70)(HS)	HS	No calcium chloride admixtures
S3	0.45	31	V + pozzolan or slag cement§	IP (HS) + pozzolan or slag§ or IS (<70) (HS) + pozzolan or slag§	HS + pozzolan or slag cement§	No calcium chloride admixtures

*Alternative combinations of cementitious materials of those listed in this table shall be permitted when tested for sulfate resistance and meeting the criteria in Table 4.2.2.7.a.1.

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

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

§The amount of the specific source of the pozzolan or slag used shall not be less than the amount determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag used shall not be less than the amount tested in accordance with ASTM C1012 and meeting the requirements of Table 4.2.2.7.a.1.

Table 4.2.2.7.a.1—Requirements for establishing suitability of cementitious materials combinations exposed to water-soluble sulfate

Exposure class	Maximum expansion when tested using ASTM C1012		
	At 6 months	At 12 months	At 18 months
S1	0.10%	NA	NA
S2	0.05%	0.10%*	NA
S3	NA	NA	0.10%

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

4.2.2.6 *Concrete temperature*—When the average of the highest and lowest ambient temperature from midnight to midnight is expected to be less than 4°C for more than three successive days, deliver concrete to meet the following minimum temperatures immediately after placement:

- 13°C for sections less than 300 mm in the least dimension;
- 10°C for sections 300 to 900 mm in the least dimension;
- 7°C for sections 900 mm to 1.8 m in the least dimension; and
- 4°C for sections greater than 1.8 m in the least dimension.

The temperature of concrete as placed shall not exceed these values by more than 11°C. These minimum requirements may be terminated when temperatures above 10°C occur during more than half of any 24-hour duration.

Unless otherwise specified or permitted, the temperature of concrete as delivered shall not exceed 35°C.

4.2.2.7 *Durability*

4.2.2.7.a *Sulfate resistance*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.7.a, based on exposure class for exposure to water-soluble sulfates defined in Contract Documents. Submit documentation verifying compliance with specified requirements.

4.2.2.7.b *Freezing and thawing resistance*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.7.b based on exposure class for freezing and thawing exposure defined in Contract Documents. Submit documentation verifying compliance with specified requirements.

4.2.2.7.c *Low permeability*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.7.c based on exposure class for structural members in contact with water requiring low permeability defined in Contract Documents. Submit documentation verifying compliance with specified requirements.

4.2.2.7.d *Corrosion protection of reinforcement*—Unless otherwise specified, provide concrete meeting the requirements of Table 4.2.2.7.d for conditions requiring corrosion protection of reinforcement defined in Contract Documents. Submit documentation verifying compliance with specified requirements.

Water-soluble chloride ion content contributed from constituents including water, aggregates, cementitious materials, and admixtures shall be determined for the concrete mixture by ASTM C1218/C1218M at age between 28 and 42 days.

4.2.2.8 *Strength and water-cementitious material ratio*—The compressive strength and, when required, water-cementitious material ratio (*w/cm*) of the concrete for each portion of the Work, shall be as specified in Contract Documents.

4.2.2.8.a Unless otherwise specified, strength requirements shall be based on a 28-day compressive strength determined on 150 x 300 mm or 100 x 200 mm cylindrical specimens made and tested in accordance with ASTM C31/C31M and C39/C39M, respectively. A strength test at designated age is the average of at least two 150 x 300 mm cylinders or the average of at least three 100 x 200 mm cylinders made from the same concrete sample.

4.2.2.9 *Steel fiber-reinforced concrete*—When required, provide steel fiber-reinforced concrete in accordance with Contract Documents.

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, and to provide an average compressive strength

Table 4.2.2.7.b—For Exposure Category F: Freezing and thawing exposure

Exposure class	Maximum *w/cm*	Minimum f'_c, MPa	Air content	Additional requirements
F0	NA	NA	NA	
F1	0.45	31	Table 4.2.2.7.b.1	NA
F2	0.45	31	Table 4.2.2.7.b.1	NA
F3	0.45	31	Table 4.2.2.7.b.1	Table 4.2.2.7.b.2

Table 4.2.2.7.b.1—Total air content for concrete exposed to cycles of freezing and thawing

Nominal maximum aggregate size, mm[‡]	Air content, %[*†]	
	Exposure Classes F2 and F3	Exposure Class F1
9.5	7.5	6.0
12.5	7	5.5
19.0	6	5
25.0	6	4.5
37.5	5.5	4.5
50[§]	5	4
75[§]	4.5	3.5

[*]Tolerance on air content as delivered shall be ± 1.5%.

[†]For f'_c > 35 MPa reducing air content by 1.0% is permitted.

[‡]Refer to ASTM C33 for tolerance on oversize for various nominal maximum size designations.

[§]These air contents apply to total mixture. When testing these concretes, however, aggregate particles larger than 37.5 mm are removed by sieving, and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is calculated from value measured on the sieved fraction passing the 37.5 mm sieve in accordance with ASTM C231.

Table 4.2.2.7.b.2—Maximum cementitious materials 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 C618	25
Slag cement conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	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 C150, C595, C845, and C1157 cement. The maximum percentages above shall include:
a) Fly ash or other pozzolans present in C1157 or C595 Type IP blended cement;
b) Slag cement present in C1157 or C595 Type IS blended cement; and
c) Silica fume conforming to ASTM C1240 present in C1157 or C595 Type IP blended cement.

[†]Fly ash or other pozzolans and silica fume shall constitute no more than 25% and 10%, respectively, of the total weight of the cementitious materials.

Table 4.2.2.7.c—For Exposure Category P: In contact with water requiring low-permeability concrete

Exposure class	Maximum *w/cm*	Minimum f'_c, MPa	Additional minimum requirements
P0	NA	NA	NA
P1	0.50	28	NA

Table 4.2.2.7.d—For Exposure Category C: Conditions requiring corrosion protection of reinforcement

Exposure class	Maximum *w/cm*	Minimum f'_c, MPa	Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement
Reinforced concrete			
C0	NA	NA	1.00
C1	NA	NA	0.30
C2	0.40	35	0.15
Prestressed concrete			
C0	NA	NA	0.06
C1	NA	NA	0.06
C2	0.40	35	0.06

adequate to meet acceptance requirements of 1.6.6.1. If the production facility has records of field tests performed within the past 12 months and spanning no less than 60 calendar days for a class of concrete within 7 MPa of that specified for the Work, calculate a sample 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 *Sample standard deviation*

4.2.3.2.a *Field test data*—Field test records used to calculate sample standard deviation shall represent materials, quality-control procedures, and climatic conditions similar to those expected in the Work. Changes in materials and concrete proportions represented by test records shall not have been more 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 compressive-strength tests with the same mixture proportions; or
- Data from two groups of consecutive compressive-strength tests totaling at least 30 compressive-strength tests. Neither of the two groups shall consist of less than 10 tests.

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

- For a single group of consecutive test results:

$$s_s = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{(n-1)}} \quad (4\text{-}1)$$

where

s_s = sample standard deviation;
n = number of test results considered;
$\bar{X}$ = average of n test results considered; and
X_i = individual test result.

- For two groups of consecutive test results:

$$s_s = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1+n_2-2)}} \quad (4\text{-}2)$$

where

s_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 sample 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 sample standard deviation, select the required average compressive strength f'_{cr} from Table 4.2.3.3.b.

4.2.3.4 *Documentation of 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 mixtures in accordance with 4.2.3.4.a or 4.2.3.4.b, respectively.

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 *w/cm* of the corresponding mixture proportions and interpolate between them to establish the required *w/cm*. Establish mixture proportions for f'_{cr} based on the required *w/cm*.

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 for each concrete class with a range of proportions that will produce a range of compressive strengths that will encompass f'_{cr}. For concrete made with more than one type of cementitious material, the concrete supplier must establish the *w/cm* and the relative proportions of the cementitious materials and admixtures, if any, that will produce the required average compressive strength;
- Proportion trial mixtures to produce a slump within 20 mm of the maximum specified, and for air-entrained concrete, an air content within 0.5% of the required air content indicated in Table 4.2.2.7.b.1, or as specified. The temperature of freshly mixed concrete shall be recorded and shall be within 6°C of the intended maximum temperature of the concrete as mixed and delivered;

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

f'_c, MPa	f'_{cr}, MPa	
	Use the larger of:	Equation
35 or less	$f'_{cr} = f'_c + 1.34ks_s$	(4-3)
	$f'_{cr} = f'_c + 2.33ks_s - 3.5$	(4-4)
Over 35	$f'_{cr} = f'_c + 1.34ks_s$	(4-3)
	$f'_{cr} = 0.90f'_c + 2.33ks_s$	(4-5)

Notes: f'_{cr} = required average compressive strength; f'_c = specified concrete strength; k = factor from Table 4.2.3.3.a.1 to adjust standard deviation if total number of tests is less than 30; and s_s = standard deviation calculated in accordance with 4.2.3.2.

Table 4.2.3.3.a.1—*k*-factor for increasing sample standard deviation for number of tests considered

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

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

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

f'_c, MPa	f'_{cr}, MPa
Less than 21	$f'_c + 7$
21 to 35	$f'_c + 8.3$
Over 35	$1.1f'_c + 5$

*When data are note available to establish standard deviation.

- For each trial mixture, make and cure three compressive strength cylinders for each test age in accordance with ASTM C192/C192M. Test for compressive strength in accordance with ASTM C39/C39M at 28 days or at the test age for f'_c designated in the Contract Documents; and
- Establish mixture proportions based on the trial batch data to achieve an average compressive strength in accordance with f'_{cr} as determined in 4.2.3.3 and to not exceed the maximum *w/cm* and other requirements of 4.2.2.7 when applicable.

4.2.3.5 *Field verification of selected mixture proportions*—When required, conduct field verification of the effects of placement methods on concrete mixture characteristics. Using materials and mixture proportions accepted for use in the Work, verify the concrete can be 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 point of placement are acceptable. Make suitable corrections to the placing methods or to the mixture proportions, if needed. Submit adjustments to the mixture proportions to 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 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 1.6.6.1 are met.

4.2.3.6.a When the actual average compressive strength $\overline{X}$ exceeds the revised value of f'_{cr} and requirements of 1.6.6.1 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 1.6.6.1 is not met, take immediate steps to increase average compressive strength of the concrete.

4.2.3.6.c Submit revised mixture proportions for acceptance before placing concrete 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 to ASTM C94/C94M.

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 C685/C685M and 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 C387 and shall satisfy the requirements of this Specification.

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

4.3.2.1 *Slump adjustment*—When concrete slump test results are below the required slump, the slump may be adjusted by adding water up to the amount allowed in the accepted mixture proportions, unless otherwise specified. Addition of water shall be in accordance with ASTM C94/C94M. Do not exceed the specified *w/cm* 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*—Unless otherwise permitted, time for completion of discharge shall comply with ASTM C94/C94M. When discharge is permitted after more than 90 minutes 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 Unless otherwise specified, submit the data specified in 5.1.2.1.a through 5.1.2.1.f.

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

5.1.2.1.b *Temperature measurement*—Submit proposed method for complying with requirements for measuring concrete temperatures.

5.1.2.1.c *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.

5.1.2.1.d *Drawings and data*—Submit shop drawings of placing, handling, and construction methods and data in accordance with Contract Documents.

5.1.2.1.e *Placement notification*—Submit notification of concrete placement at least 24 hours before placement.

5.1.2.1.f *Preplacement requirements*—Submit a request for acceptance of preplacement activities.

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 *Conveying equipment*—Submit description of conveying equipment.

5.1.2.2.b *Repair methods*—When stains, rust, efflorescence, and surface deposits must be removed as described in 5.3.7.6, submit the proposed method of removal.

5.1.2.2.c *Wet-weather protection*—When specified, submit request for acceptance of proposed wet-weather protection activities.

5.1.2.2.d *Hot-weather placement*—When specified, submit request for concrete temperature limit exceeding that specified in 5.3.2.1c, including description of proposed precautions for hot-weather concrete placement.

5.1.2.2.e *Cold-weather placement*—When specified, submit request for acceptance of proposed cold weather protection activities.

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 for use, submit specification and manufacturer's data on the retarder and the proposed method of retarder use.

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 in Contract Documents.

5.1.2.3.b *Two-course slabs*—When a bonding agent other than cement grout is proposed, submit specification and manufacturer's data on 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 or expansion joints*—When contraction or expansion joints other than those indicated in Contract Documents are proposed, submit locations for acceptance.

5.1.2.3.e *Curing 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 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 other than that described in 5.2.1.4 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 *Water for curing*—Unless otherwise specified, water complying with the requirements of ASTM C1602/C1602M is acceptable as curing water.

5.2.1.2 *Curing compounds*—Use curing compounds that conform to ASTM C309 or ASTM C1315.

5.2.1.3 *Waterproof sheet materials*—Use waterproof sheet materials that conform to ASTM C171.

5.2.1.4 *Repair materials*—Unless otherwise specified or permitted, use site-mixed portland-cement repair mortar, consisting of one part cement to two and one-half parts sand by damp loose volume. Unless otherwise permitted, match color to existing concrete when concrete is exposed to view.

5.2.1.5 *Bonding grout*—For bonding grout material, mix 1 part cement and 1-1/2 part sand passing the 2.36 mm (No. 8) sieve. Use sufficient water to achieve the consistency of thick paint.

5.2.1.6 *Scrub coat*—For scrub coat material, mix one part portland cement and one part sand by damp loose volume with water to produce the consistency of thick cream. Use sand meeting the requirements of ASTM C144 or ASTM C404.

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 in Contract Documents, in accordance with 2.2.2.5. Do not impair structure strength 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 against which concrete will be placed, and from reinforcement and embedded items;
- Comply with reinforcement placement requirements specified in Section 3; and
- Position and secure in-place expansion joint materials, anchors, and other embedded items.

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

- Subgrade and base shall be prepared in accordance with the Contract Documents.
- Tolerance for the base material elevation shall be in accordance with ACI 117M.

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 4.2.2.6, make provisions in advance of concrete placement to maintain the concrete temperature as specified in 5.3.2.1.b. Use heating, covering, or other means to maintain required temperature without drying of concrete. Do not use unvented combustion heaters.

5.3.2 *Placement of concrete*

5.3.2.1 *Weather considerations*

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

5.3.2.1.b *Cold weather*—Concrete temperatures at delivery shall meet the requirements of 4.2.2.6. Unless otherwise permitted, do not place concrete in contact with surfaces less than 2°C.

5.3.2.1.c *Hot weather*—Unless otherwise specified or permitted, concrete temperature as placed shall not exceed 35°C. When temperature of reinforcement, embedments, or forms is greater than 50°C, use a fine mist of water to moisten the hot surfaces immediately before placing concrete. Remove standing water before placing concrete.

5.3.2.2 *Conveying*—Rapidly convey concrete from mixer to final deposition by methods that prevent segregation or loss of constituents and ensure the required concrete quality. Use of aluminum pipes or chutes is prohibited.

5.3.2.3 *Conveying equipment*—Use conveying equipment of sufficient capacity to meet the requirements of 5.3.2.4.

5.3.2.3.a Use belt conveyors that are horizontal or at a slope that will not cause excessive segregation or loss of constituents. 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 belt return length.

5.3.2.3.b Use metal or metal-lined chutes having rounded bottoms, and sloped between one vertical sections to two horizontal sections and one vertical to three horizontal sections of chute. Chutes longer than 6 m 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 has sufficient capacity so that:

- Initial setting of previously placed concrete does not occur before subsequent placement;
- Discharge of pumped concrete does not result in segregation; and
- Modification of accepted concrete mixture is not required, unless permitted otherwise.

5.3.2.4 *Depositing*—Within the planned placement, deposit concrete continuously and as near as practicable to the final position. Deposit concrete in one layer or in multiple layers. Do not deposit fresh concrete on concrete that has hardened sufficiently to cause formation of cold joints, unless construction joint requirements of 5.3.2.6 are met.

Do not place concrete that contains foreign material. When temporary spreaders are used in the forms, remove the spreaders as the concrete is placed. Spreaders made of metal or concrete may be left in place if prior acceptance is obtained. Do not place concrete over columns or walls until concrete in columns and walls has reached final set. Do not subject concrete to procedures that will cause segregation. Place concrete for beams, girders, brackets, column capitals, haunches, and drop panels at the same time as the concrete for adjacent 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 minimum disturbance of the concrete surface.

5.3.2.5 *Consolidating*—Unless otherwise specified, consolidate concrete by vibration. Consolidate concrete around reinforcement, embedded items and into corners of forms to eliminate honeycombing or planes of weakness due to air voids and stone pockets. Unless otherwise specified, use the largest and most powerful internal vibrators to consolidate the concrete. Use immersion-type vibrators with nonmetallic heads when consolidating concrete around epoxy-coated reinforcement. Workers shall be experienced in the use of vibrators. Do not use vibrators to move concrete within the forms. Spacing of immersion vibrator insertions shall not exceed 1-1/2 times the vibrator's radius of action in the concrete being consolidated.

5.3.2.6 *Construction joints*—Locate construction joints as indicated in Contract Documents 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, use one of the following methods:

- Use an acceptable bonding agent 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 aggregate particles, or damaged concrete at the surface; and
- 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 form removal, 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 required by Contract Documents is to match a sample panel furnished to Contractor, reproduce a mockup of the sample finish on an area at least 9 m^2 in a location designated by Architect/Engineer. Protect mockup from damage for the duration of the project. Obtain acceptance before proceeding with that finish in the specified locations.

5.3.3.3 *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Produce as-cast formed finishes in accordance with Contract Documents and 5.3.3.3.a through 5.3.3.3.c.

5.3.3.3.a *Surface finish-1.0 (SF-1.0):*

- No formwork facing material is specified;
- Patch voids larger than 40 mm wide or 13 mm deep;
- Remove projections larger than 25 mm;
- Tie holes need not be patched;
- Surface tolerance Class D as specified in ACI 117M; and
- Mockup not required.

5.3.3.3.b *Surface finish-2.0 (SF-2.0):*

- Patch voids larger than 20 mm wide or 13 mm deep;
- Remove projections larger than 6 mm;
- Patch tie holes;
- Surface tolerance Class B as specified in ACI 117M; and
- Unless otherwise specified, provide mockup of concrete surface appearance and texture.

5.3.3.3.c *Surface finish-3.0 (SF-3.0):*

- Patch voids larger than 20 mm wide or 13 mm deep;
- Remove projections larger than 3 mm;
- Patch tie holes;
- Surface tolerance Class A as specified in ACI 117M; and
- Provide mockup of concrete surface appearance and texture.

5.3.3.4 *Rubbed finishes*—Remove forms as early as permitted by 2.3.2 and perform necessary repairs and patching. Produce one of the finishes given in 5.3.3.4.a through 5.3.3.4.c on concrete specified to have SF-2.0.

5.3.3.4.a *Smooth-rubbed finish*—When specified, produce concrete finish no later than the day following formwork removal. Wet the surface and rub it with an abrasive such as carborundum brick until uniform color and texture are produced. When insufficient cement paste can be drawn from the concrete itself by the rubbing process, use a grout made with cementitious materials from the same sources as used for in-place concrete.

5.3.3.4.b *Grout-cleaned rubbed finish*—When specified, begin cleaning operations after contiguous surfaces are completed and accessible. Do not clean surfaces as Work progresses. Wet the surface and, unless otherwise specified, apply grout consisting of 1 part by volume portland cement and 1-1/2 parts of sand meeting the requirements of ASTM C144 or ASTM C404, with sufficient water to produce the

consistency of thick paint. Scrub grout into voids and remove excess grout.

5.3.3.4.c *Cork-floated finish*—When specified, remove ties, burrs, and fins. Wet the surface and, unless otherwise specified, apply stiff grout of one part portland cement and one part sand meeting the requirements of ASTM C144 or ASTM C404, to fill voids. Use sufficient water to produce a stiff consistency. Compress grout into voids. Produce the final finish with cork float, using a swirling motion.

5.3.3.5 *Unspecified as-cast finishes*—Unless otherwise specified, apply the following finishes to a concrete surface:

- SF-1.0 on concrete surfaces not exposed to view; and
- SF-2.0 on concrete surfaces exposed to view.

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

5.3.4 *Finishing unformed surfaces*

5.3.4.1 *Placement*—Use qualified flatwork finishers acceptable to Architect/Engineer. Unless otherwise specified or permitted, a minimum of one finisher or finishing supervisor shall be a certified ACI Flatwork Concrete Finisher/Technician or a certified ACI Flatwork Technician 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 final setting. Produce a finish that meets ACI 117M tolerances for conventional surfaces.

5.3.4.2.b *Float finish*—Place, consolidate, strikeoff, and level concrete; cut high spots and fill 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 bleed water sheen has disappeared and the surface has stiffened sufficiently to permit operation of the specific float apparatus. Unless otherwise specified, produce a finish that will meet tolerance requirements of ACI 117M for a conventional surface. Refloat the slab immediately to a uniform texture.

5.3.4.2.c *Trowel finish*—Float concrete surface, then trowel the surface. Unless otherwise specified, tolerances for concrete floors shall be for a conventional surface in accordance with ACI 117M. Addition of water to surface during finishing is prohibited.

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 when specified in Contract Documents with portland cement in the proportions recommended by the aggregate manufacturer, or use bagged, premixed material where specified in Contract Documents as recommended by the manufacturer. Finishing operations shall not seal the surface before the end of bleeding to minimize potential of delamination or blistering. Float-finish the concrete surface and make initial application of dry material at approximately 2/3 of manufacturer's recommended application rate by a method that ensures even coverage without segregation. After the first application is floated-in, additional bleeding is required before the remaining application. To avoid surface delamination due to the inability to integrate the material into the slab surface, do not apply additional dry material until bleed water appears. Apply the remaining dry-shake material at right angles to the first application and where necessary to provide the specified minimum thickness. Begin final floating and finishing immediately after dry-shake application. After selected material is embedded by the two floatings, complete operation with a broomed, floated, or troweled finish, as specified in 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 bleed water in the base slab disappears and the surface will support a person without appreciable indentation.

When topping placement is to be deferred, prepare the surface to ensure bond between the base slab and topping. Wet-cure the base slab continuously for at least 3 days. Before placing the topping, clean the base slab surface thoroughly of contaminants, loose mortar, or aggregate. Dampen the surface, leaving it free of standing water. Unless otherwise specified or permitted, immediately before placing topping, scrub into the slab surface a coat of bonding grout consisting of equal bulk volumes of cement and sand meeting the requirements of ASTM C144 or ASTM C404 with sufficient 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, consolidate, compact, and float the topping mixture. Check for flatness of surface and complete operation with a floated, troweled, or broom finish as specified in 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 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 Contract Documents. Rate of application shall be not less than 1.2 kg/m^2.

5.3.4.2.i *Exposed-aggregate finish*—Immediately after concrete surface has been leveled to meet the ACI 117M tolerance for a conventional surface and the bleed water 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. Lightly tamp the aggregate to embed it into the surface. Float the surface until the embedded stone is fully coated with mortar and the surface has been finished to meet the ACI 117M tolerance for a conventional surface. After the matrix has hardened sufficiently to prevent dislodgment of coarse aggregate particles, apply the minimum

water necessary to permit exposure, but not dislodgment of coarse aggregate particles, with a fine-bristled brush. When specified or permitted, use a surface retarder sprayed on freshly floated concrete surface to extend the working time for the exposure of aggregate.

5.3.4.2.j *Nonspecified finish*—When the finish type is not specified in Contract Documents, use one of the following 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; and
- Trowel finish—For floors intended as walking surfaces, floors in manufacturing, storage, and warehousing areas, or for floors that will receive 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 117M as specified in 5.3.4.2.a through 5.3.4.2.c. Measure floor finish tolerances within 72 hours after slab finishing and before removing supporting formwork or shoring.

5.3.4.3.b Unless otherwise specified, for floor installations 900 m^2 or less in total project area, measure floor finish tolerances in accordance with the "3-m straightedge method" in ACI 117M. Measure floor finish tolerances within 72 hours after slab finishing and before removing supporting formwork and shoring.

5.3.4.3.c Unless otherwise specified, for floor installations exceeding 900 m^2 in total project area, measure floor finish tolerances in accordance with ASTM E1155 and the F-number system in ACI 117M.

5.3.5 *Sawed joints*—Where saw-cut joints are required or permitted, start cutting as soon as concrete has gained sufficient strength to prevent dislodgment of coarse aggregate particles. Saw a continuous slot to a depth one-fourth the thickness of the slab but not less than 25 mm. Complete sawing within 12 hours after placement. If an alternative method, timing, or depth is proposed for saw cutting, submit detailed procedure plans for acceptance.

5.3.6 *Curing and protection*

5.3.6.1 *Curing*—Unless otherwise specified or permitted, cure concrete in accordance with 5.3.6.2 or 5.3.6.3 for at least 7 days after placement. Unless otherwise specified, cure high-early-strength concrete for at least 3 days after placement. When permitted, and when the duration of curing is to achieve a specified level of in-place strength, moisture retention measures may be terminated when any one of the following conditions has been met, unless otherwise specified:

(a) Tests of at least two 150 x 300 mm or at least three 100 x 200 mm cylinders, that have been field cured in accordance with ASTM C31/C31M, indicate compressive strength of at least 70% of f'_c when tested in accordance with ASTM C39/C39M;

(b) The compressive strength of laboratory-cured cylinders, representative of the in-place concrete, exceeds 85% f'_c, provided the temperature of the in-place concrete has been maintained at 10°C or higher during curing; and

(c) Concrete strength reaches f'_c as determined by accepted in-place 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 after concrete is 1 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 Contract Documents.

5.3.6.2 *Unformed concrete surfaces*—Apply one of the procedures in 5.3.6.4 after 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 *Curing methods*—After placing and finishing, provide or preserve moisture in concrete. Unless otherwise specified, use one or more of the following methods:

(a) Ponding, continuous fogging, or continuous sprinkling;

(b) Application of mats or fabric kept continuously wet;

(c) Continuous application of steam (under 66°C);

(d) Application of sheet materials conforming to ASTM C171;

(e) Application of a curing compound conforming to ASTM C309 or C1315. 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 0.2 L/m^2 for each coat. 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. Do not use curing compound on 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; and

(f) Application of other accepted curing methods.

5.3.6.5 *Protection*—Immediately after placement, protect concrete from premature drying or excessively hot or cold temperatures, and mechanical injury.

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

- 28°C for sections less than 300 mm in the least dimension;
- 22°C for sections from 300 to 900 mm in the least dimension;
- 17°C for sections 900 mm to 1.8 m in the least dimension; and
- 11°C for sections greater than 1.8 m in the least dimension.

Measure concrete temperature using a method acceptable to Architect/Engineer, and record the concrete temperature. When the concrete surface temperature is within 11°C 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 other surface defects, as defined in Contract Documents, immediately after formwork removal, unless otherwise permitted. 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 5.3.7.4 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*—Unless otherwise specified or permitted, outline honeycombed or otherwise defective concrete as defined in Contract Documents with a 13 to 20 mm 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 150 mm around the patch area perimeter. Prepare scrub coat according to 5.2.1.6. Thoroughly brush scrub coat into the surface. When the scrub coat begins to lose water sheen, apply patching mortar prepared in accordance with 5.3.7.4 and thoroughly consolidate mortar into place. Strike off mortar, leaving the patch slightly higher than the surrounding surface to compensate for shrinkage. Leave the patch undisturbed for 1 hour before finishing. Keep the patch damp for 7 days.

5.3.7.4 *Site-mixed portland-cement repair mortar*—Mix repair mortar using the same materials as concrete to be patched with no coarse aggregate. 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 necessary for handling and placing. Mix the repair mortar and manipulate the mortar frequently with a trowel without adding water.

5.3.7.5 *Repair materials other than site-mixed portland-cement mortar*—Use repair materials in accordance with manufacturer's recommendations or as acceptable to Architect/Engineer.

5.3.7.6 *Removal of stains, rust, efflorescence, and surface deposits*—Use acceptable methods to remove stains, rust, efflorescence, and surface deposits considered objectionable by Architect/Engineer.

SECTION 6—ARCHITECTURAL CONCRETE

6.1—General

6.1.1 *Description*

6.1.1.1 *Scope*—This section covers architectural concrete construction 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.

