

*Manual for*

# **QUALITY CONTROL**

*for Plants and Production of*

# **ARCHITECTURAL PRECAST**

# **CONCRETE PRODUCTS**

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**FOURTH EDITION**

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**MNL-117-13**



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## **FOREWORD**

This manual has been prepared as a guideline for quality assurance of architectural concrete. Since the products are custom designed, the many combinations of shape, size, color and texture require a great degree of craftsmanship. Therefore it is important to implement and maintain the quality control standards as given in this Manual to achieve the specific performance and aesthetic requirements of a project.

Materials and performance requirements for the architectural precast concrete should be clearly stated in the plans and specifications. These requirements should neither be open to interpretation nor unduly restrictive for the project, but should be written to conform with the intended use of the architectural precast concrete. Personnel in the manufacturer's organization should be thoroughly trained and competent in order to achieve quality architectural precast concrete products.

The first edition of the Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products was prepared by the PCI Plant Certification Subcommittee for plant production of Architectural Precast Concrete Products. Subsequent to the publication and use of the first edition, a plant certification program was established for the precast and prestressed concrete industry. The inspection of architectural precast concrete production facilities, carried out under this program, was based on the recommended practices and criteria outlined in that manual. Experience by both the manufacturers and the inspection teams led to the second edition in 1977 and the third edition in 1996.

The fourth edition which is even more demanding of a high standard of industry practice was prepared by the PCI Architectural Precast Concrete Services Committee and the PCI Plant Certification Committee. It represents state-of-the-art procedures and is the industry standard for achieving consistently high quality. Committee members working on this manual were as follows:

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# INTRODUCTION

## MNL-117, Fourth Edition

The Standards and Commentary are presented in a side-by-side column format; with the Standards placed in the left column and the corresponding Commentary text aligned in the right column. The Standards have been printed in the same typeface as shown in this paragraph.

The Commentary is printed in the same typeface as shown in this paragraph. Additionally, a “C” precedes Commentary article numbers to help further distinguish the Commentary from the Standards.

Architectural precast concrete panels, through the application of finish, shape, color or texture, contribute to the architectural form and finished effect of a structure. Not generally included are the so-called industrialized precast products (standard shapes), such as double or single tees, channel sections, and flat or hollow -core slabs usually produced in fixed, long -line forms. Architectural precast concrete units may be manufactured with conventional mild steel reinforcement, or they can be prestressed. Design flexibility in surface appearance is possible by incorporating various texture and finishes and through the use of different cement, coarse and fine aggregate, and pigments into the concrete mix. Natural stone or clay products may be used as a veneer finish or alternatively, panels may be painted or stained to achieve the required colors.

This manual is divided into two parts. The first part contains Divisions 1 through 7 which form the basis for PCI Plant Certification in product Group A1- architectural precast concrete products. It is conformance to these Standards which is audited during each PCI plant inspection and provides the criteria for evaluation of the plant's capabilities.

The final part- Appendices- contains summaries of useful information for both the manufacturer and specifier.

The information in this manual is intended to serve as standards for quality control for the manufacture of architectural precast concrete products and as a complete guide for the development of an internal manufacturing quality control program. The Standard portion serves as a specification reference document, while the Commentary provides additional information and discussions of the Standards.

The fundamental intent of this manual is to provide a basis for establishing a satisfactory quality control program for architectural precast concrete operations. It should be augmented, as required by the specifier or producer, for addressing specialized products and operations. The value of the manual, in regard to establishing a standard of quality that will be recognized and respected by the general public, is dependent on the appropriate application by the owner, designer, specifier, and producer.

Routine conformance to the requirements of the Standards should result in products of consistent and optimum quality when used with proven procedures. Optimum quality is considered the level of quality, in terms of appearance, strength, and durability that appropriately satisfies the project requirements for intended use and economics of the product.

The dimensional tolerances contained in Division 7 were developed by the PCI Tolerances Committee and approved by the PCI Technical Activities Committee and PCI Board of Directors.

This manual incorporates proven standards of practice that provide an acceptable level of quality, but there is no intent to place a ceiling on excellence. The degree of success in specifying and obtaining optimum quality for products will depend on the combined efforts of designers and manufacturers to define and coordinate their individual requirements, responsibilities and expectations.

No Manual of this type can be all-inclusive. The requirements and recommendations given herein are a general presentation of the important factors governing the quality of architectural precast concrete. Their value is dependent on rational application and a determination on the part of the individual producer to establish a standard of quality that will be recognized and respected by the specifier.

Quality assurance begins when the architect determines shape, size, color and texture for the architectural precast concrete products for a specific project. These characteristics may then determine the methods of manufacture, as well as the handling and installation techniques. Consultation with qualified representatives of experienced manufacturers will be of great value in achieving high quality products at a reasonable cost to the owner.

The Standard indicates the requirements to obtain an acceptable level of quality, but not the means or methods for doing so. It is not the intention of the Manual to restrict individual plant techniques. For example, a manufacturer's methods for mixing, placement, consolidation and curing of concrete will be acceptable, provided these methods can consistently result in uniform and durable concrete of the specified quality.