6.1.1.3 *General requirements*—Architectural concrete shall comply with Sections 1 through 5, unless otherwise specified in Contract Documents or this section.

6.1.2 *Submittals*

6.1.2.1 *Drawings and data*—Submit shop drawings of forms for architectural concrete, including formwork for field mockups. 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 data specified in 6.1.2.2.a through 6.1.2.2.e.

6.1.2.2.a *Field mockups*—When required, request location for field mockup.

6.1.2.2.b *Exposed-aggregate finishes*—Submit exposed-aggregate finish samples.

6.1.2.2.c *Form face, form liner, and molds*—Submit technical data and samples.

6.1.2.2.d *Compressible tape*—Submit technical data and samples.

6.1.2.2.e *Form joint caulking*—Submit technical data and samples.

6.1.2.3 *Before review and acceptance of submittals*—Do not begin work under this section until submittals have been accepted and completed field mockups have been reviewed and accepted. Do not construct forms or place concrete until submitted plans for batching, mixing, placing, curing, and proposed method of producing exposed-aggregate finishes have been accepted.

6.1.2.4 *Waste wash-water disposal plan*—When required, submit plan for disposal of waste water resulting from washing concrete surfaces.

6.1.3 *Quality control*

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

6.1.3.2 *Preconstruction conference*—When required, schedule a preconstruction conference to review delivery, installation, and acceptance procedures for architectural concrete.

6.1.3.3 *Architectural Concrete Reference Standard*—When specified in Contract Documents, surface quality and appearance shall match a reference sample or portions of existing structure designated Architectural Concrete Reference Standard by Owner.

6.1.3.4 *Field mockup*

6.1.3.4.a When required, construct field mockups using same procedures, equipment, and materials that will be used for production of cast-in-place architectural concrete. Field mockups shall be used as a sample of acceptable quality of finished product. Construct field mockups at an acceptable location on site. Provide a simulated repair area to determine an acceptable repair procedure. Repair procedure shall be suitable to provide an acceptable color and texture match. Maintain and protect the mockups until final acceptance of architectural concrete.

6.1.3.4.b For walls, include vertical, horizontal, and rustication joints. Demonstrate methods of repair, curing, aggregate exposure, sealers, and coating. Construct mockup to include a minimum of two lifts having heights planned for placement of architectural concrete.

6.1.3.4.c For flatwork, construct minimum 3 m x 3 m mockup for review and acceptance using same materials and procedures detailed for architectural concrete.

6.1.3.5 *Contractor personnel qualifications*—Employ project superintendent and forming and concrete subcontractors having previous experience constructing architectural concrete.

6.1.3.6 *Reports*

6.1.3.6.a Maintain logs of concrete placements. Record date, location, and quantities of concrete placement, air temperature, weather conditions, and material sampling. Maintain file of architectural concrete delivery tickets.

6.1.3.6.b Report and submit proposed changes from procedures and materials used in original field mockup. Upon acceptance of proposed changes, construct another field mockup with new materials and procedures for acceptance before constructing architectural concrete. Construct with new materials to minimize difference with previously placed architectural concrete.

6.1.3.7 *Periodic acceptance*—Failure of completed architectural concrete to receive acceptance during periodic observation requires submittal of a revised method of producing acceptable concrete. Propose revisions to construction method to make Work acceptable before proceeding with additional architectural concrete construction.

6.1.4 *Product delivery, storage, and handling*

6.1.4.1 *Formwork*—Store steel forms horizontally and fully supported. Store plastic-coated forms and liners horizontally and under cover. Clean forms after each use and discard damaged forms.

6.1.4.2 Deliver materials to job site in manufacturer's original containers.

6.1.4.3 Store materials in a clean, dry location. Maintain the storage method and temperature required by manufacturer.

6.2—Products

6.2.1 *Materials*

6.2.1.1 *Cement*—Cement shall conform to Section 4. Use one source, type, and brand of cement for architectural concrete. Ensure sufficient supply of specified special cements for construction of architectural concrete required.

6.2.1.2 *Water*

6.2.1.2.a Unless otherwise specified, concrete mixture water shall be potable, shall conform to ASTM C1602/C1602M, and shall be free of oil or impurities capable of staining concrete surface.

6.2.1.2.b Water for waterblasting and for washdown shall be free of oil or impurities capable of staining concrete surface.

6.2.1.3 *Aggregate*—Aggregate shall comply with requirements of Section 4. Use special aggregate when specified in Contract Documents.

6.2.1.3.a Aggregate for architectural concrete shall be as specified in Contract Documents and shall conform to accepted field mockup. Ensure sufficient supply.

6.2.1.4 *Admixtures*—Do not use calcium chloride in architectural concrete mixture.

6.2.1.5 *Concrete*

6.2.1.5.a Concrete shall match color and finish of Architectural Reference Standard and accepted field mockup.

6.2.1.5.b Use curing methods and materials as specified in Contract Documents and used to produce accepted field mockups.

6.2.1.6 *Reinforcement, reinforcement supports, spacers, and tie wires*

6.2.1.6.a Use noncorrodible, stainless steel, plastic, or plastic-coated wire-reinforcement supports and spacers near exposed surfaces. Do not use plastic-coated products when cement paste will be removed to expose aggregate.

6.2.1.6.b Use plastic-coated tie wire for epoxy-coated reinforcement. Use stainless steel or plastic-coated tie wire for securing other reinforcement.

6.2.1.6.c Do not use galvanized reinforcement or galvanized reinforcement supports for architectural concrete.

6.2.1.7 *Formwork*

6.2.1.7.a Unless otherwise specified, formwork shall have high-density overlaid (HDO) plywood or other nonabsorptive form face.

6.2.1.8 *Form ties*

6.2.1.8.a Provide specified cone diameter for form ties.

6.2.1.8.b Steel washers shall not be used with snap ties for architectural concrete.

6.2.1.9 *Rustications*—When required in Contract Documents, provide location, size, and spacing of rustications and reveal strips. Rustication or reveal strips shall be non-water-absorbent and of sufficient stiffness to maintain alignment during concrete placement. Fabricate metal strips from same metal as metal form face.

6.2.1.10 *Form-release agents*—Use form-release agents accepted on field mockup.

6.2.1.11 *Miscellaneous*

6.2.1.11.a *Compressible tape*—Use compressible tape accepted on field mockup.

6.2.1.11.b *Form sealant*—Sealant for form caulking shall conform to ASTM C920, Type A, Grade NS, or C834.

6.2.1.11.c *Abrasive material*—Where applicable, use abrasive material previously tested and accepted on field mockup for the specified texture. Ensure sufficient supply to complete total amount of surface specified.

6.2.1.11.d *Surface retarders*—Use surface retarders accepted on the field mockup.

6.2.1.11.e *Acid*—Use muriatic or phosphoric acid to expose aggregate in locations shown on Project Drawings.

6.2.2 *Performance and design requirements*

6.2.2.1 *Formwork*

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

6.2.2.1.b Where natural plywood form finish, grout-cleaned finish, smooth-rubbed finish, or other finish is required, concrete surfaces and lines shall comply with ACI 117M Tolerances with a Class A—Class of Surface. Surfaces produced shall require only minor dressing to arrive at true surfaces. Where an as-cast finish is required, construct and install forms so that no dressing will be required in finishing operation to match the accepted field mockup.

6.2.2.1.c Where as-cast surfaces, including natural plywood form finish, are specified, ensure that the panel's

joints conform to Contract Documents. Form face, form liner, and molds shall produce a concrete surface matching accepted field mockup.

6.2.2.1.d Where panels for as-cast surfaces are separated by recessed or emphasized joints, provide, in the structural design of forms, the locations of ties within joints so patches of tie holes will be in the recessed or emphasized joints, unless otherwise specified.

6.2.2.1.e Do not reuse forms with surface wear, tears, or defects that lessen the surface quality. Thoroughly clean and properly coat forms before reuse.

6.2.3 *Proportioning concrete mixtures*—Maintain designated colors and uniformity of color. For a concrete mixture of a specified color, use the same materials and proportions used in accepted field mockup. For architectural concrete with exterior exposure, use air-entrained concrete with a *w/cm* not exceeding 0.45 by weight. Air content shall comply with 4.2.2.4 for architectural concrete with exterior exposure. Proportion concrete for specified compressive strength of 35 MPa when acid wash, mechanical tooling, or waterblast is required.

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 *Placement of reinforcement*—Provide specified concrete cover over reinforcement and coated steel embedments. Use reinforcement supports in sufficient number, size, and location to prevent vertical displacement of reinforcement and gouging of forming materials. Use reinforcement supports or spacers in walls and columns that maintain clear distance between reinforcement and face of concrete. Bend back and keep tie wires from form face. Before placement of concrete, remove tie wire clippings from horizontal surfaces that will be sandblasted or exposed to view or weather.

6.3.3 *Batching, mixing, and transporting*—Deliver concrete in clean equipment that is used exclusively to mix and transport the architectural concrete. Deliver concrete of uniform slump and proportions so the resulting concrete matches the accepted field mockup.

6.3.4 *Conveying and placement*—Schedule arrival of concrete to avoid delays in placement. Support runs or gangways for the concrete transporters, pump lines, wheel barrows, other similar equipment and foot traffic that will not displace reinforcement or interfere with concrete placing operations. Do not move concrete horizontally. Place concrete continuously without exceeding rate of placement used in form design.

6.3.5 *Consolidation*—Do not allow vibrators to contact the formwork of 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.

6.3.6 *Formwork*—Erect forms as indicated in Contract Documents and accepted shop drawings. Provide rustication joints and chamfers as indicated in Contract Documents and accepted shop drawings. Apply impermeable coating to wood rustications or chamfers. Kerf wood strips on the back side. Seal form joints, chamfers, and rustication joints. Provide closure backing materials when indented rustication is used over a ribbed form liner, and seal joint between rustication strip and form with nonabsorbent caulking.

6.3.6.1 *Form surface preparation*

6.3.6.1.a Rub natural wood grain forms or untreated wood forms with cement or lime slurry consistent with the cement to be used for architectural concrete.

6.3.6.1.b Seal form joints and tie holes by taping or with nonabsorbent caulking. Clean taper ties and she bolts and lubricate with nonstaining grease or form release agent before each use. Keep form face clean until concrete is placed.

6.3.7 *Formwork monitoring*—Continuously observe formwork during concrete placement. If deviations from specified elevation, alignment, plumbness, or camber is observed, and the formwork shows undue settlement or distortion, stop placement. Correct the affected formwork and resume placement.

6.3.8 *Formwork removal*—Schedule formwork stripping to maintain surface appearance matching accepted field mockup. Prevent damage to concrete from formwork removal. Do not pry against face of concrete. Use only wooden wedges to separate forms from concrete.

6.3.9 *Repair of tie holes and surface defects*

6.3.9.1 *General*—Repair defects as required to match adjacent surface after architectural surface has been treated. Proceed with repair work after form removal and surface finishing using the materials and methods on accepted field mockup.

6.3.9.2 *Repair area*—Where as-cast finishes are specified, the total area requiring repair shall not exceed 0.2 m^2 in each 100 m^2 of as-cast surface. Repair defects and tie holes to match accepted field mockup.

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

6.3.9.4 *Exposed aggregate*—Any finishing process intended to expose aggregate on the surface shall show aggregate faces in repaired areas. The outer 25 mm of repair shall contain the same aggregates as the surrounding concrete. In exposed aggregate finish, the repairing mixture shall contain the same selected colored aggregates. After repair has reached minimum compressive strength required by 6.3.10.3 for the method of aggregate exposure, expose the aggregates together with the aggregates of adjoining surfaces by the same process of mortar removal.

6.3.9.5 *Curing repairs*—Cure repairs in architectural concrete surfaces for 7 days. Cure in accordance with procedures used on accepted field mockup. Protect repairs from premature drying.

6.3.10 *Finishing*—Finishes shall comply with finishes specified in 6.3.10.1 through 6.3.10.3 or other finishes as indicated in Contract Documents.

6.3.10.1 *Textured finishes*—When specified, 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 that transfer 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 concrete surface.

6.3.10.2 *Aggregate transfer finishes*—When specified, produce aggregate transfer and special finishes that match accepted field mockup.

6.3.10.3 *Exposed-aggregate finishes*—When specified, expose aggregate to match accepted field mockup.

6.3.10.3.a *Aggregate exposed by abrasive blast*—When specified, begin abrasive blasting to expose aggregate when concrete has a compressive strength of at least 14 MPa and after safe removal of the forms and supports. Blast to match mockup. Achieve degree of abrasive blasting as specified in Contract Documents:

- Brush—Dull surface sheen;
- Light—Exposure of fine aggregate;
- Medium—Coarse aggregate exposure; and
- Heavy—Coarse aggregate revealed.

Repair cracks before abrasive blasting. When abrasive grits contain free water for dust abatement, wash abrasive blasting debris off finished wall surface before drying occurs.

6.3.10.3.b *Aggregate exposed by removing retarded surface paste on vertical surfaces*—When specified, use accepted surface retarder. After form removal, remove the retarded outer layer of cement paste by hand brushing, high-pressure water washing, or light sandblasting. Schedule procedures and adjust timing for weather conditions to achieve uniform aggregate exposure. The retarded surface shall not be removed until the concrete has reached a minimum in-place compressive strength of 7 MPa.

6.3.10.3.c *Aggregate exposed by removing retarded surface paste on horizontal surfaces*—When specified, use accepted surface retarder. Spray retarder on fresh cast horizontal surfaces after concrete consolidation, seeding of architectural aggregate when specified, and final finishing. Apply retarder in two perpendicular passes after bleed water evaporates from surface. Remove the chemically-retarded surface cement paste after the mortar retaining the aggregate has set sufficiently to prevent dislodgment of the aggregate.

6.3.10.3.d *Acid wash*—Use acid wash to expose aggregate on horizontal surfaces only. Do not acid wash until concrete has a compressive strength of at least 31 MPa. Wet concrete thoroughly before applying acid. Continue application while brushing or spraying until accepted depth of aggregate reveal is obtained. Flush acid and debris from concrete surface immediately after acid bubbling stops by application of water under pressure. Protect adjacent materials, surfaces, and finishes from acid and waste wash water during application and cleanup. When required, dispose of waste wash water in accordance with submitted plan.

6.3.10.3.e *Mechanical tooling (bush-hammering)*—When specified, do not use mechanical tooling until concrete compressive strength exceeds 31 MPa. Multiple bush-hammers used for tooling shall have equal wear on teeth. Maintain control of concrete chips, dust, and debris in each work area. Limit migration of airborne materials by using tarpaulins, wind-breaks, and similar devices.

6.3.10.3.f *Waterblast*—When specified, defer water-blasting of vertical surfaces until compressive strength exceeds 31 MPa. When required, dispose of water used for blasting in accordance with submitted plan.

6.3.11 *Curing architectural concrete*—Cure architectural concrete in accordance with 5.3.6. Mist concrete surface with water before applying curing compounds, and apply curing compounds at manufacturer's recommended rate. For wet cure methods, water temperature for curing shall be no more than 11°C lower than the concrete surface temperature.

6.3.12 *Final cleanup*—Protect architectural concrete surfaces from damage, staining, or contaminants of subsequent construction. Do not apply additional sealers or coatings unless accepted by Architect/Engineer. Clean concrete surfaces before final submittal for acceptance. Use cleaning materials and processes that do not change color or texture of the completed concrete surfaces, and rinse surfaces thoroughly with clean water after cleaning. Protect adjacent materials during cleaning operations.

6.3.13 *Final acceptance of architectural concrete*—Upon completion of architectural concrete, final acceptance is based upon matching the architectural cast-in-place concrete with the accepted field mockup when viewed at 6 m in daylight. Defective Work, including repair areas not accepted, shall be removed and replaced.

SECTION 7—LIGHTWEIGHT CONCRETE

7.1—General

7.1.1 *Description*—This section covers requirements for lightweight concrete. Those portions of structures to be lightweight concrete will be designated in Contract Documents. Lightweight concrete shall comply with requirements of Sections 1 through 5, unless otherwise specified in this section or in Contract Documents.

7.1.2 *Submittals*—Comply with 4.1.2 of this Specification and the following requirements.

7.1.2.1 *Aggregate moisture condition*—Submit procedures for maintaining aggregate moisture condition in accordance with 7.1.3.

7.1.2.2 *Concrete density*—Submit concrete density test results and correlation for review in accordance with ASTM C567 and 7.2.3.1.

7.1.2.3 *Batching and mixing*—Submit batching and mixing procedures that vary from specified requirements in Section 4.

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

7.1.3 *Aggregate storage and handling*—Maintain lightweight aggregate at a moisture condition before batching that ensures concrete can be placed at required slump. Do not handle aggregate in a manner that causes degradation or segregation.

7.2—Products

7.2.1 *Aggregates*—Fine and coarse lightweight aggregates shall conform to ASTM C330. 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*—Entrain air in lightweight concrete subject to exposure to freezing-and-thawing, severe or moderate weather, or deicer chemicals in accordance with 4.2.2.4.

Unless otherwise specified, air content will be measured at the point of placement. Select concrete mixture proportions for air-entrained concrete to provide specified air content and specified compressive strength f'_c.

7.2.2.2 *Slump*—Unless otherwise specified, provide slump in accordance with 4.2.2.2, at point of placement.

7.2.3 *Mixtures*

7.2.3.1 *Density*—Unless otherwise specified or permitted, proportion lightweight concrete mixtures to meet specified equilibrium density determined by calculated equilibrium method in ASTM C567. Correlate equilibrium density with fresh bulk density of concrete. Use fresh bulk density as basis for acceptance during construction.

7.2.3.2 *Proportioning*—Proportion mixture to attain specified strength in accordance with 4.2.3.

7.2.4 *Batching and mixing*—Batching and mixing shall be in accordance with 4.3.

7.2.4.1 *Batching and mixing alternative methods*—When batching and mixing procedures differ from Section 4, submit recommendations to Architect/Engineer for acceptance.

7.3—Execution

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

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

7.3.3 *Field quality control*

7.3.3.1 *Density*—Acceptance of lightweight concrete in field will be based on fresh bulk density measured in accordance with ASTM C138/C138M. The fresh bulk density required shall correspond to the specified equilibrium density. When the fresh bulk density varies by more than plus or minus 50 kg/m^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 65 kg/m^3 from the required fresh bulk density.

7.3.3.2 *Air content*—Air content of lightweight concrete sample for each strength test will be determined in accordance with ASTM C173/C173M as specified in 7.2.2.1.

SECTION 8—MASS CONCRETE

8.1—General

8.1.1 *Description*—This section covers requirements for mass concrete as designated in Contract Documents.

8.1.2 *General requirements*—Mass concrete shall comply with requirements of Sections 1 through 5, unless otherwise specified in this section or in Contract Documents.

Unless otherwise specified, the following criteria shall apply for mass concrete placements:

- The maximum temperature in concrete after placement shall not exceed 70°C; and
- The maximum temperature difference between center and surface of placement shall not exceed 19°C.

8.1.3 *Submittals*—Comply with 4.1.2 and, unless otherwise specified, submit a thermal control plan for each mass concrete placement. Unless otherwise specified or permitted, thermal control plan shall include following items:

- Concrete mixture proportions;
- Calculated or measured adiabatic temperature rise of concrete;
- Upper limit for concrete temperature at time of placement;
- Description of specific measures and equipment that will be used to ensure maximum temperature in placement will not exceed specified maximum temperature limit;
- Calculated maximum temperature in placement based on expected conditions at time of placement and use of proposed measures to control temperatures;
- Description of specific measures and equipment that will be used to ensure temperature difference will not exceed specified temperature difference limit;
- Calculated maximum temperature difference in placement based on expected conditions at time of placement and use of proposed measures to control temperature differences;
- Description of equipment and procedures that will be used to monitor and log temperatures and temperature differences;
- Drawing showing locations for temperature sensors in placement;
- Description of format and frequency of providing temperature data to Owner's Representative;
- Description of measures to address and reduce excessive temperatures and temperature differences, if they occur;
- Description of curing procedures, including materials and methods, and curing duration; and
- Description of formwork removal procedures to ensure temperature difference at temporarily exposed surface will not exceed temperature difference limit, and how curing will be maintained;

If concrete design mixture is changed, thermal control plan must be updated.

8.2—Products

8.2.1 *Materials*

8.2.1.1 *Cementitious materials*—Cementitious materials shall comply with 4.2.1.1, except as modified in 8.2.1.1.a and 8.2.1.1.b.

8.2.1.1.a Unless otherwise specified or permitted, use hydraulic cement with moderate to low heat of hydration properties or use a portland cement with Class F fly ash or slag cement, or both.

8.2.1.1.b Unless otherwise specified, do not use ASTM C150 Type III cement or ASTM C1157 HE cement.

8.2.1.2 *Admixtures*—Comply with 4.2.1.4 and following requirement.

8.2.1.2.a Unless otherwise permitted, do not use accelerating admixtures.

8.3—Execution

8.3.1 *Curing and protection*

8.3.1.1 *Preservation of moisture*

8.3.1.1a Unless otherwise specified, cure and protect concrete in accordance with 5.3.6 for a minimum of 7 days. If strength criterion in 5.3.6.1(c) is used, strength measurement shall be representative of in-place strength within 50 mm of concrete surface.

8.3.1.1.b Unless otherwise specified or permitted, preserve moisture by maintaining forms in place. For surfaces not in contact with forms, apply one of the procedures specified in 5.3.6.4. Unless otherwise specified, do not use water curing.

8.3.1.2 *Control of concrete temperature*—Unless otherwise specified, control concrete temperature and temperature difference within concrete from time the concrete is placed until time internal temperature has cooled from its maximum so the difference between average daily ambient and internal temperatures at time of protection removal is less than specified temperature difference limit.

8.3.1.2.a *Monitoring concrete temperatures*—Unless otherwise specified, place one temperature sensor at the center of mass of placement and one temperature sensor at a depth 50 mm from center of nearest exterior surface. Place an additional sensor at each location to serve as a backup in the event that other temperature sensor fails. In addition, provide a temperature sensor in a shaded location for monitoring ambient on-site temperature.

Unless otherwise specified, monitor temperatures hourly using electronic sensors capable of measuring temperature from 0°C to 100°C to an accuracy of 1°C. Ensure temperature sensors are operational before placing concrete. Unless otherwise specified, provide data from sensors to Owner on a daily basis, until requirements of 8.3.1.2 are met.

8.3.1.2.b *Excessive temperatures or temperature differences*—Unless otherwise specified or permitted, compare temperatures and temperature differences with maximum limits specified in 8.1.2 every 12 hours. If either exceeds specified limits, take immediate action as described in accepted thermal control plan to remedy situation. Do not place additional mass concrete until cause of excessive temperature or temperature difference has been identified and corrections are accepted.

SECTION 9—POST-TENSIONED CONCRETE

9.1—General

9.1.1 *Description*—This section covers requirements for post-tensioned, structural concrete members as designated in Contract Documents. Unless otherwise specified, post-tensioned concrete shall comply with requirements in Sections 1 through 5.

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.d.

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

- Sizes and heights of tendon supports, including bars and chairs;
- 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;
- Wobble and curvature friction coefficients and anchor set;
- Calculated tendon elongations;
- Details of reinforcement to prevent bursting and spalling;
- Tendon trimming procedures and details of capping procedure; and
- Duct properties including size, material, thickness, support spacing, and, when required, duct stiffness test data.

If specified, shop drawings shall be signed and sealed by a licensed design engineer and reviewed by the Architect/Engineer. When deviations from the post-tensioning forces and profiles indicated in Contract Documents are proposed, shop drawings shall be signed and sealed by a licensed design engineer and reviewed by the Architect/Engineer.

9.1.2.1.b *Calculations*—When specified, submit elongation calculations and tendon group final effective force calculations that account for loss of prestress due to anchorage set, friction, and long-term effects. When specified, calculations shall be signed and sealed by a licensed design engineer.

9.1.2.1.c When Contract Documents delegate structural design of post-tensioned concrete members to Contractor, submit drawings and design criteria used when designing for post-tensioning, signed and sealed by a licensed design engineer. When specified, submit design calculations.

9.1.2.1.d For bonded tendons, provide written certification that grout constituents comply with 9.2.2 and any other requirements of Contract Documents.

Unless otherwise specified, tests to be submitted include the following:

- Cement mill test reports;
- Admixtures test reports;
- Test reports for other constituents used in the grout; and
- For prepackaged grouts, submit the manufacturer's current certified mill test reports for the product.

9.1.2.2 *Optional submittals*—Submit the information specified in 9.1.2.2.a through 9.1.2.2.e when required by 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 9.2.1.3 through 9.2.1.4.

9.1.2.2.c Jack clearances.

9.1.2.2.d *Grouting procedures*—When required, submit written grouting procedures at least 4 weeks before the start of construction.

Develop grouting procedures to ensure the annular space in the ducts will be completely filled by grout. These procedures shall cover the following:

- Type, quantity, and brand of materials used in grouting, including certifications required;
- Type of equipment needed, including capacity in relation to demand and working condition as well as provisions for backup equipment and spare parts;

- Types and locations of inlets and outlets;
- Types and sizes of grout hoses and connections;
- Duct cleaning methods before grouting;
- Mixing and pumping procedures, including means to measure volume of grout pumped;
- Direction of grouting;
- Sequence of use for inlets and outlets;
- Procedures for handling blockages, including duct flushing;
- Procedures for possible regrouting; and
- Names of the persons in charge and other personnel who will perform the grouting operation, including their relevant experience and skill.

9.1.2.2.e When required, submit results of grouting field trial and field mockup tests.

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.d.

9.1.2.3.a Certified mill test reports for a sample taken from the production lot of the prestressing steel used in the Work.

9.1.2.3.b Stressing jack calibration certificate, including gauge pressures and calibration curves, for each set of equipment that will be used in the Work. Certificates shall be submitted prior to stressing.

9.1.2.3.c Stressing records are required for review before trimming tendons that extend past anchorages. Submit the following data:

- Project name;
- Floor number and concrete placement number;
- Tendon identification mark;
- Required elongation;
- Gauge pressure to achieve required stressing force per supplied calibration chart;
- Elongation achieved;
- Gauge pressure;
- Date of stressing operation;
- Name and signature of stressing operator and inspector;
- Serial or identification number of jacking equipment;
- Date of accepted shop drawings used for installation and stressing;
- Weather conditions, including temperature and rainfall; and
- Summary of problems encountered and corrective action taken.

9.1.2.3.d Record grouting operation and provide grouting records to Architect/Engineer within 72 hours of grouting. Information to be noted in the records shall include but not be limited to:

- Date grouted;
- Number of days from stressing to grouting;
- Type of grout mixture and additives;
- Tendon(s) grouted, injection end, and applied grouting pressure;
- Summary of problems encountered and corrective action taken; and
- Record of the volume of the grout pumped into the duct compared with the volume of the duct adjusted for the grout displaced by the prestressing tendon.

9.1.3 *Quality control*

9.1.3.1 *Testing*

9.1.3.1.a *Testing of unbonded tendon components*—Test components of unbonded tendon systems in accordance with the requirements of ACI 423.7.

9.1.3.1.b *Grout quality control testing*—Test grout for density, strength, and fluidity daily in accordance with the following:

- Two wet density tests per day or when there is a visual or apparent change in grout characteristics;
- Minimum of one strength test per day during grouting operations;
- Minimum of two fluidity tests (flow cone). One test at the mixer and one at the duct outlet in accordance with 9.2.2.3.e. Testing shall be repeated every 2 hours of grouting operations. The efflux time shall be within ±5 seconds of the values established during laboratory testing; and
- When grout is intended for an aggressive environment as indicated in Contract Documents, test for bleeding in accordance with 9.2.2.3.b.

9.1.4 *Product delivery, handling, and storage*—Deliver, handle, and store materials in a manner that prevents mechanical damage and corrosion.

9.1.4.1 *Handling*

9.1.4.1.a Identify wedges and anchorages by individual concrete placement area, floor sequence, or both. Use materials only in their identified concrete placement areas. In the event materials intended for one concrete placement area are exchanged into another concrete placement area, notify Architect/Engineer of exchanges for tracking purposes.

9.1.4.1.b Protect tendons, accessories, and equipment from exposure to water and deicing salts. Take care not to damage sheathing or anchorages during handling and storage.

9.1.4.1.c Unload tendons as close as practicable to the designated storage area to avoid excessive handling.

9.1.4.1.d Do not use chains or hooks.

9.1.4.2 *Storage*

9.1.4.2.a Store materials and equipment in a dry area on dunnage. Do not expose materials to water, snow, deicing salts, or other corrosive elements. When storage longer than 1 month is required, protect sheathing and other plastics from exposure to direct sunlight.

9.1.4.2.b Store cement and premixed grout to prevent hydration during storage. Only use cement that has been stored in accordance with manufacturer's requirements for grouting.

9.1.4.2.c Inspect tendons and accessory items before installation.

9.2—Products

9.2.1 *Materials*—For unbonded, single-strand tendons, use materials that conform to the requirements of ACI 423.7. For bonded tendons, use materials that conform to the requirements of 9.2.1.1 through 9.2.1.5.

For unbonded tendons, when specified in Contract Documents and for applications in aggressive environments, the sheathing shall be connected to stressing, intermediate,

and fixed anchorages to provide full encapsulation of the prestressing steel in accordance with ACI 423.7. Submit encapsulation system test data when required.

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

- ASTM A416/A416M;
- ASTM A421/A421M;
- ASTM A722/A722M;
- ASTM A779/A779M; and
- ASTM A882/A882M.

Prestressing steel shall be clean and free of excessive rust, scale, oil, dirt, and pitting. Surface rust shall be removable with a fine steel wool pad or by vigorous rubbing with a cloth. Pits on steel surface shall not exceed 0.05 mm in diameter or length.

9.2.1.2 *Ducts for tendons*

9.2.1.2.a Use duct-forming materials as specified in Contract Documents that do not react with alkalis in the cement, are strong enough to retain their shape and resist damage during construction, and prevent the intrusion of water and cement paste from the surrounding concrete. Duct-forming material left in place shall not directly or indirectly cause electrolytic action or deterioration. For bonded tendons, use corrugated ducts or ducts capable of transmitting forces from the grout to the surrounding concrete.

9.2.1.2.b *Duct wall thickness*—Wall thickness varies with duct diameter, depth, spacing of corrugations, and hardness as follows:

- Sheet metal—Minimum wall thickness shall be 0.45 mm gauge for ducts less than 66 mm diameter and 0.6 mm for ducts greater than 66 mm diameter;
- High-density polyethylene (HDPE)—Minimum wall thickness shall be 2 mm; and
- Polypropylene (PP)—Minimum wall thickness shall be 2 mm.

9.2.1.2.c *Duct diameter*—Unless otherwise specified, nominal internal area of the duct for grouted tendons shall be a minimum of 2-1/4 times the prestressing strand and 2-1/2 times for tendons placed by the pull-through method. When a duct-steel area ratio less than the applicable limits is specified, it shall be proven by tests that proper grouting, corrosion protection, and bond transfer is achievable.

For tendons composed of single prestressing bars, the minimum internal duct diameter shall be at least 6 mm larger than the outside diameter (maximum dimension) of the prestressing bar.

9.2.1.2.d *Grouting inlets and outlets*—Inlets shall be used for injecting grout into the duct; outlets shall allow the escape of air, water, grout, and bleed water. The inside diameter of outlets or inlets shall be no less than 20 mm for multi-strand or multi-bar tendons and 10 mm for single-strand or bar tendons. Inlets and outlets shall be provided with positive shut-offs and designed to withstand the grouting pressure. The length shall extend sufficiently out of the concrete member to allow closing of the outlets. Inlets shall be placed at or near the lowest point of a tendon. Outlets shall be placed at low points and shall be free draining. In addition, inlets and outlets shall be placed:

- At the anchorage area of the tendon;
- At the high points of the duct, when the vertical distance between the highest and lowest point is more than 500 mm;
- At major changes in the duct cross section, such as couplers and anchorages; and
- At other locations specified by Architect/Engineer.

9.2.1.2.e *Duct stiffness*

(1) Duct installed and cast into concrete before prestressing steel installation, shall be capable of withstanding at least 3 m of concrete fluid pressure. When required, test to verify that duct shall not dent more than 3 mm under 0.45 kN concentrated force applied between corrugations. The concentrated force shall be applied by a No. 13 reinforcing bar.

(2) Duct for use with preinstalled prestressing steel, before concreting, shall be capable of withstanding the equivalent of 1.5 m of concrete fluid pressure. Resistance to denting required under 9.2.1.2.e. (1) is not applicable.

(3) Ducts shall have the following longitudinal bending stiffness to ensure wobble-free placement:
   - Duct with more than 50 mm diameter shall, under its own weight, not deflect more than 75 mm when a 6 m duct segment is supported at its ends;
   - Duct of 50 mm or smaller diameter shall, under its own weight, not deflect more than 75 mm when a 3 m duct segment is supported at its ends; and
   - When specified to accommodate bending duct to a small radius, a more flexible duct is permitted.

(4) Plastic duct shall withstand above specified requirements at 38°C, except that the deflection limits of (3) shall be increased by 50%.

9.2.1.3 *Anchorages for bonded tendons*—Anchorages for bonded tendons tested in an unbonded state shall develop 95% of the specified tensile strength of prestressing steel.

9.2.1.4 *Couplers*—Use couplers only where indicated in Contract Documents or as otherwise permitted. Couplers shall develop strength in excess 95% of the specified tensile strength of the prestressing steel. Enclose couplers in housings that permit necessary movements during stressing. For bonded tendons, provide fittings to allow complete grouting of coupler components.

9.2.1.5 *Tape for repair of sheathing*—Tape used shall:

- Be self-adhesive and moisture-proof;
- Be nonreactive with sheathing, coating, or prestressing steel;
- Have ability to conform to sheathing surface;
- Have a minimum width of 50 mm; and
- Have a contrasting color to the tendon sheathing.

9.2.2 *Proportioning grout mixtures*—Unless otherwise specified, use a grout mixture that is thixotropic or nonthixotropic. When the grout type is not specified, submit the grout type that will be used. Proportion grout to achieve a minimum compressive strength in accordance with 9.2.2.3.d, and have a consistency that will facilitate placement. When required, verify the grout consistency in accordance with 9.2.2.3.e.

9.2.2.1 *Cementitious materials*—Unless permitted or specified otherwise, grout shall consist of a mixture of cement and water. When their use is permitted, fly ash and other pozzolans shall conform to ASTM C618 and slag cement shall conform to ASTM C989.

Water content shall be the minimum necessary for placement, and the *w/cm* shall not exceed 0.45 by weight.

9.2.2.2 *Admixtures*—Unless otherwise specified, admixtures shall meet the requirements of 4.2.1.1 and the requirements of 9.2.2.2.a through 9.2.2.2.d.

When permitted, other admixtures may be used, provided acceptable tests or performance records show that the admixtures will have no harmful effects on the tendons, accessories, or grout.

Do not use admixtures containing more than trace (from impurities, not as an intended constituent) amounts of chlorides, fluorides, aluminum, zinc, or nitrates.

9.2.2.2.a *Set-controlling and water-reducing admixtures*—The following admixtures, as defined in ASTM C494/C494M, are permitted:

- Type C—Accelerating admixtures;
- Type D—Water-reducing and retarding admixtures;
- Type E—Water-reducing and accelerating admixtures;
- Type F—Water-reducing, high-range admixtures; and
- Type G—Water-reducing, high-range, and retarding admixtures.

9.2.2.2.b *Admixtures to reduce bleeding*—Admixtures to reduce bleeding in grout shall meet the requirements of 9.2.2.3.b.

9.2.2.2.c *Corrosion inhibitors*—When specified, use corrosion inhibitors to improve the corrosion resistance of the grout.

9.2.2.2.d *Shrinkage-compensating or expanding admixture*—When specified, add an acceptable shrinkage-compensating or expanding admixture to produce a vertical height change no greater than 2% within 3 hours after placement, based on ASTM C940. When shrinkage-compensating or expanding admixtures are to be used, submit ASTM C940 test results if required.

9.2.2.3 *Laboratory testing of grout*—Prepare trial batches of the proposed grout mixture using the same materials and equipment to be used on the job site at least 8 weeks before the scheduled start of production grouting. Unless otherwise specified, conduct a series of tests as detailed in 9.2.2.3.a through 9.2.2.3.f with the trial grout at a laboratory meeting the requirements of ASTM C1077 or as acceptable to Architect/Engineer. Unless otherwise specified, conduct mixing and testing at temperature and humidity conditions expected on site. Use grout materials of the same type, brand, and manufacturing source throughout the duration of grouting unless additional tests are performed with the acceptance of Architect/Engineer. If a change in grout materials is made, submit test results as required.

Submit a report at the conclusion of laboratory trial tests, detailing the types and number of tests performed, test procedures, results, and comparison of results with specified values.

Hold the *w/cm* consistent throughout the series of testing described in this section. Prepackaged grouts shall state a maximum and minimum water-bagged materials ratios on the bag. Perform the testing used for qualification in this section at the maximum and minimum water-bagged materials ratios stated on the bag.

9.2.2.3.a *Chloride ion content*—The constituent materials used shall be such that the water-soluble chloride ion (Cl^-) content of the grout shall not exceed 0.06% Cl^- by weight of cement as tested in accordance with ASTM C1218/C1218M.

9.2.2.3.b *Bleeding*—When specified, perform the following test(s) and submit results.

1) *Wick-induced bleed test*—A modification of the ASTM C940 test as outlined below shall be used. The maximum permissible bleeding shall be 0.0% at 3 hours when run at 21 to 25°C.

   Modified ASTM C940:

   (a) Prepare a 500 mm length of 13 mm diameter, 7-wire strand meeting ASTM A416/A416M. Before cutting, wrap the strand at each end with 50 mm wide duct tape or electrical tape to prevent wire splaying. Degrease the strand with acetone or hexane and wire brush to remove surface dust;

   (b) Condition dry constituents, mixing water, prestressing strand, and test apparatus overnight at 21 to 25°C;

   (c) Mix the conditioned dry constituents with the conditioned water and place 800 mL of the resulting grout into the 1000 mL graduated cylinder. Mark the level of the top of the grout;

   (d) Insert the prepared strand completely into the grout in the graduated cylinder. Center and fasten the strand so it remains parallel to the cylinder's vertical axis. This can be achieved through the use of a space at the top lip of the graduated cylinder. Mark the level of the top of the grout;

   (e) Store the mixed grout at the temperature range listed in (b); and

   (f) Observe the bleed water every 15 minutes for the first hour and then hourly afterward for 3 hours. Measure and record the bleed water using the procedure in ASTM C940. Note if bleed water is absorbed into the specimen.

   Calculate the percent of bleed water (if any) and the resulting expansion (if any) in accordance with ASTM C940, with the bleed water quantity expressed as a percent of the initial grout volume. Note if the bleed water remains above or below the top of the original grout height.

2) *Bleed stability of cementitious post-tensioning tendon grout test*—When specified, conduct test in accordance with ACI 423.9M. When specified, conduct replicate tests in accordance with ACI 423.9M. Unless otherwise specified, bleed shall not exceed the values shown in the Table 9.2.2.3.

9.2.2.3.c *Setting time*—Set time shall be greater than 3 hours and less than 12 hours when tested in accordance with ASTM C953.

9.2.2.3.d *Compressive strength*—Prepare and test grout cube specimens in accordance with ASTM C942. Unless otherwise specified, minimum compressive strength at 7 days shall be 21 MPa and at 28 days shall be 35 MPa.

9.2.2.3.e *Pumpability and fluidity*—For nonthixotropic grouts, perform fluidity tests in accordance with ASTM C939.

For thixotropic grouts, modify ASTM C939 as follows:

- The flow cone shall be filled to the top instead of the standard level;
- The efflux time of grout, when thoroughly mixed, shall be measured as the time to fill a 1 L container, placed directly under the flow cone; and
- For both nonthixotropic and thixotropic grout, let the grout stand for 30 minutes without further agitation and test again, remixing for 30 seconds before final flow measurement.

The efflux time of the grout sample immediately after mixing shall be between 11 and 30 seconds for nonthixotropic grout and between 5 and 30 seconds for thixotropic grout. The efflux time after remixing shall not be more than 30 seconds.

9.2.2.3.f *Wet density test*—Establish a wet density value for the grout using ANSI/API RP 13B-1.

9.2.2.4 *Grout field testing*

9.2.2.4.a *Field trial tests*—When required, conduct field trial batching and testing with the same materials, personnel, and equipment to be used in production grouting.

Conduct field trial tests at least 1 week before initiation of production grouting or as specified in Contract Documents unless field mockup tests are required. Conduct field trial tests at the same time as the field mockup tests if required.

9.2.2.4.b *Field mockup tests*—When required, conduct field mockup tests of grout. Field mockup tests of grout shall verify and demonstrate that the materials, outlets, inlets, mixer, grouting equipment, methods, and procedures are appropriate and will result in complete filling of the duct.

Schedule field mockup tests in advance of production grouting. At least 4 weeks before the scheduled start of field mockup tests, submit a detailed, written field mockup test plan that covers test setup, materials, ducts, inlets, outlets, anchorages, prestressing element, and grouting and dissection procedures. Supervisory personnel and equipment used for the mockup tests shall be the same as those used for production grouting.

9.3—Execution

9.3.1 *Installer certification*—Unless otherwise specified or permitted, installation shall be performed by personnel certified by the Post-Tensioning Institute's training and certification program. For unbonded post-tensioning, personnel shall be certified in accordance with PTI's Level 1 Field Installation program. For bonded post-tensioning, personnel shall be certified in accordance with PTI's Level 1 Bonded PT—Field Installation program. Submit the qualifications of installation personnel.

9.3.2 *Inspection*—Conduct a visual inspection to ensure the requirements of this Specification and Contract Documents are met. Inspection shall be performed by personnel certified in accordance with the PTI's Level 2 Unbonded PT Inspector program or as otherwise specified. Submit documentation of inspector certification.

Inspection shall include, but not be limited to:

- Material cleanliness;
- Location and quantity of materials;
- Tensioning of prestressing tendons; and
- Tendon grouting.

9.3.3 *Bonded tendon installation*

9.3.3.1 Keep tendons and ducts dry. Do not start grouting until the concrete temperature around the tendon is 4°C or higher. Maintain concrete temperature around grouted tendons at 4°C or higher for at least 3 days after grouting.

9.3.3.2 When the tendon extends beyond the member ends, or when tendons are outside the concrete of the post-tensioned concrete member, cover the exposed or specified parts of the tendon with an additional corrosion protection coating. The coating shall be shop-applied or field-applied and shall be plastic, epoxy, or other acceptable material.

9.3.3.3 Keep end anchorages permanently protected from concrete and free of loose rust, grease, oil, and other debris.

9.3.3.4 *Ducts*

9.3.3.4.a Keep ducts, anchorages block-outs, openings, inlets, and outlets clean and free of debris, fuel, oil, other contaminants, and site trash at all times before and after installing the tendons. Use temporary plugs, seals, and covers as needed.

Before placing concrete, repair damaged ducts by removing locally damaged duct and splicing duct or couplers onto the damaged section, or by other means acceptable to Architect/Engineer.

9.3.3.4.b Before grouting, ducts shall be blown with oil-free, compressed air to remove water and debris blockages that may interfere with the injection. Air pressure test the ducts to locate potential grout leaks as specified.

9.3.3.4.c *Duct support spacing*—Duct support spacing (l) shall not exceed the following values:

1) Galvanized metal round duct: $l \leq 1.2$ m;

2) Plastic round duct (no strands installed in duct before placing concrete): $l \leq 600$ mm;

3) Plastic flat duct 25 x 75 mm (strand installed in duct): $l \leq 600$ mm; and

4) Plastic flat duct 25 x 75 mm (no strands installed in duct before placing concrete): $l \leq 300$ mm.

9.3.4 *Grouting*

9.3.4.1 *Personnel qualifications*—Grouting operations shall be performed by personnel trained for and experienced in the tasks required. Grouting shall be performed under the immediate control of a person skilled in grouting. The person

Table 9.2.2.3—Bleed stability values

Vertical rise x, m	Test pressure, kPa	Maximum bleeding, %
$0 \leq x \leq 0.6$	140	4
$2 < x \leq 1.8$	210	2
$6 < x < 30$	350	0

shall provide close observation and control of grouting operations necessary for compliance with specified requirements. This person shall be named and shall furnish proof of experience when required by Architect/Engineer.

9.3.4.2 Grout as soon as practicable after stressing of the prestressing steel in the ducts. Time from installing prestressing steel in the ducts in an unstressed condition to grouting after stressing shall not exceed the periods indicated in Table 9.3.4.2 unless temporary corrosion protection measures are accepted by Architect/Engineer.

9.3.4.3 *Water supply before grouting*—Provide a dependable, high-pressure water supply in case grout has to be flushed from tendons in accordance with 9.3.4.6.

9.3.4.4 *Grout mixing*—Mix 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. Pump grout as soon after mixing as practicable. Continue pumping as long as the grout retains the required consistency. Discard grout when it loses the required consistency for pumping.

9.3.4.5 *Apply grout under positive pressure*—Pressure shall not exceed 1.0 MPa during the grouting operation without written acceptance of Architect/Engineer.

9.3.4.6 The method of injecting grout shall ensure complete filling of the ducts and complete surrounding of the strand or bar with grout.

Inject grout from near the lowest end of tendons in an uphill direction. Use grout within 30 minutes of first addition of water to ensure grout flowability. Maintain a continuous, one-way flow of grout within a grouting stage. Perform grouting of tendon(s) in one operation. Pump grout through the duct so it flows continuously out of the first outlet after the inlet. Continue pumping until no visible slugs of water or air eject from the outlet and the grout consistency flowing out is similar to the injected grout, at which time the outlet shall be closed. Unless otherwise accepted by Architect/Engineer, grout injection rate shall be between 5 m and 15 m of duct per minute.

When one-way grout flow cannot be maintained, or when grouting is interrupted, immediately flush the grout from the duct with water. A water pump shall be available on site for this purpose as part of the standard flushing equipment. Limit flushing pressures to the same as those specified for grouting.

Tendon tails shall be cut within one working day of the acceptance of elongations by Architect/Engineer. In aggressive environments, protect tendon ends with coverings until tendons tails are cut, unless otherwise accepted by Architect/Engineer.

9.3.4.7 Record grouting progress for each duct and submit a written report to Architect/Engineer within 72 hours after grouting. This report shall include:

a) Quantities and types of materials used;

b) Descriptions of problems encountered during grouting and steps taken to resolve them;

c) Maximum pumping pressure at inlet; and

d) Temperature of air, water, cement, prepackaged material, mix grout, and concrete surrounding the duct.

Table 9.3.4.2—Permissible intervals between prestressing steel installation and grouting without the use of corrosion protection for different exposures

Damp atmosphere or over salt water (relative humidity greater than 70%)	7 days
Moderate atmosphere (relative humidity between 40% and 70%)	20 days
Dry atmosphere (relative humidity less than 40%)	40 days

The report shall indicate whether applicable parameters were within allowable limits of the specifications.

9.3.4.8 Fill 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 350 kPa and plug the injection hole.

9.3.4.9 *Measures taken after grouting*—Not less than 24 hours after grouting, the grout level in the outlets and grout caps shall be inspected and topped as necessary with freshly mixed grout.

9.3.5 *Unbonded tendon installation*

9.3.5.1 Support prestressing tendons at intervals not exceeding 1.2 m.

9.3.5.2 Attach tendons to supporting reinforcement supports or reinforcement without damaging sheathing.

9.3.5.3 Keep tendons and components clean and undamaged. In aggressive environments, protect exposed components within one working day after their exposure during installation, unless otherwise accepted by Architect/Engineer.

9.3.5.4 Prevent water from entering the tendons during installation.

9.3.5.5 *Stressing-end anchorage*

9.3.5.5.a Install stressing-end anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall not start closer than 300 mm from the stressing-end anchorage.

9.3.5.5.b Attach stressing-end anchorages to bulkhead forms. Connections shall be sufficiently rigid to avoid accidental loosening. In aggressive environments, attach the anchor to the form edge using fasteners that will not corrode or are protected from corrosion by other means.

9.3.5.5.c Top, bottom, and edge concrete cover for anchorages shall not be less than specified cover to reinforcement. Unless otherwise specified, concrete cover from exterior edge of concrete to wedge cavity area of anchor shall be 40 mm for nonaggressive environments and 50 mm for aggressive environments.

9.3.5.5.d Pocket formers used to provide a void form at stressing-end and intermediate anchorages shall prevent intrusion of concrete or cement slurry into the wedge cavity. At angled slab edges, minimum concrete covers shall be maintained to the anchor edges.

9.3.5.5.e In aggressive environments, cap the wedge cavity and install sleeves and seals connecting sheathing to anchorage to completely seal the area against moisture.

Install cap after coating the tendon end and wedge area with post-tensioning coating material meeting the requirements of ACI 423.7.

9.3.5.5.f Unless otherwise specified, concrete cover for the tendon end from the exterior edge of the concrete shall not be less than 20 mm for nonaggressive environments and 25 mm to the encapsulating device for aggressive environments.

9.3.5.6 *Intermediate anchorages*

9.3.5.6.a Embed intermediate anchorages in the first concrete placed at a construction joint. When required, make the joint watertight.

9.3.5.6.b Install intermediate anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall not start closer than 300 mm from intermediate anchorage.

9.3.5.6.c Top and bottom cover requirements of 9.3.5.5.c shall apply to intermediate anchorages.

9.3.5.6.d In aggressive environments, cap the wedge cavity and install sleeves and seals connecting sheathing to anchorage on both sides of anchorage to completely seal the area against moisture. Coat exposed strand and wedge area with post-tensioning coating material meeting the requirements of ACI 423.7. This protection of the intermediate anchorage shall be within one working day of exposure unless otherwise accepted by Architect/Engineer.

9.3.5.7 *Fixed-end anchorages*

9.3.5.7.a *Wedge-type anchorages*—When using the pull-on method, seat fixed-end wedges with a force between 80 and 85% of the specified tensile strength of the strand. When permitted, other methods shall be substantiated by testing acceptable to Architect/Engineer.

9.3.5.7.b Install fixed-end anchorages perpendicular to tendon axis. The transition curvature in tendon profile shall not start closer than 300 mm from the fixed-end anchorage.

9.3.5.7.c Place fixed-end anchorages in formwork at locations indicated on the shop drawings, and position them securely. Concrete cover requirements of 9.3.5.5.f apply to fixed-end anchorages.

9.3.5.7.d In aggressive environments, cap the wedge cavity and install sleeves and seals connecting sheathing to anchorage to completely seal the area against moisture. Install cap after coating the tendon end and wedge area with the same post-tensioning coating material used over the tendon length and meeting the requirements of ACI 423.7.

9.3.5.8 *Sheathing inspection and repair*

9.3.5.8.a After installing tendons in forms and before concrete placement, inspect sheathing for damage. Repair damaged areas by restoring post-tensioning coating in the damaged area and repairing the sheathing. Sheathing repairs shall be watertight, without air spaces, and acceptable to Architect/Engineer.

9.3.5.8.b Unless otherwise specified, for tendons in nonaggressive environments, small tears up to 75 mm long shall be allowed without repair if the damage is spaced a minimum of 2.4 m apart and the total damaged length is less than 2% of the tendon length. Sheathing damage in excess of that specified in this section shall be repaired as acceptable to Architect/Engineer.

Repair a breach or circumferential split in sheathing. In aggressive environments, repair damages to sheathing.

9.3.5.8.c Tape repair procedures shall be acceptable to Architect/Engineer.

9.3.6 *Tendon tolerances*

9.3.6.1 Bearing surface between anchorage and concrete shall be concentric with the tendon. The bearing plate or anchorage shall be perpendicular to the direction of the tendon at the anchorage.

9.3.6.2 Place tendons and anchorages within the tolerances of ACI 117M 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 25 mm in 4.6 m of tendon length.

9.3.6.3 Unless otherwise specified, deviations in single-strand unbonded tendon design profile shall not exceed:

- 6 mm for member depth less than or equal to 200 mm;
- 10 mm for member depth greater than 200 mm and less than or equal to 600 mm; and
- 13 mm for member depth greater than 600 mm.

9.3.6.4 Lateral deviations in unbonded tendon location are permitted if necessary to avoid openings, ducts, chases, and inserts. Such deviations shall have a radius of curvature no less than 480 strand diameters. When radius of curvature less than 480 strand diameters is necessary, provide additional hairpin reinforcement that is accepted by Architect/Engineer.

9.3.7 *Concrete placement*

9.3.7.1 *General*—Prevent water from entering the tendons during concrete placing and curing.

9.3.7.2 *Placement*—The position of post-tensioning tendons and non-prestressed reinforcement shall remain within tolerance during concrete placement. Ensure that formwork is sufficiently rigid and tendon supports maintain the tendon profile during concrete placement.

9.3.7.3 *Protection of tendons*—Support pump lines, chutes, and other concrete placing equipment above tendons.

9.3.8 *Tensioning*

9.3.8.1 *Sequence*—Stress tendons in sequence specified in Contract Documents, at a concrete strength no less than the specified compressive strength and at the construction stages indicated in Contract Documents.

9.3.8.2 *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.

9.3.8.3 *Tendon stressing*—Tension the prestressed reinforcement using hydraulic jacks equipped with a pressure gauge calibrated to the jack within an accuracy of plus or minus 2%. The pressure gauge shall have graduations no larger than 0.7 MPa.

Apply the jacking force required to produce the prestressing force indicated in Contract Documents or shop drawings and measure the tendon elongation. Verify the prestressing force is sufficient by comparing measured elongations to calculated elongations.

If the measured elongations differ from calculated elongations by more than 7%, determine the cause and correct the discrepancy. Base elongation calculations on average values of load-elongation curves for the prestressed reinforcement used.

For each tendon, keep and submit a record of the elongations and the gauge pressure readings. Do not remove stressing tails, grout ducts, or grout stressing pockets until Architect/Engineer has reviewed the elongation records.

9.3.8.3.a Ensure that formwork does not restrain elastic shortening, deflection, or camber resulting from application of the prestressing force.

9.3.8.3.b Do not remove formwork supports until sufficient prestressing force is applied to support the dead load, formwork, and anticipated construction loads.

9.3.8.4 *Loss of prestressing force*—The total loss of prestressing force in any post-tensioned structural concrete member due to unreplaced broken tendons shall not exceed 2% of the total prestressing force, unless otherwise accepted by Architect/Engineer.

9.3.8.5 *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 9.3.9.1.

9.3.9 *Tendon finishing*

9.3.9.1 *Trimming tendons*—As soon as practicable after acceptance of stressing records according to 9.1.2.3.b, cut excess strand length. Strand length protruding beyond wedges after cutting shall not be less than 13 mm. Concrete cover for the tendon tail shall comply with 9.3.5.5.f. For unbonded tendons, if cutting is delayed more than 10 days after stressing, provide protection to prevent moisture from reaching the anchorages.

For unbonded tendons in aggressive environments, cut tendon tails within one working day after acceptance of stressing records by Architect/Engineer. Strand length protruding from the wedges after cutting shall be as specified by the encapsulation system manufacturer. Encapsulation caps shall be installed within 8 hours after cutting off tendon tails. If cutting or capping is delayed, provide protection to prevent moisture from reaching the anchorages.

Unless otherwise specified, remove surplus lengths of tendons beyond anchorages by plasma cutting, rapid oxyacetylene burning, abrasive wheel, or hydraulic shears. Oxyacetylene flame cutting the tendon shall not be directed toward the wedges.

9.3.9.2 Before grouting stressing pockets, seal stressing-end anchorages in unbonded construction and intended for use in aggressive environments with a watertight cap filled with post-tensioning coating.

9.3.9.3 Fill stressing pockets with nonmetallic, nonshrink grout within 1 day after tendon cutting. Grout used for pocket filling shall not contain chlorides or other chemicals known to be deleterious to prestressing steel and shall be nonreactive with prestressing steel, anchorage materials, and concrete.