The information contained in the Commentary is not part of the Standards and shall not be used in judging quality control or production procedures.

The Commentary contains suggestions to help in carrying out the requirements or intent of the Standard.

This Manual has been prepared on the basis of current good practice. As significant changes in materials or process technology occur, revisions will be made to this Manual.

|                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Note: The production of architectural precast concrete may involve hazardous materials, operations, and equipment. This manual does not purport to address the safety issues associated with production. It is the responsibility of the producer to establish appropriate safety and health practices and determine the applicability of regulatory limitations.</p> |
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## DEFINITIONS

**Accelerated curing** – The intentional addition of heat to the concrete environment to expedite curing. For the systems described in this Manual, all curing is at atmospheric pressure.

**Admixture** – A material other than water, aggregates and cement used as an ingredient in concrete, mortar, or grout to impart special characteristics.

**Aggregate** – Granular material, such as sand, gravel, and crushed stone, used with a cementing medium to form a hydraulic-cement concrete or mortar.

**Aggregate, structural lightweight** – Aggregate with a dry, loose weight of 70 lbs/ft<sup>3</sup> (1121 kg/m<sup>3</sup>) or less.

**Air-entraining admixture** – A chemical added to the concrete for the purpose of providing minute bubbles of air (generally smaller than 1 mm) in the concrete during mixing to improve the durability of concrete exposed to cyclical freezing and thawing in the presence of moisture.

**Ambient temperature** – The temperature of the air surrounding the forms/molds into which concrete is to be cast, or of the air surrounding an element during curing.

**Anchorage** – The means by which the prestressing force is permanently transmitted from the prestressing steel to the concrete. In post-tensioning applications, a mechanical device comprising all components required to anchor the prestressing steel and transmit the prestressing force to the concrete.

**Architectural precast concrete** – A product with a specified standard of uniform appearance, surface details, color, and texture.

**Architectural precast concrete trim units** – Wet cast products with a high standard of finish quality and of relatively small size that can be installed with equipment of limited capacity, such as sills, lintels, coping, cornices, quoins, medallions, bollards, benches, planters, and pavers.

**Backup mixture** – The concrete mixture cast into the mold after the face mixture has been placed and consolidated.

**Batching** – The process of weighing or volumetrically measuring, and introducing into the mixer, the ingredients for a batch of concrete.

**Bingham fluid** – A fluid characterized by a non-null yield stress and a constant viscosity regardless of flow rate.

**Bleeding** – A form of segregation in which some of the water in a mixture rises to the surface of freshly placed concrete; also known as water gain.

**Blocking** – Materials used for keeping concrete elements from touching each other or other materials during storage and transportation.

**Blocking**—(SCC)The condition in which pieces of coarse aggregate combine to form elements large enough to obstruct the flow of the fresh concrete between the reinforcing steel or other obstructions in the concrete form/mold. This property is of increased importance in SCC because of the absence of vibration energy to dislodge these blockages.

**Bondbreaker** – A substance placed on a material to prevent it from bonding to the concrete, or between a face material such as natural stone and the concrete backup.

**Bonding agent** – A substance used to increase the bond between an existing piece of concrete and a subsequent application of concrete such as a patch.

**Bull float** – A tool comprising of a large, flat, rectangular piece of wood, aluminum, or magnesium usually 8 in. (200 mm) wide and 42 to 60 in. (1.0 to 1.5 m) long, and a handle 4 to 16 ft. (1 to 5 m) in length used to smooth the unformed surfaces of freshly placed concrete.

**Bugholes** – Small holes on formed concrete surfaces formed by air or water bubbles, sometimes called blowholes.

**Bundled strand** – Strands that are grouped together in a bundle to concentrate the prestressing force. Bundled strand are in contact with each other and must be splayed out to the end of the member to allow bond to develop each strand from the end to the bundle point.

**Camber** – (1) The deflection that occurs in prestressed concrete elements due to the net bending resulting from application of a prestressing force (It does not include dimensional inaccuracies); (2) A built-in curvature to improve appearance.

**Central-Mixed Concrete** – Concrete mixed in a central stationary mixer and delivered to the casting area by buckets, truck mixer, truck agitator or non-agitating truck.

**Certification** – Assurance by a competent third party organization, operating on objective criteria and which is not subject to undue influences from the manufacturer or purchaser or to financial considerations, that elements are consistently produced in conformity with a specification. It not only proclaims compliance of a product with a specification, but also that the manufacturer's quality control arrangements have been approved and that a continuing audit is carried out.

**Clearance** – Interface space (distance) between two items.

**Coarse aggregate** – Aggregate predominately retained on the U.S. Standard No. 4 (4.75 mm) sieve; or that portion of an aggregate retained on the No. 4 (4.75 mm) sieve.