SECTION 10—SHRINKAGE-COMPENSATING CONCRETE

10.1—General

10.1.1 *Description*—This section covers shrinkage-compensating concrete using expansive cement conforming to ASTM C845, Type E-1 (K).

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 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 Architect/Engineer's acceptance of required submittals before placing concrete.

10.1.3.2 Submit expansion test results measured in accordance with ASTM C878 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, cement shall comply with ASTM C845, Type E-1 (K).

10.2.1.1.b When permitted, silica fume shall comply with ASTM C1240.

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 Unless specified otherwise or permitted, do not use accelerating admixtures or admixtures containing calcium chloride.

10.2.1.2.b Unless otherwise permitted, do not change type, brand, or dosage rate of admixtures without evaluating the revised concrete mixture for expansion as measured in accordance with ASTM C878.

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 335 kg/m^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 C878.

10.2.2.3 *Slump*—Unless otherwise specified or permitted, the slump shall not exceed 150 mm 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 minutes, unless otherwise specified. After this time period, add water as necessary to produce the maximum specified slump within 20 mm. The concrete shall then be mixed for an additional 2 minutes.

10.2.3.2 For the proposed concrete mixture, provide laboratory test results for three expansion bars cast and tested

in accordance with ASTM C878. 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 C878. Submit test results along with the revised mixture proportions.

10.2.4 *Reinforcement*—Use deformed reinforcing bars or deformed welded wire reinforcement meeting the requirements of 3.2 as specified in Contract Documents.

10.2.5 *Isolation-joint filler materials*—Unless otherwise specified, use compressible isolation-joint filler material that does not develop a stress greater than 170 kPa at 50% strain when tested in accordance with ASTM D1621 or D3575.

10.3—Execution

10.3.1 *Reinforcement*

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

10.3.1.2 Unless otherwise specified, position reinforcement 50 mm 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 hours.

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

10.3.4 *Curing*—Unless otherwise specified, wet-cure shrinkage-compensating concrete for a minimum of 7 days in accordance with 5.3.6.4.a or 5.3.6.4.b.

SECTION 11—INDUSTRIAL FLOOR SLABS

11.1—General

11.1.1 *Description*—This section applies to ground-supported industrial floor slabs. For concrete slabs-on-ground that are designated as industrial floor slabs, provide materials and construct slabs at locations indicated and in accordance with Contract Documents.

11.1.2 *General requirements*—Concrete for industrial floor slabs shall comply with the requirements of Sections 1 through 5, unless otherwise specified in this section or in Contract Documents.

11.1.2.1 Unless otherwise specified, industrial floor slabs shall be at least 150 mm thick. Unless otherwise specified, industrial floors shall be supported by at least 100 mm of specified graded aggregate base.

11.1.3 *Submittals*

11.1.3.1 Obtain acceptance of required submittals from Architect/Engineer before placing concrete.

11.1.3.2 In addition to the submittal requirements of Sections 2 through 5, provide the following as specified in 11.1.3.2.a through 11.1.3.2.l.

11.1.3.2.a Drying shrinkage test results, if specified, for the proposed concrete mixture determined in accordance with ASTM C157/C157M, except that instead of storage for 28 days in lime-saturated water, specimens are subjected to 7 days of moist curing followed by at least 21 days of air drying. The initial length of specimens used as the basis for length change shall be at 24 hours (±1/2 hour) upon demolding specimens and drying-shrinkage measurements shall begin at the completion of the 7-day moist-curing period.

11.1.3.2.b Manufacturer's data sheet for load-transfer devices at joints if load-transfer devices are required by Contract Documents.

11.1.3.2.c Manufacturer's data sheet for vapor retarding sheet if a vapor retarder is required by Contract Documents.

11.1.3.2.d Manufacturer's data sheet on equipment to install contraction joints if required by Contract Documents.

11.1.3.2.e Manufacturer's data sheet for curing cover, liquid-applied membrane-forming curing compounds, or other curing method.

11.1.3.2.f Plan for providing protection of the concrete due to anticipated ambient conditions during transportation, placement, finishing, and specified curing period.

11.1.3.2.g Manufacturer's data sheet for joint filler.

11.1.3.2.h When specified, manufacturer's data sheet for liquid-applied surface densifiers.

11.1.3.2.i When specified, manufacturer's data sheet for mineral or metallic shake hardeners.

11.1.3.2.j *Joint layout*—Plan for joint layout. Unless otherwise specified or permitted, maximum joint spacing shall be 4.6 m.

11.1.3.2.k *Submit placing sequence*—Plan showing extent of each placement, the placing sequence, and schedule for each placement.

11.1.3.2.l If specified, design of construction joint forms.

11.2—Products

11.2.1 *Materials*—Materials used for industrial slab construction shall conform to Sections 3 and 4, except as modified in this section.

11.2.1.1 *Cementitious materials*—Comply with 4.2.1.1. Unless otherwise specified, ASTM C150 Type III, high-early-strength cement shall not be used.

11.2.1.2 *Aggregates*

11.2.1.2.a Unless otherwise specified or permitted, use aggregates with a nominal maximum size of 40 mm conforming to requirements of 4.2.1.2.

11.2.1.2.b Unless otherwise specified, aggregate used for base course shall conform to ASTM D2940.

11.2.1.3 *Admixtures*

11.2.1.3.a Unless otherwise specified, calcium chloride or admixtures containing chloride from sources other than impurities in admixture ingredients shall not be used.

11.2.1.3.b Air-entraining admixtures are prohibited in concrete mixtures for use in slabs to receive a hard-troweled finish.

11.2.2 *Concrete mixture*—Unless otherwise specified or permitted, proportion concrete mixture to satisfy the following:

- Compressive strength of 24 MPa at 28 days;
- Maximum 150 mm slump;
- Capable of being finished to achieve a densified, hard-troweled finish; and
- Shrinkage when specified in Contract Documents.

11.2.2.1 *Air content*—Concrete for slabs to receive a hard trowel finish shall not contain an air-entraining admixture or have a total air content greater than 3%.

11.2.2.2 *Concrete temperature*—Unless otherwise specified or permitted, the maximum temperature of concrete at discharge shall be 35°C.

11.2.3 *Proportioning*—Comply with Section 4 and 11.2.2.

11.2.4 *Vapor retarder*—Unless otherwise specified, vapor retarder shall conform to ASTM E1745 Class A and shall be at least of 0.25 mm thick.

11.2.5 *Reinforcement*—When specified, use deformed reinforcing bars, tendons, or deformed or plain welded wire reinforcement meeting the requirements of 3.2 at the amounts specified in Contract Documents. Supports shall be used at a spacing to result in reinforcement placement according to Contract Documents.

11.2.6 *Load-transfer devices*—When required, provide load-transfer devices at joints where indicated in Contract Documents. Submit shop drawings of load-transfer devices.

11.2.7 *Joint filler materials*—Unless otherwise specified, use a two-component semi-rigid joint filler material. The filler shall have 100% solids, a minimum Shore A hardness of 80 when measured in accordance with ASTM D2240, and an elongation below 25% when measured in accordance with ASTM D638.

11.2.8 *Isolation-joint filler materials*—Unless otherwise specified, use joint material that prevents bond and allows for horizontal and vertical movement of the slab relative to fixed abutting elements and penetrations.

11.2.9 *Curing materials*

11.2.9.1 *Curing compounds*—Membrane-forming curing compounds shall meet ASTM C309 or ASTM C1315 and be applied at the manufacturer's stipulated coverage rates. Do not use silicate-based liquid surface densifiers as curing compounds.

11.2.9.2 *Curing coverings*—Moisture-retaining covers shall meet requirements of ASTM C171. The material shall be nonstaining and absorbent.

11.2.10 *Liquid surface densifier*—When required, use an acceptable liquid surface densifier in areas where specified.

11.2.11 *Mineral or metallic shake surface hardeners*—When required, use an acceptable dry-shake hardener in areas specified.

11.3—Execution

11.3.1 *Preparation*—Proof-roll the prepared base in accordance with Contract Documents. Unless otherwise specified, compact aggregate base course to at least 95% of maximum density as tested in accordance with ASTM D698. Comply with the requirements of 5.3.1 and verify that base surface elevation is within a tolerance of +0 mm and –13 mm of the planned elevation. This base surface elevation tolerance shall be maintained during placement of concrete. When required, install acceptable vapor retarder in accordance with ASTM E1643 directly beneath slab in areas indicated in Contract Documents. Lap seams at least 150 mm and tape continuously.

11.3.2 *Measuring, batching, and mixing*—Comply with 4.3.1.

11.3.3 *Delivery*—Comply with 4.3.2.

11.3.4 *Concrete placement*—Comply with 5.3.2.

11.3.5 *Finishing slab surface*—Unless otherwise specified, comply with 5.3.4. Finishing shall be properly timed to project conditions. Water shall not be added to slab surface during finishing. When required, apply surface hardener according to manufacturer's recommendation.

11.3.5.1 *Surface tolerances*—Unless alternative tolerances are specified, the minimum overall surface flatness shall be F_F35, levelness shall be F_L25, and local area minimums shall be F_F23, F_L17 as determined by ASTM E1155.

11.3.5.2 Surface tolerances shall be measured within 72 hours after finishing and test results submitted to Architect/Engineer within 3 days of measurement.

11.3.6 *Joints*

11.3.6.1 *Isolation joints*—Install isolation joint material to full depth of slab.

11.3.6.2 *Construction joints*—Comply with 2.2.2.5, 2.3.1.4, and 5.3.2.6. Construction joints shall be perpendicular to slab surface and shall not be constructed using keyways. Unless otherwise specified, doweled construction joints designed to allow widening shall be saw cut to 1/4 slab thickness or 50 mm, whichever is smaller. Align saw cut with joint.

11.3.6.3 *Contraction joints*—Unless otherwise specified, comply with 5.3.5. If early-entry dry-cutting saws are used, replace skid plate and blade as recommended by the equipment manufacturer to minimize saw-cut raveling. Install saw cuts perpendicular to slab surface. Protect joints from damage due to construction activities.

11.3.6.4 *Load-transfer devices*—Comply with 5.3.2.5. Install devices at slab mid-depth and secure to avoid displacement. Consolidate concrete around load-transfer devices by vibration immediately adjacent to the devices to ensure complete contact between concrete and steel.

11.3.7 *Curing and protection*—Unless otherwise specified, comply with 5.3.6 and provide curing for at least 7 days. Apply curing covers as soon as practicable without marring the finished surface. Place moisture-retaining coverings in a manner to prevent surface discoloration or marking. Keep the slab continuously wet after final finishing is completed and during the curing period. Temperature of applied water shall not be more than 11°C colder than the concrete surface temperature. Unless otherwise permitted, do not apply curing compound where subsequent finish flooring or surface densifier is to be installed. When permitted, curing compounds, including those considered self-dissipating, shall be mechanically removed by method acceptable to finish flooring or surface densifier manufacturer.

11.3.8 *Liquid surface densifier*—When required, apply liquid surface densifier in accordance with manufacturer's recommendations. After the curing period, remove curing compound, allow the slab surface to air-dry for 7 days, and apply product.

11.3.9 *Joint filling*—Unless otherwise specified, fill joints with a semi-rigid joint filler. Install joint filler full-depth of saw cuts. Unless otherwise specified, do not install joint filler earlier than recommended by filler manufacturer. Joints shall be slightly overfilled and shaved flush. During the project warranty period, monitor joint filler for separation (either adhesively or cohesively) and monitor concrete deterioration along the joint as joints widen. Unless otherwise specified, separations shall be corrected within the project warranty period.

SECTION 12—TILT-UP CONSTRUCTION

12.1—General

12.1.1 *Description*—This section covers requirements for preparation, casting, and erection of tilt-up concrete panels as designated in Contract Documents.

12.1.2 *Coordination*—Coordinate Work specified in this section with work of other trades, and other concrete work on the Project.

12.1.3 *General requirements*—Tilt-up concrete shall comply with requirements in Sections 1 through 5, unless otherwise specified in this section and indicated in Contract Documents.

12.1.4 *Submittals*—Unless otherwise specified, submit items specified in 12.1.4.1 through 12.1.4.8.

12.1.4.1 *Bearing shims*—Data on type of bearing shims.

12.1.4.2 *Coloring agents*—Data on coloring agents.

12.1.4.3 *Bond breaker*—Data on bond breaker.

12.1.4.4 *Drawings*—Tilt-up panel shop drawings, including panel locations, erection, bracing and lifting details. Tilt-up panel shop drawings shall be signed and sealed by a licensed design engineer.

12.1.4.5 *Field mockups*—Field mockups shall be two panels at least 1.2 m x 2.4 m constructed and erected using materials and methods detailed in panel shop drawings. Include edge and reveal procedures, special finishes, color, repair, and aggregate sizes. Maintain field mockups until completion of Work.

12.1.4.6 *Grout*—Panel grout data.

12.1.4.7 *Sandwich insulation system*—Details of the structural connections used to construct insulated concrete sandwich panels.

12.1.4.8 *Defects repair*—Methods and materials for repair of defects.

12.1.5 *Tilt-up contractor qualifications*—Provide documentation of tilt-up contractor's qualifications. Workers shall be proficient in production and erection operations and shall be under direct supervision of an ACI certified Tilt-up Supervisor. The tilt-up concrete erector shall submit documentation of at least 2 years of experience in tilt-up product erection, including projects similar in size and scope.

12.2—Products

12.2.1 *Aggregates*—Unless otherwise specified, aggregates shall conform to the requirements of Section 4.

12.2.1.1 *Facing aggregates*—Provide fine and coarse aggregate for each type of exposed finish from a single source pit or quarry.

12.2.1.2 *Structural aggregates*—Provide fine and coarse aggregate from a single source pit or quarry.

12.2.2 *Bearing shims*—Unless otherwise specified or permitted, use plastic bearing shims. Plastic bearing shims shall be designed to support the applied construction loads.

12.2.3 *Bond breaker*—Bond breaker shall be compatible with the curing material and with coating applied to the interior or exterior concrete panels or floor slab.

12.2.4 *Cast-in anchors and connections*

12.2.4.1 *Lifting inserts*—Provide structural inserts and components to engage the lifting inserts from a single-source manufacturer for lifting tilt-up panels.

12.2.4.2 *Bracing inserts*—Provide structural inserts from a single-source manufacturer for temporary bracing of tilt-up panels.

12.2.5 *Coloring agent*—Coloring agent shall conform to ASTM C979.

12.2.6 *Curing compound*—Liquid-type membrane-forming curing compounds shall comply with ASTM C309, Type I and ID, Class B.

12.2.6.1 Curing compound and bond breaker may be same product, if accepted.

12.2.6.2 Where the curing compound is not the same material as the bond breaker, compatibility shall be determined before application of the curing compound.

12.2.7 *Face mixture*—Minimum thickness of face mixture shall be the largest of 25 mm, 1-1/2 times nominal maximum size of aggregate used, and minimum thickness to provide 20 mm cover over reinforcement.

12.2.8 *Grout*—Portland cement used in grout shall conform to ASTM C150.

12.2.8.1 Nonshrink grout shall be a premixed, packaged, ferrous or nonferrous aggregate, shrink-resistant grout conforming to ASTM C1107/C1107M.

12.2.9 *Sandwich insulation systems*—Unless otherwise specified, structural connections used in construction of insulated concrete sandwich panels shall maintain effective acceptable material R-value of panels as specified in ASHRAE Standard 90.1.

12.3—Execution

12.3.1 *Casting bed*—Cast panels on floor slab or waste slab. Waste slabs, if used, shall be at least 50 mm thick when placed on compacted base or at least 75 mm if compacted base is not used. Compressive strength of casting bed concrete shall be at least 17 MPa at 28 days.

12.3.1.1 Use clean slab and side forms when concrete is placed.

12.3.1.2 Seal form joints between casting bed and side forms.

12.3.1.3 Treat saw cuts, cracks, or joints in casting bed with a filler material that will minimize mirroring of casting surface on tilt-up panel surface.

12.3.1.4 For panels cast in a vertical stack arrangement, the troweled surface shall be considered the casting bed.

12.3.2 *Bond breaker*—Apply bond breaker to casting surface in accordance with manufacturer's recommendations.

12.3.3 *Reveals*—Fasten reveals (rustication) or false joints to prevent movement or floating during concrete placement operations.

12.3.3.1 Reveals shall not deviate from designed location more than 6 mm over 3 m in any plane.

12.3.3.2 Verify correct alignment between adjacent reveals before placement of concrete.

12.3.4 *Panel identification*—Each panel shall have a panel mark that corresponds to identification marks on shop drawings. Mark test cylinders and test beams with the same identification.

12.3.5 *Side forms*—Side forms shall remain in place and be braced until panels achieve compressive strength of 3.5 MPa.

12.3.6 *Placing concrete*—Do not place concrete until side forms and reinforcement placement have been accepted.

12.3.6.1 Cold joints shall not be permitted.

12.3.6.2 Set anchorage devices into concrete before it reaches initial setting as defined by ASTM C403/C403M and consolidate concrete around anchorage devices.

12.3.7 *Finishes*—Concrete finishes shall be in accordance with Contract Documents.

12.3.7.1 Repair panels and casting bed with acceptable concrete repair material.

12.3.7.2 Exposed faces shall match accepted sample or mockup panel.

12.3.8 *Smooth finishes*—Smooth finishes shall be the result of casting on a smooth, hard-troweled surface or achieved by hard trowel.

12.3.9 *Smooth textured finishes*—Smooth textured finishes shall be the result of casting on fluted, sculptured, or textured form liners.

12.3.10 *Treated textured finishes*—Treated textured finishes shall be the combined result of casting on fluted, sculptured, or textured form liners followed by breaking off portions of surface projections.

12.3.10.1 Achieve uniformity of cleavage by alternately striking opposite sides of flute.

12.3.11 *Retarded exposed aggregate finishes*—To achieve retarded exposed aggregate finishes, apply surface retarder to face of casting bed in accordance with manufacturer's recommendations.

12.3.11.1 Expose coarse aggregate by washing and brushing, lightly sandblasting, or waterblasting surface mortar in accordance with surface retarder manufacturer's directions.

12.3.11.2 Unless otherwise specified, expose aggregate to produce 10 mm aggregate exposure.

12.3.12 *Bush-hammered exposed aggregate finish*—Concrete shall achieve specified lifting strength before applying bush-hammered finish.

12.3.13 *Hand-placed aggregate for exposed aggregate finish*—Secure hand-placed, facing aggregate, natural stone, or cobblestone over casting bed with a cement/sand mixture.

12.3.13.1 Roughen exposed surface of slurry for bond with backing concrete. Fill remaining panel thickness with backing concrete.

12.3.13.2 Direct placement of backing concrete to aggregate is not permitted.

12.3.13.3 The backing concrete shall be placed within 3 hours of slurry placement or slurry shall be wet cured.

12.3.13.4 Do not use curing compound between slurry and backing concrete.

12.3.14 *Sandblasted finish*—Unless otherwise specified, sandblast mortar to produce a 3 mm aggregate reveal.

12.3.14.1 When abrasive medium contains water, wash abrasive blasting debris from finished wall surface before drying occurs.

12.3.15 *Veneer faced finish*—Place veneer brick, tile, terra cotta, or natural stone. Place backing concrete over brick, tile, terra cotta, or natural stone placed in the bottom of casting bed.

12.3.15.1 Connect natural stone face material to concrete by mechanical means.

12.3.16 *Curing of panels*—Unless otherwise specified, apply liquid membrane-forming curing compounds in accordance with manufacturer's recommendations.

12.3.16.1 Wet cure methods are acceptable. Initiate wet curing after final finishing without damaging the surface. Wet cure for at least 7 days.

12.3.17 *Handling and erection of panels*—Concrete strength at time of erection shall meet requirements of accepted tilt-up panel shop drawings.

12.3.17.1 Panel-to-panel connections shall be made in accordance with Contract Documents.

12.3.17.2 Panels not attached to building frame at time of erection shall be braced in position until final attachment.

12.3.17.3 Perform welding required to attach panels to building frame and to each other in accordance with AWS D1.4/D1.4M.

12.3.17.4 Repair erection damage to concrete tilt-up panels.

12.3.17.5 Brace concrete panels to control warping and cracking.

12.3.18 *Tolerances*—Tolerances shall conform to ACI 117M.

12.3.19 *Testing for panel erection*

12.3.19.1 When specified, cast and field cure beams in accordance with ASTM C31/C31M. Test beams in accordance with ASTM C78.

12.3.19.2 Cast and field cure cylinders in accordance with ASTM C31/C31M. Test cylinders in accordance with ASTM C39/C39M.

12.3.19.3 For each day concrete is placed, take at least four cylinders and if specified, four beams for each class of concrete, or each 110 m^3 or fraction thereof, not less than once for each 450 m^2 of panel area. Specimens shall be field cured. Mark specimens for proper identification with associated panels.

12.3.19.4 For each set of four cylinders or beams, at least two shall be tested before panel erection. The average results of the two specimens tested shall equal or exceed the strength required for erection. Remaining specimens shall be kept in reserve for additional testing, if required.

SECTION 13—PRECAST STRUCTURAL CONCRETE

13.1 General

13.1.1 *Description*—This section covers requirements for precast structural concrete members.

Precast structural concrete shall comply with the requirements of Sections 1 through 5, unless otherwise specified in this

section. When lightweight precast concrete members are specified, comply with Section 7 in addition to provisions of this section.

13.1.2 *Submittals*

13.1.2.1 Submittals required before execution of the Work are specified in 13.1.2.1.a through 13.1.2.1.h.

13.1.2.1.a *Concrete mixtures*—Unless otherwise specified or permitted, submit mixture proportions and characteristics for each precast concrete mixture in accordance with Section 4.

13.1.2.1.b *Shop drawings*—Submit shop drawings for erection of precast concrete members, including member locations, plan views, elevations, dimensions, handling procedures, and connection details.

If required, submit shop drawings for temporary bracing and shoring including erection sequence and bracing plan. Submit calculations if required, indicating the design for temporary connections, erection bracing, and sequence of completing connections.

If required, submit shop drawings for fabrication in accordance with Contract Documents.

13.1.2.1.c *Welding certificates*—Submit welding procedure specifications and personnel certificates meeting the requirements of 13.1.3.3.

13.1.2.1.d *Structural design submittal*—Submit, if required, structural calculations prepared, signed, and sealed by a licensed design engineer licensed in the jurisdiction the project is located.

Submit shop drawings indicating specified design criteria and design methods unless design calculations are required.

When design calculations are to be submitted, include design calculations for members and their connections to resist handling loads and other loads as required by Contract Documents. Calculations shall indicate design for connections at the member ends and to each adjoining member.

When members are designed using a computer program, calculations shall include documentation of the computer program identifying method of solution, input data, and output for each member. At least one member shall be analyzed and designed in a detailed calculation that allows step-by-step comprehensive review and be submitted with computer data for verification.

13.1.2.1.e *Design modifications*—If design modifications to Contract Documents are proposed, notify Architect/Engineer immediately and submit drawings for acceptance. Submit design calculations when required in accordance with 13.1.2.1.d. Maintain the specified design requirements when altering size of members and alignment.

13.1.2.1.f Submit erector qualifications as required in 13.1.3.1.

13.1.2.1.g Submit fabricator qualifications as required in 13.1.3.2.

13.1.2.1.h *Plant quality control*—Submit certification of precast concrete plants in accordance with the Precast/Prestressed Concrete Institute (PCI) Plant Certification program. Alternatively, submit manufacturing procedures and a quality control and testing program to Architect/Engineer for review and acceptance. Submit evidence of plant certification or documentation of manufacturing procedures and quality control program.

13.1.2.2 Submit the data specified in 13.1.2.2.a when required.

13.1.2.2.a Submit, if required, material test reports from an accredited testing agency or material certificates, signed by manufacturers or suppliers certifying that each of the following items complies with specification requirements:

- Cementitious materials;
- Concrete aggregates;
- Reinforcement and prestressing steel;
- Admixtures;
- Bearing pads;
- Structural-steel shapes and hollow structural sections;
- Insulation; and
- Any other components specified in Contract Documents with applicable standards.

13.1.2.3 *Retention of records*—Unless a longer period is specified, retain quality control records and compliance certificates for each type of precast member for 5 years.

13.1.3 *Quality assurance*

13.1.3.1 *Erector qualifications*—Unless otherwise specified or permitted, precast concrete erector shall be qualified by the PCI Erector Certification Program in the Category as specified in Contract Documents before beginning work at the project site. Submit a current Certificate of Compliance furnished by PCI designating qualification in the Work.

When erector not qualified by PCI is permitted, erector shall have acceptable experience in precast concrete erection on at least three projects comparable in scope to the Work. Erector not qualified by PCI shall retain a PCI Certified Field Auditor to conduct a field audit of a project in the same category as this Project before start of erection. Erectors' Post Audit Declaration shall be submitted.

13.1.3.2 *Fabricator qualifications*—Unless otherwise specified, fabricator shall be certified in accordance with PCI Plant Certification program for the Group and Category as specified in Contract Documents.

Unless otherwise specified, testing and inspection shall be performed by PCI certified personnel. Submit documentation of certification of plant and personnel.

Unless otherwise specified, fabricator shall have at least 5 years of experience in producing precast concrete members similar to those required in the Work.

13.1.3.3 *Welding*—Unless otherwise specified, use qualified welders. Comply with AWS D1.1/D1.1M and AWS D1.4/D1.4M.

13.1.3.4 *Fire resistance*—Provide precast concrete members whose fire resistance meets the requirements of Contract Documents. Unless otherwise specified, submit calculation of fire resistance rating.

13.1.3.5 *Preconstruction conference*—Unless otherwise specified, conduct a preconstruction conference at the project site.

13.1.4 *Product delivery, storage, and handling*

13.1.4.1 Store members to prevent contact with soil, to prevent staining, and to control cracking, distortion, warping, or other physical damage.

13.1.4.2 Place stored units so identification marks are clearly visible and units can be inspected.

13.1.4.3 Deliver precast concrete units in such quantities and at such times to comply with the agreed-upon project schedule and proper setting sequence to ensure continuity of installation.

13.1.4.4 Handle and transport units in a position consistent with their shape and design as indicated on shop drawings.

13.1.4.5 Lift and support units only at designated points indicated on the shop drawings.

13.2—Products

13.2.1 *Performance requirements*

13.2.1.1 *Structural design*—Unless otherwise specified, design each member for required loads, handling, transportation, erection, and other loads as specified in Contract Documents. Shop drawings shall indicate design methods used and shall indicate details for connections at the member ends and to each adjoining member.

13.2.2 *Form materials and accessories*

13.2.2.1 *Forms*—Use forms that are dimensionally stable and nonabsorptive, that will provide continuous precast concrete surfaces within fabrication tolerances. Use forms that are nonreactive with materials in concrete and are suitable for producing specified finishes.

13.2.2.2 *Form-release agent*—Use commercially produced form-release agent that does not bond with, stain, or affect hardening of precast concrete surfaces, and does not impair subsequent surface or joint treatments of precast concrete.

13.2.3 *Prestressing steel*

13.2.3.a *General*—Use materials as specified in Contract Documents and conforming to Section 3. Prestressing steel shall be clean and free of scale, oil, dirt, and pitting. A light coating of rust that can be removed with fine steel wool is permitted.

13.2.3.b *Prestressing strand*:

- ASTM A416/A416M, Grade 1860 MPa uncoated, 7-wire, low-relaxation strand;
- ASTM A886/A886M, Grade 1860 MPa indented, 7-wire, low-relaxation strand (including supplement); and
- ASTM A910/A910M, Grade 1860 MPa uncoated, weldless, 2- and 3-wire, low-relaxation strand.

13.2.3.c *Unbonded post-tensioning tendons*—ASTM A416/A416M Grade 1860 MPa 7-wire, low-relaxation strand with corrosion inhibitor coating conforming to ACI 423.7.

13.2.3.d *Post-tensioning bars*—ASTM A722/A722M, uncoated high-strength steel bar.

13.2.4 *Concrete materials*

13.2.4.1 *General*—Unless otherwise specified, materials shall conform to Section 4 and the following supplemental requirements.

13.2.4.2 *Aggregates*—Where exposed aggregate finishes are specified, provide and stockpile fine and coarse aggregates conforming to ASTM C33, except for gradation, for each type of exposed finish using aggregate(s) from the same source to match the accepted finish sample for the entire Project. When lightweight aggregates are specified, comply with Section 7 except as modified in Contract Documents.

13.2.5 *Steel connection materials*—Provide steel connection materials of the grades, types, and surface finish specified. Weld headed studs and deformed bar anchors used for anchorage according to AWS D1.1/D1.1M and AWS C5.4.

13.2.6 *Bearing pads and other accessories*

13.2.6.1 Unless otherwise specified or permitted, provide one of the bearing pads for precast concrete members in 13.2.6.1.a through 13.2.6.1.e.

13.2.6.1.a *Elastomeric pads*—AASHTO M 251, plain, vulcanized, 100% polychloroprene (neoprene) elastomer, molded to size or cut from a molded sheet, 50 to 70 Shore A Durometer according to ASTM D2240, minimum tensile strength 16 MPa in accordance with ASTM D412.

13.2.6.1.b *Random-oriented, fiber-reinforced elastomeric pads*—Preformed, randomly oriented synthetic fibers set in elastomer. Surface hardness of 70 to 90 Shore A Durometer according to ASTM D2240. Capable of supporting a compressive stress of 21 MPa without cracking, splitting, or delaminating in the internal portions of the pad.

13.2.6.1.c *Cotton-duck-fabric-reinforced elastomeric pads*—Preformed, horizontally-layered, cotton-duck fabric bonded to an elastomer. Surface hardness of 80 to 100 Shore A Durometer according to ASTM D2240. Conforming to Division II, Section 18.10.2 of AASHTO LRFD Bridge Design Specifications or Military Specification, MIL-C-882E.

13.2.6.1.d *Frictionless pads*—Tetrafluoroethylene, glass fiber reinforced, bonded to stainless or mild-steel plates, or random-oriented, fiber-reinforced elastomeric pads.

13.2.6.1.e *High-density plastic*—Multimonomer, nonleaching, plastic strip capable of supporting loads with no visible overall expansion.

13.2.6.2 *Other accessories*

13.2.6.2.a *Reglets*—When specified, provide surface-mounted reglets meeting the requirements of Contract Documents.

13.2.6.2.b *Erection accessories*—Provide clips, angles, bolts, washers, nuts, hangers, plastic or steel shims, and other accessories required to install precast concrete members. Provide connection items, anchors, angles, plates, and other items secured to or embedded in precast concrete or other work and necessary to support and anchor precast concrete members.

13.2.7 *Grout materials*

13.2.7.1 *Sand-cement grout*—Unless otherwise specified or permitted, use portland cement, ASTM C150, Type I, clean, natural sand, and ASTM C144, or ASTM C404, to produce a grout that achieves specified strength. If more than one grout type is required, each type shall be used in locations indicated in Contract Documents. The constituent materials used shall be such that the water-soluble chloride ion (Cl^-) content of the grout shall not exceed 0.06% Cl by cement weight as tested in accordance with ASTM C1218/C1218M.

13.2.7.2 *Nonshrink grout*—When specified, use premixed, prepackaged nonshrink grout complying with ASTM C1107/C1107M. Unless otherwise specified, use nonferrous grouts. When required, submit field installation procedures. The constituent materials used shall be such that the water-soluble chloride ion (Cl^-) content of the grout shall not exceed 0.06% Cl^- by weight of cement as tested in accordance with ASTM C1218/C1218M.

13.2.7.3 *Epoxy-resin grout*—When specified, use a two-component, mineral-filled, epoxy-resin grout meeting the requirements of ASTM C881/C881M for the type, grade, and class specified.

13.2.8 *Insulated panel components and accessories*

13.2.8.1 *General*—When specified in Contract Documents, provide insulated precast concrete members of the specified thickness and R-value. Use insulation material meeting the requirements of 13.2.8.2 through 13.2.8.4 at the locations indicated in Contract Documents.

13.2.8.2 *Expanded-polystyrene board insulation*—Rigid, cellular polystyrene thermal insulation complying with ASTM C578.

13.2.8.3 *Extruded-polystyrene board insulation*—Rigid, cellular polystyrene thermal insulation complying with ASTM C578.

13.2.8.4 *Polyisocyanurate board insulation*—Square-edged, rigid, cellular, polyisocyanurate thermal insulation complying with ASTM C591 or ASTM C1289.

13.2.8.5 *Wythe connectors*—Provide wythe connectors manufactured to connect to wythes of precast concrete panels. Unless otherwise specified, wythe connectors shall be one of the following:

- Glass-fiber and vinyl-ester polymer connectors;
- Polypropylene pin connectors;
- Stainless-steel pin connectors;
- Bent zinc-coated (galvanized) reinforcing bars;
- Zinc-coated (galvanized) welded wire trusses;
- Zinc-coated (galvanized) bent wire connectors;
- Epoxy-coated carbon fiber grid; and
- Cylindrical metal sleeve anchors.

13.2.9 *Concrete mixtures*

13.2.9.1 *General*—Prepare concrete mixtures for each type of concrete required.

13.2.9.2 *Normalweight concrete mixtures*—Unless otherwise specified, proportion mixtures by laboratory trial batch or field test data methods according to Section 4 with materials to be used on Project to provide normalweight concrete with the following properties:

- Specified compressive strength at 28 days: at least 35 MPa;
- Maximum *w/cm*: 0.45, unless otherwise specified; and
- Air-entrained concrete as required in 4.2.2.7.b, unless otherwise specified or permitted.

13.2.9.3 *Lightweight concrete mixtures*—Unless otherwise specified, when lightweight concrete is specified, proportion mixtures by laboratory trial batch or field test data methods according to Section 7, with materials to be used on Project, to provide lightweight concrete with the following properties:

- Specified compressive strength at 28 days: at least 35 MPa;
- Calculate equilibrium density according to ASTM C567; and
- Air-entrained concrete as required in 4.2.2.7.b, unless otherwise specified or permitted.

13.2.10 *Form fabrication*

13.2.10.1 *General*

13.2.10.1.a Formwork shall comply with Section 2 except as modified in this section.

13.2.10.1.b Maintain forms to provide completed precast concrete members of shapes, lines, and dimensions specified in Contract Documents within fabrication tolerances specified in ACI ITG-7M. Unless otherwise specified, edges and corners shall be chamfered.

13.2.11 *Hardware*

13.2.11.1 *Cast-in anchors, inserts, plates, angles, and other anchorage hardware*—Position embedded anchorage hardware for attachment of loose hardware and secure in place during precasting operations. Locate anchorage hardware where it does not affect position of main reinforcement or concrete placement. Fabricate anchorage hardware to comply with design requirements. Do not relocate bearing plates in units unless permitted by Architect/Engineer.

13.2.11.2 Furnish loose hardware items including steel plates, clip angles, seat angles, anchors, dowels, cramps, hangers, and other hardware for securing precast concrete units to supporting and adjacent construction. Provide setting diagrams, templates, instructions, and installation directions.

13.2.12 *Fabrication*

13.2.12.1 Unless otherwise permitted, provide sizes and shapes of members specified in Contract Documents.

13.2.12.2 Provide cast-in reglets, slots, holes, and other accessories as indicated in Contract Documents.

13.2.12.3 Openings larger than 250 mm in any dimension shall be formed. Do not drill or cut openings without obtaining acceptance from Architect/Engineer.

13.2.12.4 *Reinforcement*

13.2.12.4.a Place non-prestressed reinforcement and prestressing steel within tolerances specified in ACI ITG-7M to maintain concrete cover required by Contract Documents. Arrange, space, and securely tie bars and reinforcement supports to hold reinforcement in position during concrete placement and consolidation operations. Position wire tie ends away from exposed concrete surfaces.

13.2.12.4.b Install welded wire reinforcement in lengths as long as practical. Unless otherwise specified, lap adjoining pieces at least one full wire spacing and use wire to tie laps. Offset laps of adjoining widths to prevent continuous laps in either direction.

13.2.12.5 Place concrete in a continuous operation to prevent cold joints or planes of weakness from forming in precast concrete members.

13.2.12.6 Consolidate concrete by internal vibration, external vibration, or both without dislocating or damaging reinforcement and built-in items.

13.2.12.7 Identify pickup points of precast concrete members and orientation in structure with permanent markings, complying with markings indicated on shop drawings. Imprint or permanently mark casting date and member identification on each precast concrete member on a surface that will not show in finished structure.

13.2.12.8 Cure concrete by moisture retention or by accelerated heat curing using steam or radiant heat and moisture. Cure members until the compressive strength exceeds the specified release strength.

13.2.12.9 *Maximum initial curing temperature*—Unless otherwise specified or permitted, maximum concrete temperature during initial curing shall not exceed 67°C. Measure the temperature inside the portion of the member that is likely to experience the highest concrete temperature during curing. A temporary rise in maximum initial curing concrete temperature is permitted for a period less than 2 hours provided it does not exceed the maximum allowable temperature by more than 3°C.

13.2.12.10 Prestress the precast concrete members by pretensioning or post-tensioning methods when specified.

13.2.12.10.a Delay detensioning or post-tensioning of precast prestressed concrete members until concrete reaches the specified compressive strength for release or tensioning.

13.2.12.10.b Detension pretensioned steel by gradually releasing tensioning jacks or by flame-cutting tendons, using a sequence and pattern to prevent shock or unbalanced loading.

13.2.12.10.c If concrete was heat cured, detension while concrete is still warm and moist.

13.2.12.10.d Protect strand ends and anchorages, not exposed to view when in service, with bitumastic, zinc-rich, or epoxy paint.

13.2.12.10.e When appearance of member ends is specified as critical or exposed to severe environment, protect strand ends and anchorages with at least a 25 mm thickness of nonmetallic, nonshrink mortar and sack rub surface. Ensure the inside surfaces of the pocket are clean, free of release agent and grease. Coat or spray the inside surfaces of the pocket with a latex or epoxy bonding agent before installing the pocket mortar.

13.2.12.11 Unless otherwise specified, repair damaged precast concrete members to meet the requirements of repair procedures accepted by Architect/Engineer.

13.2.12.12 *Insulated panel casting*

13.2.12.12.1 When insulated panels are specified, cast and screed bottom wythe supported by form.

13.2.12.12.2 Place insulation boards so that sides and ends abut with adjacent boards. Insert wythe connectors through insulation and consolidate concrete around connectors according to connector manufacturer's written instructions.

13.2.12.12.3 Cast and screed top wythe to meet specified finish.

13.2.13 *Fabrication tolerances*

13.2.13.1 Unless otherwise specified, fabricate precast concrete members to size and shape with exposed edges and corners so each finished member complies with ACI ITG-7M.

13.2.14 *Finishes*

13.2.14.1 *Structural member finishes*—Provide one of finishes in 13.2.14.1.a to 13.2.14.1.d for formed surfaces of precast structural members as designated in Contract Documents:

13.2.14.1.a *Commercial grade finish*—Remove fins and protrusions larger than 3 mm and fill holes with a diameter larger than 13 mm. Rub or grind ragged edges. Air holes, water marks, and color variations are acceptable. Allowable form joint offsets are limited to 5 mm.

13.2.14.1.b *Standard grade finish*—Produce smooth form finish in forms that impart a smooth concrete finish. Surface air holes smaller than 13 mm, color variations, form joint marks, chips, and spalls are acceptable. Fill air holes greater than 13 mm wide that occur in high concentration (more than one per 1300 mm^2). Allowable form joint offset is limited to 3 mm.

13.2.14.l.c *Grade B finish*—Fill air pockets and holes with a diameter larger than 6 mm with sand-cement paste matching color of adjacent surfaces. Fill air holes with a diameter greater than 3 mm that occur in high concentration (more than one per 1300 mm^2). Grind smooth form offsets or fins larger than 3 mm. Repair surface blemishes due to dents in forms. Discoloration is permitted at form joints.

13.2.14.1.d *Grade A finish*—Repair surface blemishes with the exception of air holes with a diameter less than 1.5 mm and form marks where the surface deviation is less than 1.5 mm. Float-apply a neat cement-paste coating to exposed surfaces. Rub dried paste coat with burlap to remove loose particles. Discoloration is permitted at form joints. Grind smooth form joints.

13.2.14.2 *Unformed surfaces finish*—Unless otherwise specified, screed or float finish unformed surfaces. Strike off and consolidate concrete with vibrating screeds to a uniform finish, if required. Hand screed at projections. Color variations or defects are permitted.

13.2.14.3 *Top surface of composite members*—Top surfaces of double tees, hollow-core plank, or other precast concrete members to receive a topping shall have a rough scratch finish transversely scarified to provide ridges at least 6 mm deep.

13.2.15 *Source quality control*

13.2.15.1 *Quality control testing*—Unless otherwise specified, fabricator shall be certified in accordance with PCI Plant Certification program and comply with source testing requirements. Testing and inspection programs shall use certified personnel and be acceptable to Architect/Engineer. Submit documentation of PCI certification of plant and personnel.

13.2.15.2 Owner may employ an accredited independent testing agency to evaluate fabricator's quality control and testing methods.

13.2.15.2.a Allow Owner's testing agency access to material storage areas, concrete production equipment, concrete placement, and curing facilities. Cooperate with and provide necessary facilities for Owner's testing agency and provide samples of materials and concrete mixtures as requested for additional testing and evaluation.

13.2.16 *Acceptance of precast elements*—Precast concrete members will be considered deficient if concrete fails to comply with concrete strength, durability, or surface finish requirements.

13.2.17 *Defective Work*—When permitted, repair chipped, spalled, or cracked members. Obtain acceptance from licensed design engineer responsible for design of precast concrete members before making structural repairs. Replace unacceptable member with precast concrete members that comply with requirements.

13.3—Execution

13.3.1 *Preparation*

13.3.1.1 Deliver anchorage devices to be embedded in or attached to the building structural frame or foundation. Provide shop drawings for locations, setting diagrams, and templates for the proper installation of each anchorage device.

13.3.2 *Examination*

13.3.2.1 Examine supporting structural frame or foundation for compliance with requirements for installation tolerances, bearing surface tolerances, and other conditions affecting performance. Notify Architect/Engineer of unsatisfactory conditions. Proceed with installation only after unsatisfactory conditions have been corrected.

13.3.2.2 Do not install precast concrete members until supporting cast-in place concrete foundation and building structural framing has attained in-place compressive strength indicated in Contract Documents and supporting steel, precast concrete frames, or assemblies are structurally ready to receive loads from precast concrete members.

13.3.3 *Erection*

13.3.3.1 Install loose clips, hangers, bearing pads, and other accessories required for connecting precast concrete members to supporting members and backup materials.

13.3.3.2 Erect precast concrete members within tolerances specified in 13.3.4. Provide temporary structural framing, supports, and bracing to maintain position, stability, and alignment of members until permanent connections are completed.

13.3.3.2.a Install temporary steel or plastic spacing shims or bearing pads as precast concrete members are being erected. Tack weld steel shims together to prevent them from separating.

13.3.3.2.b Maintain horizontal and vertical joint alignment and uniform joint width within specified tolerances as erection progresses.

13.3.3.2.c Remove projecting lifting devices, and when recess is exposed, use sand-cement grout to fill voids within recessed lifting devices flush with surface of adjacent precast concrete surfaces.

13.3.3.2.d Provide and install headers for openings larger than one slab width according to hollow-core slab unit fabricator's written instructions.

13.3.3.3 Connect precast concrete members in position by bolting, welding, or grouting as indicated on shop drawings. Remove temporary shims, wedges, and spacers after permanent connections and grouting are completed and grout has achieved design strength. Grout shall have a compressive strength as specified in Contract Documents, but not less than 14 MPa. Test grout strength in accordance with ASTM C109/C109M.

13.3.3.4 *Welding*—Comply with AWS D1.1/D1.1M or AWS D1.4/D1.4M requirements for welding, welding electrodes, appearance, weld quality, and methods used in correcting welding work.

13.3.3.4.a Protect precast concrete members and bearing pads from damage due to field welding or cutting.

13.3.3.4.b Welds not otherwise specified shall be continuous fillet welds, using not less than the minimum fillet as specified by AWS D1.1/D1.1M or D1.4/D1.4M.

13.3.3.4.c For galvanized metal, clean weld-affected metal surfaces with chipping hammer and follow with brushing or power tool cleaning. Inspect welds for defects. If welds satisfy AWS D1.1/D1.1M, apply at least a 0.10 mm thick coat of galvanized repair paint to galvanized surfaces in conformance to ASTM A780.

13.3.3.4.d Clean weld-affected metal surfaces with chipping hammer followed by brushing or power tool cleaning and prime damaged painted surfaces in accordance with paint manufacturer's recommendations.

13.3.3.4.e Unless otherwise permitted, visually inspect welds using a Certified Welding Inspector. Remove, reweld, or repair unsatisfactory welds.

13.3.3.5 Use lock washers, welding, or other means at bolted connections to prevent loosening of nuts after final adjustment.

13.3.3.5.a Where slotted connections are used, verify bolt position and tightness at installation. For sliding connections, properly secure bolt but allow bolt to move within connection slot.

13.3.3.5.b For slip-critical connection, apply specified bolt torque and check 25% of bolts at random by calibrated torque wrench. Unless otherwise permitted, test all bolts if insufficient bolt torque is found. Cost for this testing will be borne by Contractor.

13.3.3.6 *Grouting or dry packing connections and joints*—Joints and connections to be grouted and critical grouting sequences shall be as indicated on shop drawings. Ensure grout remains in place until it gains sufficient strength to support itself. Pack spaces with stiff grout material, tamping until voids are completely filled. Place grout and finish smooth and flush with adjacent concrete surfaces. Promptly remove grout material from exposed surfaces before it affects finishes or hardens. Keep grouted joints damp for at least 24 hours.

13.3.3.6.a Trowel top of grout joints on roofs smooth to prevent unevenness that might interfere with placing of, or cause damage to, insulation and roofing. Finish transitions due to different surface levels at a slope not steeper than 1 to 12.

13.3.3.6.b When grouting slab ends of hollow-core slabs, provide suitable end cap or dams in voids.

13.3.3.6.c For areas where slab voids are to be used as electrical raceways or mechanical ducts, provide a taped butt joint at slab ends, making sure voids are aligned.

13.3.3.7 After installation, do not cut or core precast concrete units unless specified or permitted.

13.3.3.8 Do not use drilled-in or powder-actuated fasteners for attaching accessory items to precast, prestressed concrete members unless specified or permitted by Architect/Engineer. If permitted, do not allow fasteners to hit prestressed tendons.

13.3.4 *Erection tolerances*

13.3.4.1 Erect precast concrete members in accordance with noncumulative erection tolerances of ACI ITG-7M.

13.3.5 *Field quality assurance*

13.3.5.1 *Testing and inspections*

13.3.5.1.a In addition to field quality control performed by Contractor, field tests and inspections will be performed by Owner's independent testing and inspecting agency.

13.3.5.1.b Field welds will be subject to visual inspections and dye penetrant or magnetic particle testing in accordance with ASTM E165 or ASTM E1444. When performing testing to ASTM E165 or E1444, the testing agency shall be qualified in accordance with ASTM E543.

13.3.5.1.c Testing agency will report test results within 7 days from inspection and in writing as directed by Owner.

13.3.5.1.d Repair or remove and replace work that does not comply with Contract Documents.

13.3.5.1.e Additional testing and inspection, at Contractor's expense, will be performed to determine compliance of corrected work with Contract Documents.

13.3.6 *Repairs*

13.3.6.a Repairs will be permitted provided structural adequacy, serviceability, durability, and appearance are not impaired.

13.3.6.b Repair damaged members to meet acceptability requirements of 13.2.14 and 13.2.15.

13.3.6.c Mix patching materials and repair members so cured patches blend with color, texture, and uniformity of adjacent exposed surfaces and show no apparent line of demarcation between original and repaired work when viewed in daylight from 6 m.

13.3.6.d Prepare and repair damaged galvanized coatings with galvanizing repair paint according to ASTM A780.

13.3.6.e Wire brush, clean, and paint damaged prime-painted steel hardware with same type of shop primer.

13.3.6.f Remove and replace damaged precast concrete members when repairs are unacceptable in accordance with Contract Documents.

13.3.7 *Cleaning*

13.3.7.1 Clean mortar, plaster, fireproofing, weld slag, and other deleterious material from concrete surfaces and adjacent materials immediately.

13.3.7.2 After completion of joint treatment, clean exposed surfaces of precast concrete members to remove weld marks, other markings, dirt, and stains.

13.3.7.2.a Perform cleaning procedures according to precast concrete fabricator's recommendations. Protect other work from staining or damage due to cleaning operations.

13.3.7.2.b Do not use cleaning materials or processes that could change the appearance of exposed concrete finishes or damage adjacent materials.

SECTION 14—PRECAST ARCHITECTURAL CONCRETE

14.1—General

14.1.1 *Description*—This section covers requirements for precast architectural concrete units and precast structural concrete members with commercial architectural (CA) finish.

Precast architectural concrete units and precast structural concrete with an architectural finish shall comply with the requirements of Section 13, unless otherwise specified in this section or in Contract Documents.

14.1.2 *Submittals*

14.1.2.1 *Concrete mixtures*—Submit proportions for each precast concrete mixture. Include results of compressive strength tests and when specified, water-absorption tests in accordance with ASTM C642, except for boiling requirement.

14.1.2.2 *Design reference sample*—Submit design reference sample for initial verification of design in accordance with 14.1.3.1.

14.1.2.3 *Sample panels*—Submit sample panels in accordance with 14.1.3.2.

14.1.2.4 *Range sample panels*—Provide range sample panels in accordance with 14.1.3.7.

14.1.2.5 When required in Contract Documents, submit data specified in 14.1.2.5.a through 14.1.2.5.c.

14.1.2.5.a *Full-size mockup*—Provide in accordance with 14.1.3.8.

14.1.2.5.b Design calculations and shop drawings signed and sealed by a licensed design engineer responsible for their preparation showing governing panel types, connections, concrete cover, and reinforcement types including special reinforcement. Submit and coordinate location, type, magnitude, and direction of loads imposed on the building structural frame from architectural units with Architect/Engineer.

14.1.2.5.c Material test reports from an accredited testing agency or material certificates signed by manufacturers certifying that each of the following items complies with specification requirements:

- Clay product units; and
- Stone and stone anchors.

14.1.2.6 *Fabricator qualifications*—Unless otherwise specified, fabricator shall be certified in accordance with PCI Plant Certification program and be designated a PCI-certified plant for Group A, Category A1—Architectural Cladding and Load Bearing Units or Group CA member as required in Contract Documents.

14.1.3 *Sample panels and mockup*

14.1.3.1 *Design reference samples*—Design reference samples for initial verification of design intent shall be approximately 300 mm x 300 mm x 50 mm and be representative of finishes, color, and textures of precast concrete unit exposed surfaces. When back face of precast concrete unit is to be exposed, include reference samples illustrating workmanship, color, and texture of backup concrete and facing concrete.

Design reference samples shall include brick units showing full range of color and texture expected including joint treatment. Provide drawing of each corner or special shape with dimensions if not included on design reference sample.

14.1.3.2 *Sample panels*—Unless otherwise specified, before fabricating CA members or architectural precast concrete units, produce and submit at least two sample panels each with at least 1.5 m^2 in area for review by Architect/Engineer. Incorporate full-scale details of architectural features, finishes, textures, and transitions in the sample panels.

14.1.3.3 Locate sample panels where indicated in Contract Documents.

14.1.3.4 Damage part of an exposed-face surface on two sample panels for each finish, color, and texture, and demonstrate sufficiency of repair techniques proposed for repair of surface blemishes.

14.1.3.5 After acceptance of repair technique, maintain one sample panel at manufacturer's plant and one at the Project site in an undisturbed condition as a standard for judging the completed Work.

14.1.3.6 Demolish and remove sample panels when directed.

14.1.3.7 *Range sample panels*—When precast architectural concrete units are specified, after sample panel acceptance and before starting production of precast architectural concrete units, produce and submit, when required, at least three samples each with at least 1.5 m^2 in area representing anticipated range of each color and texture on Project's units. Following range sample acceptance by Architect/Engineer, maintain accepted range sample panels at the manufacturer's plant as color and texture acceptability reference.

14.1.3.8 *Mockups*—When required, construct mockups to demonstrate aesthetic effects and set quality standards for materials and execution. Mockup shall be constructed after sample and range sample acceptance, but before production of precast structural members with an architectural finish or precast architectural concrete units. Mockup shall be representative of the finished Work including glass, aluminum framing, sealants, and precast concrete complete with anchors, connections, flashings, and joint fillers as accepted on the final shop drawings. Build mockups to comply with the following requirements, using materials indicated for completed Work.

14.1.3.8.a Build mockups in the location and of the size indicated in Contract Documents.

14.1.3.8.b Notify Architect/Engineer in advance of dates and times when mockups will be constructed.

14.1.3.8.c Obtain Architect/Engineer's acceptance of mockups before fabrication.

14.1.3.8.d Maintain mockups during construction in an undisturbed condition as a standard for judging completed Work.

14.1.3.8.e Demolish and remove mockups when directed. Do not use mockup in part of completed Work unless permitted by Architect/Engineer.

14.1.3.9.f *Testing mockup*—When required by Contract Documents, provide a single, full-sized mockup for testing by others to the extent indicated in Contract Documents to simulate precast concrete and window wall assembly.

14.2—Products

14.2.1 *Window washing system*—When support of window washing system is specified, design precast concrete units supporting window washing system to resist specified loads transmitted from window washing equipment.

14.2.2 *Stone to precast concrete anchorages*—If stone veneer precast concrete units are specified, provide number and types of anchors as required.

14.2.3 *Form liners*—When form liners are specified, the design, texture, arrangement, and configuration shall match those used for the precast concrete design reference sample. Provide solid backing and form supports to ensure that form liners remain in place during concrete placement. Use with manufacturer's recommended form-release agent that will not bond with, stain, or adversely affect hardening of precast concrete surfaces and will not impair subsequent surface or joint treatments of precast concrete.

14.2.4 *Surface retarder*—When specified or permitted, use chemical set retarder to delay setting of freshly placed concrete to specified depth of reveal.

14.2.5 *Thin and half-brick units and accessories*

14.2.5.1 When specified, half-brick units shall comply with ASTM C216 or ASTM C1088 and meet the type, grade, face size, and dimensional tolerances specified in Contract Documents.

14.2.5.2 Unless otherwise specified or permitted, provide thin brick units meeting the requirements given in 14.2.5.2.a to 14.2.5.2.m.

14.2.5.2.a *Thickness and tolerances*—Thickness not less than 13 mm nor more than 25 mm with an overall tolerance of +0 mm, –1.5 mm for any unit dimension 200 mm or less and an overall tolerance of +0 mm, –2.5 mm for any unit dimension greater than 200 mm measured according to ASTM C67.

14.2.5.2.b *Cold water absorption at 24 hours*—Maximum 6% when tested in accordance with ASTM C67.

14.2.5.2.c *Efflorescence*—Provide brick that has been tested according to ASTM C67 and rated "not effloresced."

14.2.5.2.d *Out of square*—Plus or minus 1.5 mm measured according to ASTM C67.

14.2.5.2.e *Warpage*—Plus 0, minus 1.5 mm when tested in accordance with ASTM C67.

14.2.5.2.f *Variation of shape from specified angle*—Plus or minus 1 degree.

14.2.5.2.g *Tensile bond strength and resistance to freezing and thawing*—Tensile bond strength according to ASTM E488, as modified below, shall not be less than 1.0 MPa before and after freezing-and-thawing testing. Freezing and thawing testing in accordance with Method B of ASTM C666/C666M shall be run for 300 cycles and specimens shall show no detectable deterioration.

Prepare 10 test specimens measuring 200 mm x 400 mm with brick embedded into a concrete substrate (assembled system) for tensile bond strength and resistance to freezing-and-thawing testing. Divide test specimens with five designated as Sample A assemblies and five designated as Sample B assemblies. Specimen shall have a thickness of at least 65 mm plus brick thickness. Concrete shall have a compressive strength of at least 35 MPa and 4 to 6% entrained air. Embedded brick coursing pattern for test specimens shall be modular size brick 57 mm x 194 mm on a half running bond pattern with a formed raked joint geometry of no less than 10 mm wide and a depth no greater than 6 mm from the exterior face of the brick.

One brick from the center of each Sample A assembly shall be tested for tensile bond strength. In place of anchor specified in ASTM E488, use 6 mm minimum thickness steel plate of same size as single brick face bonded with epoxy to a single brick face for each tensile bond strength test. The steel plate shall have a centrally located pull-rod welded to the plate. Each Sample B assembly shall first be tested for freezing-and-thawing resistance in accordance with ASTM C666/C666M Method B. Subsequent to the freezing-and-

thawing resistance testing one brick from the center of each Sample B assembly shall be tested for tensile bond strength.

14.2.5.2.i *Modulus of rupture*—Not less than 1.7 MPa when tested in accordance with ASTM C67.

14.2.5.2.j *Chemical resistance*—Rated "not affected," when tested according to ASTM C650.

14.2.5.2.k *Surface coloring*—Brick specified with surface coloring, other than flashed or sand-finished brick, shall withstand 50 cycles of freezing and thawing according to ASTM C67 with no observable difference in applied finish when viewed in daylight from 6 m.

14.2.5.2.l When specified, face color and texture shall match design reference sample accepted by Architect/Engineer.

14.2.5.2.m When specified, provide back surface texture in accordance with Contract Documents.

14.2.6 *Glazed and unglazed ceramic tile units*—Unless otherwise specified, unit properties shall comply with the following:

- Thickness of units shall not be less than 10 mm;
- Body of glazed tile shall have water absorption of less than 3% using ASTM C373;
- Manufacturer shall warrant materials as frost-resistant; and
- Glazed units shall conform to ASTM C126.

14.2.7 *Architectural terra cotta units*—When terra cotta is specified, units shall comply with requirements of architectural terra cotta manufacturer's standards for the application indicated.

14.2.8 *Setting mortar*—Unless otherwise specified, mortar for setting thin or half-brick, ceramic tile or terra cotta unit joints before placing precast concrete shall use backup concrete or portland cement, ASTM C150, Type I, and clean, natural sand, ASTM C144. Mix at a ratio of one part portland cement to four parts sand, by bulk volume, with minimum water required for placement.

14.2.9 *Latex portland cement pointing grout*—When Contract Documents specify filling brick unit joints after precast concrete panel production, unless otherwise specified, use pointing grout conforming to ANSI A118.6 (included in ANSI A108.1) and meeting 14.2.9.1 or 14.2.9.2, or both.

14.2.9.1 Dry-grout mixture, factory prepared, of portland cement, graded aggregate, and dry, redispersible, ethylene-vinyl-acetate additive for mixing with water.

14.2.9.2 Commercial portland cement grout, factory prepared, with liquid styrene-butadiene rubber or acrylic-resin latex additive.

14.2.9.3 *Colors*—Unless otherwise specified or permitted, color of pointing grout shall match design reference sample.

14.2.10 *Setting systems for brick and ceramic tile*—When thin and full brick or ceramic tile is laid after casting unit, comply with the requirements in Contract Documents.

Unless otherwise specified, setting systems with thin and full brick or ceramic tile laid after casting precast concrete units shall conform to 14.2.10.1 or 14.2.10.2.

14.2.10.1 Thin brick and ceramic tile units shall be set using dry-set mortar conforming to ANSI A118.1 (included in ANSI A108.1) or latex-portland cement mortar conforming to ANSI A118.4 (included in ANSI A108.1).

14.2.10.2 For full brick units, use galvanized or stainless steel dovetail slots in precast concrete, not less than 0.5 mm thick, felt- or fiber-filled dovetail slots, or cover face opening of slots as specified in Contract Documents.

14.2.11 *Stone facing*—When specified, provide stone facing for precast concrete meeting the following requirements and Contract Documents.

14.2.11.1 Tolerance of length and width of +0, –3 mm.

14.2.11.2 Anchors shall be stainless steel, ASTM A666, Type 304, of temper, diameter, and embedment required to support loads without exceeding allowable design stresses.

14.2.11.3 When a flexible sealant material is specified for filling anchor holes, use a low-modulus sealant that is nonstaining to stone substrate and that complies with ASTM C920.

14.2.11.4 When rigid filler is specified to resist water penetration in anchor holes, use epoxy conforming to ASTM C881/C881M, 100% solids, sand-filled with a maximum sand-to-binder ratio between 6 and 9, nonshrinking, nonstaining of a type, class, and grade to suit application.

14.2.11.5 If filling anchor holes with rigid epoxy, fit each anchor leg with 60 Durometer neoprene grommet collar, having a width at least twice the diameter and length at least five times the anchor diameter.

14.2.11.6 *Bond breaker*—Unless otherwise specified, bond breaker between stone and precast concrete shall be polyethylene sheet, ASTM D4397, 0.15 to 0.25 mm thick.

14.2.12 *Form fabrication*

14.2.12.1 *General*—Construct mortar-tight forms of sufficient strength to withstand pressures due to concrete placement, vibration operations, and temperature changes. Coat contact surfaces of molds with release agent before reinforcement is placed.

Maintain forms to provide completed precast concrete units of shapes, lines, and dimensions within ACI ITG-7M fabrication tolerances. Form joints are prohibited on faces exposed to view in the finished Work.

14.2.12.1.a *Thin and half-brick facing*—When thin or half-brick facings are specified, place form liner templates accurately to provide grid for brick facings. Provide solid backing and supports to maintain liner stability while placing bricks and during concrete placement. Securely place brick units face-down into form liner pockets and place precast concrete backing mixtures. Clean faces and joints of brick facing.

14.2.12.1.b *Form liners*—Place form liners to provide finished surface appearance indicated in Contract Documents. Provide solid backing and supports to maintain liner stability during concrete placement. Coat form liner with form-release agent that will not affect form liner material.

14.2.13 *Stone facing installation*—When stone facings are specified, accurately position stone facings in locations indicated in Contract Documents.

Install spring clips, anchors, supports, and other attachments indicated or necessary to secure stone in place. Maintain minimum embedment depth requirements of stone anchors into concrete substrates. Orient stone veining in direction indicated in Contract Documents. Space anchors at least 150 mm

from an edge and provide no less than two anchors per stone unit of less than 0.20 m^2 in area and four anchors per unit of less than 1.1 m^2 in area. For units larger than 1.1 m^2 in area, provide anchors spaced no more than 600 to 750 mm on center depending on the local building code and wind loading. Use continuous spacers to obtain uniform joints of widths indicated in Contract Documents and with edges and faces aligned according to specified pattern and tolerances. Ensure no passage of concrete matrix to stone surface or joints between stones.

14.2.13.1 Furnish and install sealant backings and sealant into stone-to-stone joints and stone-to-concrete joints on each unit. Apply a continuous sealant bead along both sides and top of precast concrete units at the stone/precast concrete interface. Do not seal bottom edge of unit.

14.2.13.2 *Stone anchor shear and tensile testing*—Engage accredited testing agency acceptable to Architect/Engineer to evaluate and test the proposed stone anchorage system. Submit qualifications of selected testing agency. Provide two sets of six stone samples 300 x 300 mm with stone of proposed thickness. Test for shear and tensile strength of proposed stone anchorage system in accordance with ASTM E488 or ASTM C1354/C1354M modified as follows:

- Before testing, submit for acceptance a description of the test assembly (including pertinent data on materials), test apparatus, and procedures;
- Test stone anchors of the sizes and shapes proposed for the installation; and
- Test the assembly to failure and record the test load at failure. Record the type of failure, anchor pullout, stone breakage, and other pertinent information in accordance with the requirements of ASTM E488. In addition, submit load-deflection curves of each test assembly.

14.2.14 *Face and backup concrete mixtures*—When only one face of unit is exposed, unless otherwise specified, use either of the techniques in 14.2.14.1 or 14.2.14.2.

14.2.14.1 The same concrete mixture throughout the thickness of panel; or

14.2.14.2 Different concrete mixtures for face and backup.

14.2.14.2.a Place face concrete to a thickness after consolidation that equals or exceeds the largest of the following:

- 40 mm;
- One and a half times the nominal maximum aggregate; and
- Specified concrete cover indicated in Contract Documents.

14.2.14.2.b Unless otherwise permitted, use cement and aggregate for face concrete mixture as specified in Contract Documents.

14.2.15 *Precast architectural concrete unit finishes*

14.2.15.1 *General*—Exposed faces shall be free of joint marks, grain, or defects not accepted in the accepted sample or mockup units. Corners, including false joints, shall be uniform and straight. Finish exposed-face surfaces of precast concrete units to match the accepted sample or mockup units.

14.2.15.2 Provide one of the finishes described in 14.2.15.2.a through 14.2.15.2.i as specified in Contract Documents.

14.2.15.2.a *As-cast surface finish*—Provide surfaces to match accepted sample or mockup units for acceptable surface air voids, and sand streaks of as-cast surface finishes.

14.2.15.2.b *Textured-surface finish*—Provide surfaces to match accepted sample or mockup units for acceptable surface air voids, sand streaks, and uniformity of color for textured-surface finishes.

14.2.15.2.c *Bush-hammer finish*—Use power or hand tools to remove matrix and fracture coarse aggregates to match accepted sample or mockup units.

14.2.15.2.d *Exposed aggregate finish*—Use chemical retarding agents applied to molds and washing and brushing procedures to expose aggregate and surrounding matrix surfaces after form removal to match accepted sample or mockup units.

14.2.15.2.e *Abrasive-blast finish*—Use abrasive grit, equipment, application techniques, and cleaning procedures to expose aggregate and surrounding matrix surfaces to match accepted sample or mockup units. Remove matrix to a maximum depth of 1/3 the average diameter of the maximum size of coarse aggregate but not more than 1/2 the diameter of smallest-sized coarse aggregate.

14.2.15.2.f *Acid-etched finish*—Use acid/hot-water solution, application equipment and techniques, and cleaning procedures to expose aggregate and surrounding matrix surfaces to match accepted sample or mockup units. Protect hardware, connections, and insulation from acid attack.

14.2.15.2.g *Honed finish*—Use continuous mechanical abrasion with fine grit, followed by filling and rubbing procedures to match accepted sample or mockup units.

14.2.15.2.h *Polished finish*—Use continuous mechanical abrasion with fine grit, followed by filling and rubbing procedures to match accepted sample or mockup units.

14.2.15.2.i *Sand-embedment finish*—Use selected stones placed in a sand bed in bottom of mold, with sand removed after curing to match accepted sample or mockup units. Sand depth shall keep backup concrete 25 to 35% of the stone's diameter from the face.

14.2.15.3 Unless otherwise specified, finish unexposed surfaces of architectural concrete units by smooth steel-trowel finish.

14.2.15.4 *Defective Work*—Precast concrete units that do not comply with requirements including concrete strength, manufacturing tolerances, and color and texture range are unacceptable. Chipped, spalled, or cracked units may be repaired, if repaired units match the accepted sample and mockup units. Architect/Engineer maintains the right to reject any unit if it does not match the accepted sample and mockup units. Replace unacceptable units with precast concrete units that comply with requirements.

14.2.15.5 *Cleaning*—Unless otherwise specified, fabricator will clean surfaces of precast concrete units with mild soap and high-pressure water before shipping.

14.2.15.6 *Protection*—Protect the architectural face of the precast unit from contamination and damage during transportation and handling.

14.3—Execution

14.3.1 *Erection*

14.3.1.1 Unless otherwise specified, provide for uniform joint widths of 20 mm.

14.3.1.2 Disruption of roof flashing continuity by connections is prohibited; concealment within roof insulation is acceptable.

(nonmandatory portion follows)

NOTES TO SPECIFIER

General notes

G1. ACI Specification 301M-10 is to be used by reference or incorporation in its entirety in the Project Specification. Do not copy individual Sections, Parts, Articles, or Paragraphs into the Project Specification, because taking them out of context may change their meaning.

G2. If Sections or Parts of ACI Specification 301M-10 are copied into the Project Specification or any other document, do not refer to them as an ACI specification, because the specification has been altered.

G3. A statement such as the following will serve to make ACI Specification 301M-10 a part of the Project Specification: "Work on (Project Title) shall conform to all requirements of ACI 301M-10 Specifications for Structural Concrete published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by these Contract Documents."

G4. Each technical Section of ACI Specification 301M-10 is written in the three-part Section format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

G5. ACI Specification 301M-10 is written to the Contractor. When a provision of this Specification requires action by the Contractor, the verb "shall" is used. If the Contractor is allowed to exercise an option when limited alternatives are available, the phrasing "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 Architect/Engineer.

Foreword to checklists

F1. This foreword is included for explanatory purposes only; it is not a part of ACI Specification 301M-10.

F2. ACI Specification 301M-10 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. ACI Specification 301M-10 cannot and does not address responsibilities for any project participant other than the Contractor.

F3. Checklists do not form a part of ACI Specification 301M-10. Checklists assist the Specifier in selecting and specifying project requirements in the Project Specification.

F4. The Mandatory Requirements Checklist indicates Work requirements regarding specific qualities, procedures, materials, and performance criteria that are not defined in ACI Specification 301M-10. The Specifier must include these requirements in the Project Specification.

F5. The Optional Requirements Checklist identifies Specifier choices and alternatives. The Checklist identifies the Sections, Parts, and Articles of the ACI Reference Specification 301M-10 and the action required or available to the Specifier. The Specifier should review each of the items in the Checklist and make adjustments to the needs of a particular project by including those selected alternatives as mandatory requirements in the Project Specification.

F6. The Submittals Checklist identifies information or data to be provided by the Contractor before, during, or after construction.

F7. *Recommended references*—Documents and publications that are referenced in the Checklists of ACI Specification 301M-10 are listed below. These references provide guidance to the Specifier and are not considered to be part of ACI Specification 301M-10.

American Concrete Institute (ACI)

CP-1	Technical Workbook for ACI Certification of Concrete Field Testing Technician—Grade 1
CP-10	Craftsman Workbook for ACI Certification of Concrete Flatwork Technician/Finisher
201.2R	Guide to Durable Concrete
207.2R	Report on Thermal and Volume Change Effects on Cracking of Mass Concrete
209R	Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures
211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
216.1/ TMS 0216.1	Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies
222R	Protection of Metals in Concrete Against Corrosion
223	Standard Practice for the Use of Shrinkage-Compensating Concrete
225R	Guide to the Selection and Use of Hydraulic Cements
228.1R	In-Place Methods to Estimate Concrete Strength
302.1R	Guide for Concrete Floor and Slab Construction
305R	Hot Weather Concreting
306.1	Standard Specification for Cold Weather Concreting
308R	Guide for Curing Concrete
308.1	Standard Specification for Curing Concrete
311.1R	ACI Manual of Concrete Inspection (SP-2)
311.4R	Guide for Concrete Inspection
311.5	Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete
318M	Building Code Requirements for Structural Concrete and Commentary
347	Guide to Formwork for Concrete
347.2R	Guide for Shoring/Reshoring of Concrete Multistory Buildings
360R	Design of Slabs-on-Ground

423.7 Specification for Unbonded Single-Strand Tendon Materials and Commentary

American National Standards Institute (ANSI)

ANSI A137.1 Specifications for Ceramic Tile

ASTM International

A53 Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless

A653/A653M Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

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

C441 Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction

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

D1557 Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)]

D3350 Standard Specification for Polyethylene Plastics Pipe and Fittings Materials

D4101 Standard Specification for Polypropylene Injection and Extrusion Materials

National Ready Mixed Concrete Association (NRMCA)

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

Guideline Manual for Quality Assurance Quality Control, NRMCA Publication No. 190

Portland Cement Association (PCA)

Gajda, J., 2007, *Mass Concrete for Buildings and Bridges*, EB547, Portland Cement Association, Skokie, IL, 44 pp.

Kosmatka, S. H.; Kerkhoff, B.; and Panarese, W. C., 2002, *Design and Control of Concrete Mixtures*, EB001, 14th edition, Portland Cement Association, Skokie, IL, 358 pp.

Precast/Prestressed Concrete Institute (PCI)

MNL 116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products, 4th edition

MNL 117 Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products, 3rd edition

MNL 124 Design for Fire Resistance of Precast Prestressed Concrete

Sason, A. S., 1992, "Evaluation of Degree of Rusting on Prestressed Concrete Strand," *PCI Journal*, V. 37, No. 3, May-June, pp. 25-30.

The International Federation for Structural Concrete (fib)

Federation Internationale Beton Technical Bulletin 7: "Corrugated Plastic Ducts for Internal Bonded Post-Tensioning," Jan. 2000.

U.S. Army Corps of Engineers

CRD-C 401-75 Method of Test for the Staining Properties of Water

Wire Reinforcement Institute (WRI)

WRI Manual of Standard Practice

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

American National Standards Institute (ANSI)
1819 L Street, NW
6th floor
Washington, DC 20036
www.ansi.org

American Concrete Institute (ACI)
38800 Country Club Drive
Farmington Hills, MI 48331
www.concrete.org

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

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

Precast/Prestressed Concrete Institute
200 West Adams, Suite 2100
Chicago, IL 60606
www.pci.org

Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60076
www.cement.org

The International Federation for Structural Concrete
Office GC A2 424 at the Swiss Federal Institute of Technology Lausanne
http://fib.epfl.ch

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

MANDATORY REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Specifier
Reinforcement and reinforcement supports	
3.2.1.1	Specify required grades, types, and sizes of reinforcing bars.
3.2.1.10	Specify types of reinforcement supports and location used within structure. Refer to Chapter 3 in *CRSI Manual of Standard Practice*.
3.3.2.3	Specify the cover for headed shear stud reinforcement and headed reinforcing bars. Refer to ACI 318M-08 Chapter 7.
3.3.2.7	Show splices on Project Drawings.
Concrete mixtures	
4.2.2.7.a	Designate in Contract Documents the exposure class for portions of the structure requiring concrete resistant to sulfate attack. Refer to ACI 318M-08 for description of exposure classes.
4.2.2.7.b	Designate in Contract Documents the exposure class for portions of the structure requiring resistance to freezing and thawing. Refer to ACI 318M-08 for additional guidance.
4.2.2.7.c	Designate in Contract Documents the exposure class for portions of the structure requiring low permeability when in contact with water. Refer to ACI 318M-08 for description of exposure classes.
4.2.2.7.d	Designate in Contract Documents the exposure class for portions of the structure requiring corrosion protection of reinforcement. Refer to ACI 318M-08 for additional guidance. Refer to ACI 201.2R and ACI 222R for additional information on the effects of chlorides on corrosion of reinforcement.
4.2.2.8	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 3 days of 12 MPa or higher. Refer to ACI 302.1R for guidance on compressive strengths to specify for various classes of floors.
Handling, placing, and constructing	
5.3.1.4	Specify requirements of base and subgrade preparation. Specify the test methods for base and subgrade.
5.3.7.1	Specify in Contract Documents a project-specific definition of surface defects. Such definition may include dimensions, frequency of occurrence, and visibility under prescribed conditions.
Architectural concrete	
6.1.1.1	Designate areas to be treated as architectural concrete. Describe special requirements of each designated area.
6.2.1.8.a	Specify cone diameter.
6.3.10	Specify which of the finishes from 6.3.10.1 through 6.3.10.3 (a through f) are required. Specify other special finishes required.
Lightweight concrete	
7.1.1	Designate portions of the structure to be constructed of lightweight concrete.
7.2.3.1	For lightweight concrete, specify equilibrium density.
Mass concrete	
8.1.1	Designate portions of structure to be treated as mass concrete. Concrete placements where maximum temperatures and temperature differences must be controlled due to factors including the cementitious content, type of cementitious materials, environment surrounding placement, and minimum dimension of placement should be designated mass concrete. Evaluate the requirements for each portion of project. In general, a placement of structural concrete with a minimum dimension equal to or greater than 2 m should be considered mass concrete. Similar considerations should be given to other concrete placements that do not meet this minimum dimension but contain Type III cement, accelerating admixtures, or cementitious materials in excess of 390 kg/m^3 of concrete. Consideration should also be given to placements that trap heat.
Post-tensioned concrete	
9.2.1.1	Specify type and minimum tensile strength of prestressing steel.
9.2.1.2.a	Specify the type of duct. Ducts may be made from: (a) Galvanized strip steel conforming to ASTM A653/A653M with coating weight of G90; (b) Smooth steel pipes conforming to ASTM A53; (c) Smooth high-density polyethylene ducts conforming to ASTM D3350, cell classification range 424432C to 335534C; and (d) Corrugated polyethylene and polypropylene ducts shall comply with Federation Internationale Beton Technical Bulletin 7, except that polypropylene corrugated duct shall be manufactured from noncolored, unfilled polypropylene meeting the requirements of ASTM D4101 with a cell classification range of PP0340B44544 to PP0340B65884.

MANDATORY REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
9.3.8.1	Specify stressing sequence, minimum concrete compressive strength, and stages at which tendons should be stressed.
Shrinkage-compensating concrete	
10.1.2	Designate areas to be constructed using shrinkage-compensating concrete.
Industrial floor slabs	
11.1.1	Designate portions of structure to be constructed as industrial floor slabs in Contract Documents.
11.3.1	Specify proof-rolling procedure, method of acceptance, and corrective requirements when unacceptable material is identified. Refer to ACI 302.1R and 360R for guidance.
Tilt-up construction	
12.1.1	Designate areas to be constructed as tilt-up concrete panels.
12.3.7	Specify type, location, and extent of each finish.
Precast structural concrete	
13.1.2.1.d	Specify design criteria, and applicable codes and standards.
13.1.3.1	Specify in Contract Documents the category for the erector certification: • Category A (Architectural Systems) for non-load-bearing members; • Category S1 (Simple Structural Systems) for horizontal decking members and single-lift wall panels; and • Category S2 (Complex Structural Systems) for load-bearing members.
13.1.3.2	Specify in Contract Documents the Group and Category for the fabricator: • Group A Category A1—Architectural Precast Products • Group C or CA Category C1—Precast Concrete Products (no prestressed reinforcement) Category C2—Prestressed Hollow-Core and Repetitive Products Category C3—Prestressed Straight-Strand Structural Members Category C4—Prestressed Deflected-Strand Structural Members
13.1.3.4	Specify fire rating in hours of precast concrete members.
13.2.3.a	Specify type and minimum tensile strength of prestressing steel.
13.2.5	Specify grades, types, and surface finish of steel connection materials.
13.2.7.1	Specify strength of grout in Contract Documents.
13.2.12.1	Specify precast concrete member sizes and shapes in Contract Documents.
13.2.12.2	Specify cast-in reglets, slots, holes, and accessories in Contract Documents.
13.2.12.8	Specify compressive strength at release of prestressing force.
13.2.12.10.e	Specify where appearance is critical or exposure is severe.
13.2.14.1	Specify finish. If more than one finish is required, create a finish schedule in Contract Documents. Finishes are in ascending order of finish quality and cost. Specify other specific finish requirements to suit Project. Specify the minimum finish grade consistent with a member's application and the intended use of the structure. Consult fabricators regarding the finishes appropriate for various members and cost effectiveness. Coordinate precast concrete finishes with required floor, ceiling, roof, deck finishes, or toppings. Specify Commercial Grade when the member will not be visible in the completed structure, or when the function of the structure does not require an enhanced surface. This is essentially an "as-cast" finish. Specify Standard Grade where members are exposed to view but the function of the structure does not require a special finish. The surface is suitable for an applied textured coating but not necessarily suitable for painting. This is the typical finish grade for structural members. Specify Grade B Finish on visually exposed structural members such as columns or walls. Grade B Finish is primarily for surface finish. Color variations are acceptable. Specify Grade A Finish where surface will be painted (especially with a textured or "sand" paint); however, some surface blemishes will be visible. If a surface with fewer imperfections than allowed for Grade A is needed, specify the requirements as a "special finish." Requirements for Grade A Finish are not applicable to extruded members manufactured with zero-slump concrete.
13.3.2.2	Specify in-place strength of supporting cast-in-place foundation and building structural framing concrete required before installation of precast concrete members.
13.3.3.5.b	Specify bolt torque.
Precast architectural concrete	
14.1.2.6	Specify the required PCI Category and Group.
14.1.3.3	Specify in Contract Documents where sample panels are to be located.
14.1.3.8.a	Specify size and location of mockup.
14.2.1	When precast concrete is to support all or any part of window washing system, specify design loads including material and equipment to be used.

MANDATORY REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
14.2.2	Specify number and types of anchors if stone veneer precast units are required.
14.2.10	Specify requirements for thin and full brick or ceramic tile.
14.2.12.1.b	Specify selected form liners.
14.2.15.2	Specify required finish for exposed faces. Specify in Contract Documents which structural precast concrete members require an architectural finish (CA category). If more than one finish is required, add locations to finish descriptions or indicate on Drawings. Specify more detailed descriptions of finishes if greater definition is required, such as light, medium, or deep.

OPTIONAL REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Specifier
General requirements	
1.5.2	Specify when Contractor is required to submit a Quality Control Plan.
1.6.1.2	Indicate acceptable certification programs in Contract Document. As a minimum, certification programs should include written and performance evaluations as described in ACI CP-1.
1.6.2.2, 1.6.2.3, 1.6.3.1	Specify if other testing arrangements are required.
1.6.2.2.g	If accelerated testing of concrete is specified or permitted, specify the procedure from ASTM C684 that is to be followed. Specify when standard-cured compressive test specimens are to be tested if other than 28 days.
1.6.3.2.d	Specify in Contract Documents if more frequent sampling and testing will be required. More frequent sampling is typical with high-strength concrete, especially for columns and shear walls, or when control of air content is critical.
1.6.3.2.e	Specify when compressive test specimens are to be tested if other than at 28 days.
1.6.3.2.f	If accelerated testing of concrete is specified or permitted to complement standard strength testing, specify the procedure from ASTM C684 that is to be followed. Specify when standard-cured test specimens are to be tested if other than at 28 days. Specify if companion specimens are to be cast.
1.6.3.2.g	For concrete that will be exposed to deicing salts, define the sampling frequency that will be used for air content tests if different from the frequency for making strength test specimens. It may be appropriate to require more frequent testing at the start of placement. For example, samples may be required from the first three batches in the placement and until three consecutive batches have air contents within the range specified in 4.2.2.7.b, at which time every fifth batch may be tested. This test frequency may be maintained until a batch is not within the range specified in 4.2.2.7.b, at which time testing of each batch may be resumed until three consecutive batches have air contents within the range specified in 4.2.2.7.b.
1.6.3.3	Specify additional testing and inspections services desired for the Work, if applicable. Refer to ACI 311.1R, ACI 311.4R, and 311.5 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. Refer to the discussion under Optional Requirements in 4.2.2.4.
1.6.4.2	Specify if rebound hammer or pulse velocity testing will be permitted to evaluate uniformity of in-place concrete. Refer to ACI 228.1R for guidance on these test methods.
1.6.4.3.a	Specify when cores may be required. Specify alternative moisture conditioning procedures and duration to those defined in ASTM C42/C42M. The core conditioning procedures defined in ASTM C42/C42M are intended to minimize the effects of moisture gradients on the measured strengths of cores.
1.6.4.3.c	Specify alternative curing requirements for repairs to core holes.
1.6.6.1.b	If another basis for acceptance of concrete strength is required for accelerated strength testing, specify the basis for acceptance.
1.6.6.3	Specify requirements for use of in-place tests, such as pullout testing or penetration resistance (probe) testing, in the event standard-cured specimens fail to meet the strength criteria. Include procedures to develop strength correlations. Refer to ACI 228.1R for guidance on required correlation data and acceptable data analysis methods.
1.6.7.1	Indicate in Contract Documents if on-site addition of air-entraining agent is not permitted when air content as delivered is less than required.
1.6.7.2	Indicate in Contract Documents when job-site adjustments in accordance with ASTM C94/C94M are not permitted.
1.6.7.3	Indicate in Contract Documents if maximum and minimum temperatures other than those given in 4.2.2.6 are permitted. The Architect/Engineer will need to decide if other limits are acceptable without affecting performance.
1.7.2.1	Specify tolerances different from those in ACI 117M or in this Specification.
Formwork and formwork accessories	
2.1.2.1	Review the submittal list and specify in Contract Documents the items that are not required to be submitted.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
2.1.2.2	Review the submittal list and specify in Contract Documents the items to be submitted.
2.2.1.1	Specify specific form-facing materials.
2.2.1.2	Indicate where walls require form ties with a positive water barrier. Specify alternative breakback distance for ferrous ties.
2.2.1.6	Specify alternative materials or size, or both, for chamfer strips.
2.2.2.1	Specify when design calculations and drawings for formwork should be signed and sealed by a licensed design engineer.
2.2.2.3	Specify if earth cuts will be permitted or required.
2.2.2.4	Specify more stringent limitations on deflection of facing materials when needed. Refer to ACI 347 for further guidance.
2.2.2.5.a	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.b	Specify keyway depths other than 40 mm when required. Specify mechanical load transfer required for industrial floors.
2.2.3.2, 2.3.1.2	Specify if chamfer strips are not required on exterior corners of permanently exposed surfaces. Specify if bevels are required on reentrant corners of concrete or on edges of formed concrete joints.
2.2.3.3	Specify alternative breakback distance for ferrous ties.
2.3.1.5	Specify tolerance limits different from those of ACI 117M. Specify when a more or less restrictive tolerance for abrupt offset is required. Refer to ACI 347 and ACI 117M for further guidance.
2.3.2.5	Specify the minimum compressive strength for removal of forms supporting the weight of concrete if different from f_c'. Refer to ACI 347 and ACI 347.2R for guidance on items to consider. Specify if non-load-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.
2.3.5.2	Specify if Owner's quality assurance inspection is to be coordinated by Contractor.
Reinforcement and reinforcement supports	
3.1.1.1	Specify if the submittals listed in 3.1.1.1.a through 3.1.1.1.g are not required to be submitted.
3.1.1.2	Specify if the submittals listed in 3.1.1.2.a and 3.1.1.2.b are not required to be submitted.
3.1.1.3	Specify if the submittals listed in 3.1.1.3.a and 3.1.1.3.b are not required to be submitted.
3.2.1.2	Specify if coated reinforcing bars are required and, if so, whether coating is to be zinc or epoxy.
3.2.1.2.a	For zinc-coated reinforcing bars conforming to ASTM A767/A767M, specify coating class, 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 reinforcement or other embedded steel that could result in galvanic cells.
3.2.1.2.b	Specify ASTM specification to which epoxy-coated reinforcing bars are to conform.
3.2.1.4	Specify use of bar mats.
3.2.1.5	For headed bars, specify alternative type of steel for reinforcing bars: • Carbon-steel (ASTM A615/A615M), also specify grade; and • Low-alloy steel (ASTM A706/A706M).
3.2.1.7	Specify sheets or rolls of plain or deformed welded wire reinforcement and, if required, epoxy-coated or stainless steel welded wire reinforcement. Refer to *WRI Manual of Standard Practice* for additional guidance.
3.2.1.9	Specify if steel fiber reinforcement is required for use in accordance with ACI 318M-08.
3.2.2.2.a	Specify if welding of reinforcing bars is required or permitted. If required or permitted, specify desired requirements for welding preparation (such as removal of zinc or epoxy coating) more stringent than those in AWS D1.4/D1.4M. Specify desired requirements for chemical composition of reinforcing bars more stringent than 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 cover requirements for corrosive atmosphere, other severe exposures, or fire protection. Refer to ACI 318M-08 Chapter 7.
3.3.2.4	Specify if 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 control joints, including saw-cut joints.
3.3.2.8	Specify if bending or straightening reinforcing bars partially embedded in concrete is permitted.
3.3.2.9	Specify if field cutting reinforcement is permitted and specify cutting methods to be used.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
Concrete mixtures	
4.2.1.1	Specify when cementitious material other than ASTM C150 Type I or Type II is required or permitted. Specify the cementitious materials that may be used. When one or combinations of cementitious materials given in 4.2.1.1.a through 4.2.1.1.f are used in structures that will be subjected to deicing chemicals, verify compliance of the concrete with 4.2.2.7.d. Use ACI 318M-08 and 225R to determine what will be acceptable for the project conditions. Refer to PCA Publication EB001 for additional guidance. If it is anticipated that concrete will be exposed to sulfates in service, evaluate the water-soluble sulfates in the soil and groundwater. Use the criteria in 4.2.2.7.a and Table 4.2.2.7.a.1 to determine the cement type. Verify the availability of the cement specified. 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, the proposed project mixture of fly ash and portland cement from the same source should be tested and compared with a control mixture using only the portland cement in accordance with ASTM C441. 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 can be critical, consider requiring the test comparison at a frequency such as every 3 months during the Work. 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 effective in mitigating harmful expansions due to alkali-silica reactivity. Alternatively, specify low-alkali cement be used as described in the Optional Requirements Checklist for 4.2.1.2.
4.2.1.1.d	Specify when the minimum amount of fly ash may be different than 15%.
4.2.1.2	If aggregates are to conform to a specification other than ASTM C33 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 additional requirements for aggregate such as hardness, color, mineralogical composition, texture, or shape (crushed or gravel). If concrete will be exposed to wetting, extended humidity, or in contact with moist ground, specify 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 C441.
4.2.1.3	Specify if nonpotable water complying with ASTM C1602/1602M is permitted.
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 finishability of the proposed concrete mixture.
4.2.2.2	If slump is to be different than 100 mm, specify the requirement. Sometimes, it is necessary 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 100 mm at the point of delivery to obtain 100 mm slump at the end of the pumpline. Once 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 40 mm slump loss during pumping is established and confirmed by comparative testing, a slump of 140 mm measured at the point of delivery will meet the 100 mm 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 (*w/cm*), such as 0.25 to 0.30, modify the slump requirements accordingly 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 should be non-air-entrained or an alternative air content is required. Air entrainment should not be used in flatwork to receive a hard steel-troweled finish. Specify if a particular ASTM test method (ASTM C231 or C173/C173M) is required for measuring air content. 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 discharge can be determined.
4.2.2.5	Specify admixture types 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 that will be subjected to severe (S2) or very severe (S3) sulfate exposure as defined in Table 4.2.1 of ACI 318M-08.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
4.2.2.6	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 Contractor to follow specific procedures to achieve the limits of 4.2.2.6, the temperature limits for cold weather may be deleted and ACI 306.1 can be referred to in its entirety. Options provided in ACI 306.1 must then be exercised. Also, Refer to the Optional Requirements Checklist for 5.3.6.1. If concrete delivered in hot weather with a temperature higher than 35°C has been used successfully in given climates or situations, the higher temperature may be specified in place of the 35°C limit.
4.2.2.7.a	Specify alternative mixture requirements for sulfate resistance.
4.2.2.7.b	Specify alternative mixture requirements for freezing and thawing resistance.
4.2.2.7.c	Specify alternative requirements for low permeability.
4.2.2.7.d	Specify alternative mixture requirements for corrosion protection of reinforcement.
4.2.2.8	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 *w/cm* not exceeding the value in ACI 318M-08 Table 4.3.1.
4.2.2.8.a	If the test specimen is other than a 150 x 300 mm or 100 x 200 mm cylindrical specimen, specify the specimen size. 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.
4.2.2.9	Indicate in Contract Documents where steel fiber-reinforced concrete is required and specify properties in accordance with ACI 318M-08.
4.2.3.4.b	Specify the test ages, if other than 28 days, for trial mixture proportioning. Specify if submittal trial mixture proportions and strength test records from trial mixture with proposed mixture properties is not required.
4.2.3.5	Specify when field verification of concrete mixtures is required. Specify method for sampling at point of placement.
4.3.1.1	If concrete materials are to be measured, batched, or mixed other than in conformance to ASTM C94/C94M, specify how these procedures are to be accomplished. Specify if the ready mixed concrete production facility should be certified by the NRMCA Program for Certification of Ready-Mixed Concrete Production Facilities or an equivalent program. NRMCA's Certification Program is in accordance with *NRMCA Quality Control Manual* — Section 3.
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.f are not required to be submitted.
5.1.2.1.f	Specify if a request for acceptance of preplacement activities is not required. When necessary, specify a preconstruction conference be held before construction activities commence.
5.1.2.2.c	Specify if a request for acceptance of wet-weather protection should be submitted.
5.1.2.2.d	Specify if a request for acceptance of hot-weather precautions should be submitted.
5.1.2.2.e	Specify if a request for acceptance of cold-weather precautions should 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.
5.2.1.1	Where appearance is a factor, specify curing water that is free of substances that will stain or discolor concrete. The staining ability of curing water can be evaluated by means of CRD-C 401.
5.2.1.4	Specify alternative repair materials. The material should be appropriate for exposure conditions and bond to the existing member.
5.3.2.1.c	If a concrete temperature limit higher or lower than 35°C for concrete members is required or acceptable, based on member being cast, location, relative humidity, and past experience, specify a lower or higher allowable concrete temperature in hot weather. Review ACI 305R for guidance on specifying a higher temperature.
5.3.2.5	Specify when consolidating of concrete by methods other than vibration will be permitted. Specify when other methods of consolidation are permitted.
5.3.2.6	Specify if bond is required at construction joints.
5.3.3.2	Specify if the required finish is to match that of a sample panel 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. Refer to Optional Requirements Checklist for 2.2.2.6 for additional guidance.
5.3.3.3.b	Specify if mockup is not required.
5.3.3.4	Designate those portions of the structure to receive surface finish SF-2.0.
5.3.3.4.a	Designate those portions of the structure to receive a smooth-rubbed finish.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
5.3.3.4.b	Designate those portions of the structure to receive a grout-cleaned rubbed finish. Specify alternative grout requirements. One example may be matching the color of grout to color of concrete surface to which grout will be applied. Where color is a concern, consider including a statement that when color of grout lightens due to drying, rub the surface and keep the surface damp for 36 hours afterward.
5.3.3.4.c	Designate those portions of the structure to receive a cork-floated finish. Specify alternative grout requirements. One example may be matching the color of grout to color of concrete surface to which grout will be applied.
5.3.3.5	Specify location and type of alternative as-cast formed finish.
5.3.4.1	Specify when more or less certified flatwork concrete finishers may be required or permitted. More stringent qualifications for finishing contractor and finishers may be appropriate where floor serviceability is significant to 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 skilled in the specific Work required. Flatwork finishers should be certified on the basis of documented work experience or successful completion of a certification program that includes written and performance examinations as described in ACI CP-10.
5.3.4.2.b	When applicable, specify tolerances that are more restrictive. The ACI 117M tolerance for conventional surfaces applies to most general floor construction. For floors requiring tighter tolerances, specify "moderately flat," "flat," "very flat," or super flat" floor tolerances from ACI 117M. Refer to ACI 302.1R and the commentary for ACI 117M for more guidance.
5.3.4.2.c	When applicable, specify tolerances that are more restrictive. The conventional tolerance from ACI 117M 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 117M. Refer to ACI 302.1R and the commentary for ACI 117M for more guidance.
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. Specify when bonding agents other than cement grout are permitted or required.
5.3.4.2.h	Specify the location of nonslip finishes. 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 9.5 to 16.0 mm).
5.3.4.3.a	Specify if an alternative time for measuring tolerances is required.
5.3.4.3.b	Alternative floor finish tolerances, floor types, and floor areas may be specified where applicable. The "3-m straightedge method" of measuring tolerances specified in ACI 117M applies to many small general floor construction applications. The F-number measuring system specified in ACI 117M 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 117M 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. Use caution when 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 ACI 302.1R and the commentary for ACI 117M for further guidance.
5.3.5	Specify if saw-cut joints are required.
5.3.6.1	The measures specified in 5.3.6 are for final curing of the concrete. Specify initial curing in accordance with ACI 308.1 for additional protection against moisture loss from the time of placement to initiation of final curing measures. Initial curing measures are beneficial when bleed rate is expected to be low due to use of supplementary cementitious materials such as fly ash, slag, or silica fume; high air content; low *w/cm*, or when evaporative conditions are likely to be severe during placing and finishing. Refer to ACI 308R for additional guidance. For concrete surfaces that require enhanced durability, such as high wear resistance, low permeability, or minimal cracking, a longer curing duration could 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. Specify a longer curing duration as appropriate to the performance requirements of the concrete. Refer to ACI 308R for additional guidance. Specify if a curing procedure of 5.3.6.4 that supplies additional water is required. Specify if one of the three criteria for terminating curing, or of some other criterion for terminating curing is required. Specify if supplying additional water is required for entire curing period.
5.3.6.4	Specify locations requiring specific curing methods. Refer to ACI 308R for specific curing method recommendations.
5.3.6.5	Requirements for rate of temperature change have been excerpted from ACI 306.1. For optional cold-weather concreting requirements, refer to the Optional Requirements Checklist for 4.2.2.6 and specify ACI 306.1 in its entirety, if appropriate.
5.3.7.3	Specify alternative repair method.
5.3.7.6	Specify where stains, rust, efflorescence, and surface deposits are to be limited, and describe the degree to which they are unacceptable.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
Architectural concrete	
6.1.1.3	Review Sections 1 through 5 and specify requirements to be omitted or added for architectural concrete.
6.1.2.4	Specify when Contractor is required to submit a disposal plan for waste water resulting from surface washing operations.
6.1.3.1	Specify which systems or products require manufacturer's on-site technical specialist. Specify when and for how long a technical specialist approved by the specialty item manufacturer should be on site to provide technical assistance.
6.1.3.2	Specify in Contract Documents if preconstruction conference is required.
6.1.3.3	Specify when architectural concrete shall match an Architectural Concrete Reference Standard. Indicate locations of Architectural Concrete Reference Standards in Bid Documents and Contract Documents.
6.1.3.4.a	Specify when field mockups are required and indicate specific requirements for mockups.
6.2.1.1	Specify when a specific cement will be required for architectural concrete.
6.2.1.2.a	Specify if water other than potable water is acceptable.
6.2.1.3	Specify when special aggregate is required for architectural concrete. Special aggregate requirements may include a specific color, shape, or size.
6.2.1.3.a	Specify aggregate requirements.
6.2.1.7.a	Specify type of formwork if other than high-density, non-vapor-transmitting form face is permitted.
6.2.1.9	Specify when location, size, and spacing of rustications and reveal strips are required to be indicated.
6.2.1.11.e	Specify where acid is to be used.
6.2.2.1.b	Specify if tolerances other than ACI 117M Class A finishes are required.
6.2.2.1.d	Specify if it is permissible for ties to be located within exposed areas of architectural concrete.
6.3.5	Specify areas where a smooth-rubbed or similar finish is required.
6.3.8	Specify conditions for form removal if other than specified in Section 2.
6.3.9.2	Specify areas where as-cast finishes are permitted or required. Specify if ties are permitted within as-cast areas.
6.3.10.3.a	Specify degree of abrasive blasting using the description "brush," "light," "medium," or "heavy."
Lightweight concrete	
7.1.1	Review Sections 1 through 5 and specify requirements to be omitted or added for lightweight concrete.
7.2.2.1	Specify if air content will be measured at alternative locations. Air measurement is allowed at the point of delivery when there is no concern over air loss in lightweight concrete during conveying and placement procedures. When concrete is sampled in any method other than as specified by ASTM C172, specify where the concrete is to be sampled and describe the method to obtain samples.
7.2.2.2	Specify that if slump loss during pumping is determined, acceptance or rejection of concrete based on slump may be determined at delivery point. Specify if a plasticizing or high-range water-reducing admixture is required or permitted to produce concrete with high flowability. If so, specify required slump if different from those indicated in 4.2.2.2.
7.2.3.1	Specify method of determining equilibrium density if other than calculated method in ASTM C567. Other methods listed in ASTM C567 include oven-dry method, and measured equilibrium density method.
Mass concrete	
8.1.2	Specify if maximum temperature limit in concrete after placement can be other than 70°C. Maximum temperature is limited to minimize future durability concerns due to delayed ettringite formation (DEF) and potential reductions in ultimate strength. Concrete that contains supplementary cementitious materials may have a reduced risk of DEF and may justify internal temperatures above 70°C (Gajda 2007). Specify if maximum temperature difference limit in concrete after placement can be other than 19°C. The temperature difference must be limited to minimize thermal cracking. A higher temperature difference limit may be acceptable depending on concrete properties, placement dimensions, and reinforcement configuration. The temperature difference limit for a specific concrete mixture and placement conditions can be determined through numerical simulations and comparing calculated thermally-induced strains with tensile strain of concrete. Refer to ACI 207.2R for additional guidance.
8.1.3	Specify if thermal control plan is not required. Specify if thermal control plan shall have requirements other than listed. A thermal control plan may address a single placement or a series of similar placements that use same concrete mixture.
8.2.1.1.a	Specify if other types of cementitious materials are allowed. Specify maximum allowable quantities of supplementary cementitious materials. In many mass concrete placements, Class F fly ash makes up 40 to 50% of cementitious materials, or slag cement makes up 50 to 75% of cementitious materials. Ternary mixtures are also sometimes used. Reduced replacement levels are sometimes required due to durability concerns related to exposure, as addressed in Section 4. Because concretes with low heat-of-hydration cements, high replacement levels of slag cement, or Class F fly ash generally have delayed set times and lower early strengths, consider early age implications on setting times, form pressures, formwork removal, cylinder handling, curing duration, and post-tensioning. When slag cement is less than 50% of cementitious materials, adiabatic temperature rise may be higher than if slag cement is not included in cementitious materials.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
8.2.1.1.b	Specify if high-early-strength cement is permitted, when thermal control plan demonstrates that specified maximum temperature and temperature difference limits will not be exceeded.
8.3.1.1.a	Specify if a curing duration longer than given in 5.3.6.1 is required. 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, extend curing period at least 14 days. If a measurement or determination of early-age in-place strength is used to reduce curing time, strength measurement should be at weakest location of placement, which is at its surface.
8.3.1.1.b	For formed surfaces, specify acceptable methods of preserving moisture, other than maintaining forms in place. Specify if water curing is permissible when thermal control plan demonstrates specified maximum temperature and temperature difference limits will not be exceeded.
8.3.1.2	Specify if a specific duration of thermal control is required. At least 7 days of thermal control is typically required to avoid exceeding temperature difference limits. A longer period may be required for certain placements.
8.3.1.2.a	Specify alternative requirements for the minimum number of temperature sensors and where they should be located. Specify alternative requirements for how frequently temperature sensors should be monitored. Specify frequencies of data submittal if other than daily transmittals are required.
8.3.1.2.b	Specify if temperature comparisons are not required or are permitted at a different frequency. Comparisons are recommended at least once per working day.
Post-tensioned concrete	
9.1.1	Review Sections 1 through 5 and specify additional requirements or requirements to be omitted for post-tensioned concrete.
9.1.2.1.a	Specify if shop drawings are to be signed and sealed by a licensed design engineer. Specify when duct stiffness test data are to be submitted.
9.1.2.1.b	Specify when calculations are to be submitted. Specify if calculations are to be signed and sealed by a licensed design engineer.
9.1.2.1.c	Specify if design calculations are to be submitted.
9.1.2.1.d	Specify additional test submittals.
9.1.2.2	Specify required submittals.
9.1.3.1.b	Specify when aggressive environments exist and appropriate testing is required.
9.2.1	Indicate areas considered aggressive environments where encapsulation of prestressing steel at stressing, intermediate, and fixed anchorages is required. Specify if test data is to be submitted to demonstrate compliance of encapsulated anchors with the watertightness requirements of ACI 423.7.
9.2.1.2.c	Specify minimum duct-steel area ratio. In the case of space limitations, the minimum duct area may be reduced to 2.0 times the net area of prestressing steel, and should be considered acceptable for short tendons (approximately 30 m).
9.2.1.2.d	If required, specify other locations of outlets and inlets.
9.2.1.2.e	Specify when duct testing is required. Specify minimum duct radius and bending stiffness, if more flexible duct is required to accommodate small radius bends.
9.2.1.4	Indicate coupler locations when required.
9.2.2	Specify if either a thixotropic or nonthixotropic grout is required. Specify when verification of grout consistency is desired.
9.2.2.1	Specify whether supplementary cementitious materials are permitted. If desired, specify grout mixture proportions.
9.2.2.2	Specify if alternative admixtures can be used.
9.2.2.2.c	Indicate when corrosion inhibitors are required.
9.2.2.2.d	Indicate when shrinkage-compensating or expanding admixtures are required. Specify if ASTM C940 test results are required.
9.2.2.3	Specify which tests are not required.
9.2.2.3.b	Specify test(s) for bleeding if the grout is intended for an aggressive environment. Specify test pressure and maximum bleed for the bleed stability test if default values are unacceptable. Specify when replicate tests are required and the number of tests required.
9.2.2.3.d	Specify minimum compressive strength.
9.2.2.4.a	Specify field trial tests. When required, specify field mockup tests of grout.
9.3.1	Specify alternative qualifications for installers.
9.3.2	Specify additional parameters of inspection. Specify certification requirements for inspectors.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
9.3.3.4.b	Specify air pressure and acceptance criteria for pressure testing duct.
9.3.4.1	Specify experience requirements for grouting supervisor and required proof of experience.
9.3.4.6	In aggressive environments, specify that the tendon ends are protected by coverings until the acceptance for cutting of the tendons tails has been given by Architect/Engineer.
9.3.5.5.c, 9.3.5.5.f	Specify alternative cover requirements.
9.3.5.6.a	Specify watertight joints when required. In aggressive environments, the joint should be watertight.
9.3.5.8.b	Specify if repairs are not required.
9.3.6.3	Specify other tolerances when required.
9.3.6.4	Specify other additional hairpin reinforcement where radius of curvature is less than 480 strand diameters.
9.3.9.1	Specify alternative methods of removing surplus lengths of tendons beyond anchorages.
Shrinkage-compensating concrete	
10.1.2	Specify requirements of Sections 1 to 5 that do not apply.
10.2.1.1.a	If expansive cement other than ASTM C845, 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 sufficient testing.
10.2.1.2.a	Accelerating admixtures, specifically ones that contain calcium chloride, may reduce concrete expansion and should not be permitted for use in shrinkage-compensating concrete.
10.2.2.2	If different minimum and maximum expansion limits 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 150 mm 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 minutes, 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 quantity of reinforcement required. Shrinkage-compensating concrete must always be reinforced. Determine the required amount of reinforcement in accordance with ACI 318M-08. Refer to ACI 223 for additional guidance.
10.2.5	Specify alternative compressible isolation-joint filler material if desired.
10.3.1.2	Specify bar position in reinforced slabs-on-ground if different from 50 mm from top surface.
10.3.2.2	If a longer time between casting adjoining sections is needed, specify the time required. Refer to ACI 223 for guidance.
10.3.4	If curing is to be continued for longer than 7 days, or if a method other than water curing is acceptable, specify the requirements in Contract Documents.
Industrial floor slabs	
11.1.2	Specify requirements of Sections 1 to 5 that do not apply.
11.1.2.1	Specify if less than 150 mm thick slab is allowed. Specify alternative base requirements.
11.1.3.2.a	Specify if shrinkage test results are to be submitted and the shrinkage limit required. Ultimate concrete shrinkage may be predicted from early-age test results in accordance with ACI 209R. If desired, specify longer drying period for shrinkage data.
11.1.3.2.d	Specify if manufacturer's data sheet on equipment to install contraction joints is a required submittal.
11.1.3.2.e	Specify if curing compound can be used where subsequent finish flooring is to be installed. Specify acceptable curing compound or require curing compound removal by acceptable method before installing floor finish.
11.1.3.2.j	Specify if maximum joint spacing greater than 4.6 m is acceptable. Joint layout should adhere to the maximum joint spacing recommended by ACI 360R based on the shrinkage characteristics of the concrete mixture. Joints should be continuous. Avoid "T" intersections.
11.1.3.2.l	Specify if design of construction joint forms is to be submitted.
11.2.1.1	Specify whether ASTM C150 Type III, high-early-strength cement is acceptable. Type III cement may significantly increase the potential for concrete shrinkage and thermal cracking.
11.2.1.2.a	Specify aggregate requirements if ASTM C33 requirements are insufficient or if alternative nominal maximum size is desired. More restrictive gradation or limitations of lignite, coal, or other deleterious substances may be required. Refer to ACI 302.1R for further guidance.
11.2.1.2.b	Specify if alternative aggregate is acceptable for use as a base course material.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
11.2.1.3.a	Specify if admixtures containing chloride ions are acceptable and maximum dosage based on ultimate shrinkage submittal.
11.2.2	Specify alternative or additional mixture requirements if desired.
11.2.2.2	Specify an alternative maximum temperature if desired. Refer to ACI 360R and ACI 305R for guidance and consider a lower alternative temperature limit to decrease risk of cracking due to thermal contraction. Consider requiring that evaluation of concrete mixture in 11.2.2 be performed at the anticipated placement temperature.
11.2.4	Specify alternative vapor retarder material and required thickness if less than 0.25 m.
11.2.5	When required, specify the type(s) of slab reinforcement and indicate the amounts and locations of slab reinforcement in Contract Documents.
11.2.6	Specify joints to receive load-transfer devices and indicate acceptable types of devices. Acceptable mechanical load-transfer devices may be smooth dowel bars (round or square) or dowel plates (available in a variety of shapes and installation systems). Steel load-transfer devices must have a method to prevent bonding with concrete.
11.2.7	Specify alternative joint filler material.
11.2.8	Specify additional material requirements if required. If the joint material is anticipated to be in compression such as at the perimeter of columns in post-tensioned slabs or shrinkage-compensated slabs, use compressible isolation-joint filler material that does not develop a stress greater than 170 kPa at 50% strain when tested in accordance with ASTM D1621 or D3575.
11.2.10	Specify areas where densifier is to be used.
11.2.11	Specify areas where dry-shake hardener is to be used.
11.3.1	Specify compaction in accordance with ASTM D1557 when a higher base density is required. Indicate areas where a vapor retarder is required directly beneath slab.
11.3.5	Specify if alternative finish is desired. Refer to ACI 302.1R for guidance. Consider requiring the use of a highway straightedge to improve flatness. In addition, when aggregate shadowing appears while finishing concrete that has been optimized for shrinkage performance, consider requiring walk-behind power trowels equipped with float shoes as first pass instead of pan floats. Specify when surface hardener is required.
11.3.5.1	Specify alternative surface tolerances if required.
11.3.6.2	Specify construction joints that do not have to be saw cut. Joints trafficked by hard-wheeled vehicles should be saw cut and filled with a semi-rigid joint filler.
11.3.6.3	Specify alternative requirements for contraction joints when required.
11.3.7	Specify if a curing period of less than 7 days is acceptable.
11.3.8	Specify when a liquid surface densifier is required.
11.3.9	Specify joints not to receive semi-rigid filler. Specify if joint filling should be performed at a time other than that recommended by the manufacturer. According to ACI 209R, 90% of the shrinkage can be expected during the first 12 to 18 months under sustained drying. As concrete shrinks, joints widen. Joint widening causes filler separation that requires correction. Specify if joint filler monitoring/correction should be extended for longer than the warranty period.
Tilt-up construction	
12.1.3	Review Sections 1 through 5 and specify requirements to be omitted or added for tilt-up concrete.
12.1.4	Specify which submittal items are not required.
12.2.1	Specify if special aggregates are required.
12.2.2	Specify alternative bearing shims.
12.2.9	Specify different R-value if applicable.
12.3.1	Specify if waste slabs are to be used.
12.3.11.2	Specify if aggregate exposure other than 10 mm is required.
12.3.14	Specify if aggregate reveal other than 3 mm is required.
12.3.16	Specify where liquid membrane-forming curing compounds are not to be used.
12.3.17.4	Specify repair procedure to correct panel damage.
12.3.19.1, 12.3.19.3	Specify when beams are required.
Precast structural concrete	
13.1.1	Specify if Section 7 lightweight concrete requirements apply.
13.1.2.1.a	Specify if submittal of concrete mixture proportions and characteristics are not required.
13.1.2.1.b	Specify if shop drawings for temporary bracing and shoring should be submitted. Specify if calculations for temporary bracing and shoring are required. Specify if shop drawings for fabrication should be submitted.
13.1.2.1.d	Specify if structural design calculations are to be submitted.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
13.1.2.1.e	Specify if design calculations are to be submitted.
13.1.2.2.a	Specify if test reports or material certifications are to be submitted and signed by authorized manufacturer or suppliers' representative.
13.1.2.3	Specify retention period of product data if longer than 5 years is desired.
13.1.3.1	If applicable, specify that erector is not required to be qualified by PCI. Erector to have experience in precast concrete work on at least three comparable projects of similar scope with Owner or Architect/Engineer determining the suitability of the experience. Contact PCI for current listing of PCI Qualified Erectors.
13.1.3.2	Specify if different fabricator qualifications are allowed. PCI MNL 116 and MNL 117 mandates source testing requirements and a plant Quality Systems Manual. PCI certification also ensures periodic auditing of plants for compliance with requirements in PCI MNL 116 and MNL 117. Specify alternative personnel certification requirements for testing and inspection. Specify if 5 years of work experience is not required.
13.1.3.3	Specify if welder qualification is not required.
13.1.3.4	Specify if fire resistance calculation is not required. When fire resistance is required to be calculated, specify PCI MNL 124 or ACI 216.1/TMS 0216.1.
13.1.3.5	Specify if preconstruction conference is not required.
13.2.1.1	Specify when Contractor does not have design responsibility.
13.2.3.a	Specify requirements differing from Section 3 or those specified in this section. Guidance for evaluating the degree of rusting on strand is given in Sason (1992).
13.2.4.1	Specify requirements differing from Section 4 or those specified in this section.
13.2.4.2	Specify if lightweight aggregates are required. Review Section 7 and modify requirements to suit project.
13.2.6.1	Specify if a particular bearing pad is required.
13.2.6.2.a	Specify requirements of reglets.
13.2.7.1	Specify alternative materials if desired. Add other proprietary grout systems to suit Project. Show locations of each grout in Contract Documents if requiring more than one type.
13.2.7.2	Specify if nonshrink grout is required. Specify if ferrous grouts can be used. Specify when field installation procedures should be submitted.
13.2.7.3	Specify type, grade, and class if epoxy grout is required.
13.2.8.1	Specify if insulated members are required. Specify insulation type, thickness, R-value, and location for each member type used in the Work.
13.2.8.5	Specify wythe connectors if particular connector desired.
13.2.9.2	Specify different compressive strength when required. Higher-strength mixtures may be available; verify availability with fabricators. Specify if lower *w/cm* is required to suit Project. Specify air content.
13.2.9.3	Specify when lightweight concrete is required. Specify different 28-day compressive strength and density when required. Coordinate with lightweight aggregate supplier and precast concrete fabricator. Some combinations of lightweight and normalweight aggregates in lightweight concrete mixtures may produce densities greater than 1840 kg/m^3. Specify air content.
13.2.10.1.b	Specify different edge or corner treatment when required.
13.2.12.4.b	Specify if laps are not required, or if different lap length is required for welded wire reinforcement.
13.2.12.9	Indicate if a temperature higher than 67°C is acceptable. A maximum concrete temperature of 77°C is acceptable if one of the following measures is used: • ASTM C150 Type V portland cement with Blaine fineness less than 400 m^2/kg, or ASTM C595 Type IP blended cement with at least 20% Class F fly ash, or ASTM C595, Type IS blended cement with at least 35% slag cement; • Cement with 1-day mortar strength (ASTM C109/C109M) less than 20 MPa; • Replace portland cement with 20 to 35% (by mass) of fly ash meeting ASTM C618, Class F; • Replace portland cement with 35 to 50% (by mass) of slag cement meeting ASTM C989; • Replace 35 to 50% (by mass) of portland cement with a combination of ASTM C618, Class F fly ash (maximum 35%), ASTM C989 slag cement, and ASTM C1240 silica fume (maximum 10%); • Replace 35 to 50% (by mass) of portland cement with a combination of ASTM C618, Class C fly ash (maximum 35%) and at least 6% ASTM C1240 silica fume (maximum 10%), ultra-fine fly ash, or ASTM C618 Class N metakaolin; and • Replace 10% (by mass) of portland cement with a metakaolin meeting ASTM C618 Class N. Indicate which combination of cementitious materials will be acceptable. Select the combinations that will be suitable for the expected service conditions. For concrete dry or protected from moisture, specify if maximum concrete temperature of 82°C is acceptable.

OPTIONAL REQUIREMENTS CHECKLIST (cont.)

Section/Part/Article	Notes to Specifier
13.2.12.10	Specify if pretensioning or post-tensioning is required.
13.2.12.11	Specify alternative acceptance requirements for repairs if required.
13.2.12.12.1	Specify if insulated panels are required.
13.2.12.12.3	Specify finish for insulated panels.
13.2.13.1	Specify tolerances different than those specified in ACI ITG-7M.
13.2.14.2	Specify if screed finish, float finish, or other finish is desired.
13.2.15.1	Specify if PCI plant certification and testing and inspection program is not required.
13.3.3.4.b	Specify alternative weld requirements.
13.3.3.7	Specify if cutting or coring is permitted after installation.
13.3.3.8	Specify if drilled or powder-actuated fasteners may be used.
Precast architectural concrete	
14.1.1	Review Section 13 and modify requirements to fit project.
14.1.2.1	Specify if water-absorption tests are to be submitted.
14.1.2.5	Specify which of the items in 14.1.2.5.a through 14.1.2.5c are required.
14.1.2.6	Specify different fabricator qualifications if acceptable.
14.1.3.2	Revise size and number of sample panels to suit Project. Specify if sample panels are not required.
14.1.3.7	Specify if range samples are required.
14.1.3.8	If mockups are required, specify number, location, size, and other details in Contract Documents.
14.1.3.9.f	Specify if separate mockup is required for testing by others. Specify required testing.
14.2.3	Specify if form liner is required and add description of the particular form liner selected.
14.2.4	Specify if surface retarder is required.
14.2.5.1	If half-brick, veneer-faced, precast concrete units are required, specify ASTM standard type and grade, face size, and dimensional tolerances.
14.2.5.2	Specify if different properties are required or permitted.
14.2.5.2.l	Specify face color and texture to match design reference sample, if required. Specify if surface-colored brick, other than flashed or sand-finished, is to be used.
14.2.5.2.m	If required, specify back surface texture. Examples of descriptions are scored, combed, wire-roughened, ribbed, key backed, or dovetailed.
14.2.6	Specify properties if different than noted or as required for particular project. Refer to ANSI A137.1 for commonly available sizes, shapes, physical properties, basis for acceptance, and testing methods.
14.2.7	Specify applications where terra cotta units are required.
14.2.8	Specify other allowable mortar for joints.
14.2.9	Specify if brick unit joints are to be filled after precast concrete panel production. Specify if a particular grout type is required. Refer to ANSI A118.6 for additional recommendations.
14.2.9.3	Specify pointing grout color if reference sample panel not used or required.
14.2.11.3	Specify if flexible sealant is required in anchor holes to prevent water intrusion into stone and future discoloration at anchor locations. Specify if filling anchor holes is not required.
14.2.11.4	Specify if rigid filler is required to prevent water intrusion into stone and future discoloration at anchor locations. Specify if filling anchor holes is not required.
14.2.11.5	Specify if epoxy is required in anchor holes.
14.2.11.6	Specify other types of bond breaker if desired such as preformed, compressible, resilient, nonstaining, nonwaxing, closed-cell polyethylene foam pad, nonabsorbent to liquid and gas, 3 mm thick.
14.2.12.1.a	Specify thin or half-brick facings.
14.2.13	Specify if stone facing is required. Specify location of stone facings and anchorage requirements if different from minimum specified, embedment depth of anchors into concrete, supports, and attachments. Indicate stone veining direction on drawings.
14.2.14	Specify particular face technique when required.
14.2.14.2.b	Specify cement and aggregate requirements. Face and backup mixtures should have similar aggregate shrinkage and coefficient of thermal expansion with similar *w/cm*.
14.2.15.3	Specify float finish, light-broom finish, stippled, or as-cast finish if smooth, steel-trowel finish is unnecessary.
14.2.15.5	Specify if cleaning is not necessary.
14.3.1.1	Specify different joint width.

SUBMITTALS CHECKLIST

These items listed will be submitted by the Contractor and reviewed by the Architect/Engineer. 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 Specifier
General requirements	
1.5.2	When required, Quality Control Plan.
1.6.2.1	Qualifications of proposed testing agency.
1.6.2.2.e	Test data on materials and concrete mixtures.
1.6.2.2.f	Quality control program of the concrete supplier. Refer to the NRMCA publication *Guideline Manual for Quality Assurance and Quality Control* for a description of suitable quality control program.
1.6.2.2.g	Request to use accelerated testing. Correlation data and statistical procedure that will be used to estimate the standard-cured, 28-day strength from the measured accelerated strength.
1.6.5.1	Documentation of actions to increase strength test results.
1.6.5.3	Correlation data relating compressive strength to the results of the in-place test. Refer to ACI 228.1R for acceptable correlation testing programs. Using cast-in-place cylinders in accordance with ASTM C873/C873M does not require correlation; however, measured strengths need to be corrected using the factors in ASTM C42/C42M if the length-diameter ratio is less than 1.75.
1.7.1.4	Proposed repair methods, materials, and modifications to the Work.
1.7.4.2.e	Description of repair to be performed to bring potentially under-strength concrete into compliance with Contract Documents.
1.7.5.2.e	Description of repair work performed to bring nondurable concrete into compliance with Contract Documents.
Formwork and formwork accessories	
2.1.2.1.a	Data on form-facing materials if different from that specified in 2.2.1.1.
2.1.2.1.b	Alternative locations and details for construction and contraction joints.
2.1.2.1.c	Correlation data on alternative methods of determining concrete strength for formwork removal. Refer to ACI 228.1R for recommendations on developing suitable correlation data.
2.1.2.1.d	Drawings and procedures for installation and removal of reshoring and backshoring. Refer to ACI 347 and ACI 347.2R for guidance on items to consider.
2.1.2.1.e	Data on formwork release agent or formwork liners.
2.1.2.2.a	Shop drawings for formwork.
2.1.2.2.b	Design calculations for formwork shoring, reshoring, and backshoring.
2.1.2.2.c	Data sheet on form ties.
2.1.2.2.d	Data sheet on expansion joint materials.
2.1.2.2.e	Data sheet on waterstop materials and splices.
2.2.1.1	Other form-facing materials.
2.2.1.2	Request to use ferrous ties with breakback less than 20 mm with Surface Finish-2.0 or Surface Finish-3.0.
2.2.1.6	Alternative material or size, or both, for chamfer strips.
2.2.2.3	Request to use earth cuts as form surfaces.
2.2.2.5.a	Alternative location and details of construction joints.
2.2.2.5.c	Alternative locations and details for construction, expansion, and contraction joints.
2.2.3.3	Request to use ferrous ties with breakback less than 20 mm.
2.3.2.5	Request to remove formwork at a lower compressive strength than specified compressive strength for removal of forms.
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 indicated in Contract Documents.
3.1.1.1.d, 3.3.2.7	Request to use mechanical splices not indicated in Contract Documents.
3.1.1.1.e	Request for placement of column dowels without using templates.
3.1.1.1.f	Request and procedure to field bend or straighten partially embedded reinforcing bars.
3.1.1.1.g	Copy of CRSI Plant Certification.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
3.1.1.2.a	Description of reinforcing bar weld locations, welding procedure specifications, 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	When 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 reinforcement arrangement.
3.1.1.3.b	Inspection and quality-control program of plant that is not certified by Concrete Reinforcing Steel Institute.
3.2.1.2.b	Provide equivalent certification program for evaluation by Architect/Engineer.
3.2.1.10	Request use of alternative reinforcement support type.
3.2.1.12	Precast concrete support materials.
3.2.2.1	Request to heat reinforcement before bending.
3.3.2.2	When Contractor finds it necessary to move reinforcement beyond specified placing tolerances to avoid interference with other reinforcement, conduits, or embedded items, review submittal showing resulting reinforcement arrangement.
3.3.2.5	Request to extend reinforcement through control joints, including saw-cut joints.
3.3.2.6	Request to use alternative method for setting column dowels.
3.3.2.8	Request a procedure to field bend or straighten partially embedded reinforcing bars.
3.3.2.8.a	Request to use other method to measure preheat temperature.
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, *w/cm*, 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	Method and test data used to establish mixture proportions. Several different methods can be used to select mixture proportions that will 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 no field test records are available, refer to ACI 211.1 for selecting the initial quantities of materials based on material properties and specified concrete properties. ACI 211.1 recommends 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 similar proportioning methods is 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 C33 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 to applicable specifications shall not be older than 90 days. 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 C33 indicate that aggregate quality has not changed.
4.1.2.4, 4.1.2.5	Test data used to establish mixture proportions.
4.1.2.6	Requests for adjustments to mixture proportions. Requests to adjust mixture proportions necessary for workability or consistency. If 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 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.
4.1.2.7	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.
4.1.2.8	Request to use calcium chloride.
4.1.2.9	Request to use the volumetric batching and proposed method.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
4.1.2.10	Requests to exceed the ASTM C94/C94M required time of discharge.
4.2.1.1	Requests to use cementitious materials other than ASTM C150 Type I or Type II. When ASTM C595 or C1157 cements are used in structures that will be subjected to deicing chemicals, verify compliance of the concrete with Table 4.2.2.7.b.2.
4.2.1.3	Request to use other than potable 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 materials content.
4.2.2.2	Request to use a slump other than that specified.
4.2.2.6	Request to deliver concrete at a temperature exceeding 35°C.
4.2.2.7.a	Documentation indicating compliance with the specified requirements for sulfate resistance.
4.2.2.7.b	Documentation verifying compliance with specified requirements for freezing and thawing exposure.
4.2.2.7.c	Documentation verifying compliance with specified requirements for low permeability.
4.2.2.7.d	Documentation verifying compliance with specified requirements for corrosion resistance.
4.2.3.4.a	Method and test data used to establish mixture proportions.
4.2.3.4.b	Test data used to establish mixture proportions.
4.2.3.5	Requests for adjustments to mixture proportions.
4.2.3.6	Revised mixture proportions based on revised value of f'_{cr}.
4.3.1.2	Request to use the volumetric batching method.
4.3.2.2	Request to extend time or revolution limits for discharge.
Handling, placing, and constructing	
5.1.2.1.a	Testing and inspection records.
5.1.2.1.b	Proposed method of measuring concrete temperature.
5.1.2.1.c	Qualifications of finishing contractor and flatwork finishers.
5.1.2.1.d	Shop drawings of placing, handling, and constructing methods.
5.1.2.1.e	Notification of concrete placement.
5.1.2.1.f	Request for acceptance of preplacement activities to ensure the preplacement activities are properly inspected.
5.1.2.2.a	Description of conveying equipment.
5.1.2.2.b	Proposed method for removal of stains, rust, efflorescence, and surface deposits.
5.1.2.2.c	Proposed wet-weather protection activities.
5.1.2.2.d	Request for placement of concrete with a temperature exceeding that required in 5.3.2.1.c, including description of precautionary measures.
5.1.2.2.e	Proposed cold weather protection activities.
5.1.2.2.f	Sample finish.
5.1.2.2.g	Specification and manufacturer's data on surface retarder used in producing exposed-aggregate finish and method of use.
5.1.2.3.a	Proposed location and treatment of construction joints not indicated in Contract Documents, including method for surface preparation and achieving bond.
5.1.2.3.b	Bonding agents other than cement grout for two-course slabs.
5.1.2.3.c	Proposed method for underwater placement.
5.1.2.3.d	Proposed location of contraction or expansion joints not indicated in Contract Documents.
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	Specification data and methods of use for proposed repair material other than site-mixed portland-cement mortar described in 5.3.7.4.
5.2.1.4	Request to use alternative repair materials and supporting data. Request to not match color.
5.3.2.1.a	Proposed wet-weather protection activities.
5.3.2.1.b	Proposed cold-weather protection activities. Request to place concrete on surfaces less than 2°C.
5.3.2.1.c	Request to exceed the maximum specified concrete temperature.
5.3.2.3.c	When permitted, alternative mixture for pumped concrete.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
5.3.2.4	Proposed method for underwater placement.
5.3.4.1	Qualifications of flatwork finishers.
5.3.4.2.f	Request to use bonding agents other than cement grout.
5.3.4.2.i	Specification and manufacturer's data on surface retarder used in producing exposed-aggregate finish along with method of use.
5.3.5	Detailed plan for alternative saw cutting method, such as shallow-cut and dry-cut method. Refer to ACI 302.1R for further guidance.
5.3.6.1	Request to use shorter duration for moisture retention, or if a curing method other than that specified is desired.
5.3.6.4	Request to use alternative curing methods other than those listed.
5.3.6.5	Method of measuring concrete surface temperature.
5.3.7.1	Request to delay repair of tie holes and surface defects.
5.3.7.3	Alternative repair method.
5.3.7.4	Procedures to apply repair materials.
5.3.7.6	Methods to remove stains.
Architectural concrete	
6.1.2.1	Shop drawings, fabricating drawings of formwork for architectural concrete.
6.1.2.2.a	Location for mockup.
6.1.2.2.b	Samples of exposed aggregate finish.
6.1.2.2.c, 6.1.2.2.d, 6.1.2.2.e	Technical data and samples.
6.1.2.4	When required, plan for disposal of waste wash water.
6.1.3.6.b	Changes to new field mockup.
6.1.3.7	Revised method of producing acceptable architectural concrete.
6.2.1.9	Location, size, and spacing of rustications and reveal strips.
Lightweight concrete	
7.1.2.1	Aggregate moisture procedures.
7.1.2.2	Test results or calculations correlating equilibrium density to the required fresh bulk density.
Mass concrete	
8.1.3	Thermal control plan. Request for alternative items for thermal control plan.
8.2.1.1.a	Request to use alternative cementitious materials.
8.2.1.2.a	Request to use an accelerating admixture.
8.3.1.1.b	Alternative curing procedures for formed surfaces.
8.3.1.2.a	Recorded temperature data from concrete placement.
8.3.1.2.b	Request alternative comparison frequency. Documentation of actions taken to reduce excessive temperatures or temperature differences.
Post-tensioned concrete	
9.1.2.1.a	Shop drawings. Request to deviate from the specified post-tensioning forces and profiles. When required, signed and sealed installation drawings.
9.1.2.1.b	Required calculations.
9.1.2.1.c	Drawings and design criteria. When required, design calculations.
9.1.2.1.d	Certification for grout constituents.
9.1.2.2.a	When required, test data substantiating the expected coefficient and anchorage set.
9.1.2.2.b	When required, results of tests required in 9.1.3.1.
9.1.2.2.c	When required, jack clearances.
9.1.2.2.d	When required, written grouting procedures.
9.1.2.2.e	Results of field trial and field mockup tests.
9.1.2.3.a	Certified mill test reports.
9.1.2.3.b	Stressing jack calibration certificates.
9.1.2.3.c	Stressing records.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
9.1.2.3.d	Grouting records.
9.2.1	Watertightness test data for encapsulated anchors, if required.
9.2.1.2.c	If a duct-steel area ratio less than specified is used, testing data showing that proper grouting, corrosion protection, and bond transfer is achievable.
9.2.1.2.e	When required, duct test data.
9.2.1.4	Proposed coupler locations other than indicated in Contract Documents.
9.2.2	The grout type used when not specified.
9.2.2.1	Request to use different grout mixtures.
9.2.2.2	Request to use other admixtures. Tests or performance records should accompany request showing proposed admixtures will have no harmful effects on tendons, accessories or grout.
9.2.2.2.d	When required, ASTM C940 test results.
9.2.2.3.b	Test results when required.
9.2.2.4.a	Mockup test plan.
9.3.1	Documentation of installer certification.
9.3.2	Documentation of certification.
9.3.3.2	Request to use other type(s) of corrosion protection coating.
9.3.3.4.a	Request to use other means of repair.
9.3.4.1	Name and qualifications of the grouting supervisor when required.
9.3.4.2	Request for acceptance of exposure interval exceeding limits in Table 9.3.4.2 and plan for temporary corrosion protection.
9.3.4.5	Request to use pressure in excess of 1.0 MPa during grouting operation.
9.3.4.6	Request to use an injection rate outside the limits specified.
9.3.4.7	Report of grouting operations.
9.3.5.7.a	Request acceptance of alternative method of application of fixed-end anchorage.
9.3.5.8.c	Tape repair procedures.
9.3.6.4	Acceptance of additional hairpin reinforcement where radius of curvature is less than 480 strand diameters.
9.3.8.3	Records of elongation and gauge pressure readings for the prestressing force.
9.3.8.4	Request to accept greater than 2% loss of prestressing force due to broken tendons.
Shrinkage-compensating concrete	
10.1.3.2	Expansion test results for the proposed concrete mixtures.
10.1.3.3	Proposed sequences of concrete placements.
10.2.1.1.b	Request to use silica fume.
10.2.1.2.a	Request to use accelerating admixtures or admixtures containing calcium chloride.
10.2.1.2.b	Request to change type, brand, or dosage rate of admixtures.
10.2.2.3	Request to use a higher slump.
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.
10.3.2.2	Request to exceed time between casting adjoining sections.
Industrial floor slabs	
11.1.3.2.a	When required, shrinkage test results for proposed concrete mixture.
11.1.3.2.b	Manufacturer's data sheet for load transfer devices, when used.
11.1.3.2.c	Manufacturer's data sheet for vapor retarder sheet, when used.
11.1.3.2.d	Manufacturer's data sheet on equipment to install contraction joints when required.
11.1.3.2.e	Manufacturer's data sheet for curing cover, curing compound, or other curing method.
11.1.3.2.f	Procedure for ensuring protection of the concrete during transportation, placement, finishing, and specified curing period.
11.1.3.2.g	Manufacturer's data sheet for joint filler.
11.1.3.2.h	Manufacturer's data sheet for liquid-applied surface densifiers, when used.
11.1.3.2.i	Manufacturer's data sheet for mineral or metallic shake hardeners, when used.
11.1.3.2.j	Joint layout. Request to exceed 4.6 m joint spacing.
11.1.3.2.k	Placing sequence showing extent and schedule of each placement.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
11.1.3.2.1	When required, design of construction joint forms.
11.2.1.2.a	Request to use a different nominal maximum size aggregate.
11.2.2	Request alternative mixture requirements.
11.2.2.2	Request for discharge temperature greater than 35°C.
11.2.6	Shop drawings of details of load-transfer devices.
11.3.5.2	Flatness and levelness test results in accordance with ASTM E1155.
11.3.7	Request to apply curing compound in areas where subsequent finish flooring or surface densifier is to be installed.
Tilt-up construction	
12.1.4.1	Bearing shim data.
12.1.4.2	Coloring agents data.
12.1.4.3	Bond breaker data.
12.1.4.4	Tilt-up panel shop drawings.
12.1.4.5	Field mockups.
12.1.4.6	Panel grout data.
12.1.4.7	Details for insulated concrete sandwich panels.
12.1.4.8	Methods and materials for repair of defects.
12.1.5	Tilt-up contractor's qualifications.
12.2.2	Request to use alternative bearing shims.
12.2.6.1	Request to use same material for curing compound and bond breaker.
Precast structural concrete	
13.1.2.1.a	Mixture proportions and characteristics. Request to submit information on precast mixtures if different than that required in Section 4.
13.1.2.1.b	Shop drawings for erection. Shop drawings for temporary bracing and shoring if required. Calculations for temporary bracing and shoring if required. Shop drawings for fabrication if required.
13.1.2.1.c	Welding procedure specifications and personnel certifications.
13.1.2.1.d	When required, structural design calculations. Detailed calculations for verification of computer design. Shop drawings indicating specified design criteria and design methods.
13.1.2.1.e	Design calculations when required and drawings for modifications.
13.1.2.1.f	Erector qualifications.
13.1.2.1.g	Fabricator qualifications.
13.1.2.1.h	Evidence of plant certification or documentation of manufacturing procedure and quality control.
13.1.2.2.a	When required, material test reports or certifications.
13.1.3.1	Erector qualification and post-audit declaration. Request to use erector not qualified by PCI.
13.1.3.2	Documentation of certification of plant and personnel.
13.1.3.4	Calculations for fire resistance rating for precast concrete members.
13.2.6.1	Request for acceptance of alternative bearing pads.
13.2.7.1	Request to use alternative materials.
13.2.7.2	Field installation procedures when required.
13.2.9.3	Request to use alternative air content.
13.2.11.1	Request permission to relocate bearing plates in units.
13.2.11.2	Setting diagrams, templates, instructions, and installation directions.
13.2.12.1	Request deviations of size and shape of precast concrete members.
13.2.12.3	Request to drill or cut openings or prestressing strand along with location.
13.2.12.9	Request to increase maximum temperature to 77°C with documentation of mixture proportion. Request to increase maximum concrete temperature to 82°C for concrete dry or protected from moisture.
13.2.12.11	Repair procedures.
13.2.15.1	Documentation of certification of plant and personnel.
13.2.17	Request to repair chipped, spalled, or cracked members.
13.3.1.1	Shop drawings for locations, setting diagrams, and templates for installation of each anchorage device.

SUBMITTALS CHECKLIST (cont.)

Section/Part/Article	Submittal items and Notes to Specifier
13.3.3.4	Welding procedure specification.
13.3.3.4.e	List welds that do not require inspection by a Certified Welding Inspector.
13.3.3.5.b	Request less than 100% bolt testing in the event insufficient torque is found within the first 25%.
13.3.3.7	Request to cut or core precast concrete units after installation.
13.3.3.8	Request to use drilled or powder-actuated fasteners.
13.3.6.a	Repair procedures and request to repair members.
Precast architectural concrete	
14.1.2.1	Proportions and compressive strength of concrete mixtures.
14.1.2.2	Design reference sample.
14.1.2.3	Sample panels.
14.1.2.4	Range sample panels.
14.1.2.5.a	When required, full-size mockups.
14.1.2.5.b	When required, design calculations and shop drawings.
14.1.2.5.c	When required, material test reports or manufacturer's certifications.
14.1.2.6	Fabricator qualifications.
14.1.3.2	Required sample panels.
14.1.3.5	Repaired samples.
14.1.3.7	Range of sample panels.
14.1.3.8.b	Dates and times when mockups will be constructed.
14.1.3.8.c	Request for acceptance of mockup.
14.1.3.8.e	Request to use mockup in completed Work.
14.2.4	Request to use surface retarder.
14.2.5.2	Requests to use thin brick units with properties different from those specified in Contract Documents.
14.2.9.3	Request to use pointing grout that is different from design reference sample.
14.2.13.1	Specify when continuous sealant bead is not required along sides and top.
14.2.13.2	Qualifications of testing agency to perform stone anchor shear and tensile tests along with description of test assembly and load-deflection curves.
14.2.14.2.b	Request to use alternative cement and aggregate for face mixture.

American Concrete Institute®
Advancing concrete knowledge

As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains "to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge." In keeping with this purpose, ACI supports the following activities:

- Technical committees that produce consensus reports, guides, specifications, and codes.
- Spring and fall conventions to facilitate the work of its committees.
- Educational seminars that disseminate reliable information on concrete.
- Certification programs for personnel employed within the concrete industry.
- Student programs such as scholarships, internships, and competitions.
- Sponsoring and co-sponsoring international conferences and symposia.
- Formal coordination with several international concrete related societies.
- Periodicals: the *ACI Structural Journal* and the *ACI Materials Journal*, and *Concrete International*.

Benefits of membership include a subscription to *Concrete International* and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

Specifications for Structural Concrete

The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and representing the user interest in the field of concrete. ACI gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of ACI is conducted by individual ACI members and through volunteer committees composed of both members and non-members.

The committees, as well as ACI as a whole, operate under a consensus format, which assures all participants the right to have their views considered. Committee activities include the development of building codes and specifications; analysis of research and development results; presentation of construction and repair techniques; and education.

Individuals interested in the activities of ACI are encouraged to become a member. There are no educational or employment requirements. ACI's membership is composed of engineers, architects, scientists, contractors, educators, and representatives from a variety of companies and organizations.

Members are encouraged to participate in committee activities that relate to their specific areas of interest. For more information, contact ACI.

www.concrete.org