**Cold weather** - A period when, for more than three consecutive days, the following conditions exist: 1) the average daily air temperature is less than 40°F (5°C) and 2) the air temperature is not greater than 50°F (10°C) for more than one-half of any 24-hr period. The average daily temperature is the mean of the highest and lowest temperature occurring during the period from midnight to midnight.

**Cohesiveness** – The tendency of the SCC concrete constituent materials to stick together, resulting in resistance to segregation, settlement, and bleeding.

**Compaction** – The process whereby the volume of the concrete is reduced to the minimum practical space by the reduction of voids usually obtained through vibration, tamping, or a combination of both.

**Connection** – A device for the attachment of precast concrete units to each other or to the building or structure.

**Covermeter** – See R-meter.

**Crazing** – A network of visible, fine hairline cracks in random directions breaking the exposed face of a panel into areas from 1/4 in. to 3 in. (6 to 75 mm) across.

**Creep** – The time dependent deformation (shortening) of prestressing steel or concrete under sustained loading.

**Curing** – The maintenance of moisture and temperature within freshly placed concrete during some defined period following placing, casting, or finishing to assure satisfactory hydration of the cementitious materials and proper hardening of the concrete.

**Detensioning (of strand or wire)** – The transfer of strand or wire tension from the bed anchorage to the concrete.

**Draft** – The slope of concrete surface in relation to the direction in which the precast concrete element is withdrawn from the mold; it is provided to facilitate stripping with a minimum of mold breakdown.

**Dunnage** – See Blocking.

**Dynamic stability** - That characteristic of a fresh concrete mixture that ensure uniform distribution of all solid particles and air voids as the concrete is being transported and placed. Dynamic stability provides an indication of passing ability and blocking resistance. It also provides a measure of segregation resistance to prevent segregation resulting from energy inputs during placement and transport (i.e., free fall, etc.). Dynamic stability also provides a measure of resistance to flow separation over distance and around corners in the form/mold.

**Ease of placement** – Characterizes the amount of labor required to place the concrete during casting operations.

**Elastic shortening** – The shortening of a member that occurs immediately after the application of the prestressing force.

**Elongation** – Increase in length of the prestressing steel (strand) under the applied prestressing force.

**Exposed aggregate concrete** – Concrete manufactured so that the aggregate on the face is left protruding.

**Face mixture** – The concrete at the exposed face of a concrete unit used for specific appearance purposes.

**Filling Capacity** – A combination of fluidity and stability (passing ability) characteristics. It is the ability of the concrete to completely fill intricate form/mold or form/mold containing obstacles, such as reinforcement.

**Fine aggregate** – Aggregate passing the 3/8 in. (9.5 mm) sieve and almost entirely passing the No. 4 (4.75 mm) sieve and predominately retained on the No. 200 (75 $\mu$ m) sieve; or that portion of an aggregate passing the No. 4 (4.75 mm) sieve and predominately retained on the No. 200 (75 $\mu$ m) sieve.

**Flowability** – The ability of a fresh concrete to flow in a confined or unconfined form/mold of any shape, reinforced or not, under gravity and/or external forces, and assume the shape of that container.

**Fluidity** – The ability of a concrete mixture to flow. Inherent in this ability is the mixture's rheological characteristics of yield stress and plastic viscosity.

**Fly ash** – A finely divided residue with pozzolanic properties that results from the combustion of ground or powdered coal and that is transported by flue gasses. Due to its spherical shape and fineness, it can improve the rheology of SCC.

**Form/Mold** – The container or surface against which fresh concrete is cast to give it a desired shape.

**Formed surface** – A concrete surface that has been cast against a form/mold.

**Form/mold release agent** – A substance applied to the form/mold for the purpose of preventing bond between the mold and the concrete cast in it.

**Friction loss** – In post-tensioning applications, the stress (force) loss in a prestressing tendon resulting from friction created along the tendon profile during stressing.

**Gap-graded concrete** – A mixture with one or a range of normal aggregate sizes eliminated,

and/or with a heavier concentration of certain aggregate sizes over and above standard gradation limits. It is used to obtain a specific exposed aggregate finish.

**Ground (granulated) blast furnace slag (GGBFS)** – A fine granular, mostly latent hydraulic binding material that can be added to SCC to modify the rheological properties of the material.

**Grout** – A mixture of cementitious materials and water, with or without sand or admixtures.

**Hardware** – Items used in connecting precast concrete units or attaching or accommodating adjacent materials or equipment. Hardware is normally divided into three categories:

**Contractor's hardware** – Items to be placed on or in the structure in order to receive the precast concrete units, e.g., anchor bolts, angles, or plates with suitable anchors.

**Plant hardware** – Items to be embedded in the concrete units themselves, either for connections and precast concrete erector's work, or for other trades, such as mechanical, plumbing, glazing, miscellaneous iron, masonry, or roofing trades.

**Erection hardware** – All hardware necessary for the installation of the precast concrete units.

**Homogeneous mixture** – A uniform concrete mixture used throughout a precast concrete element.

**Hot weather** – A period when, for more than three consecutive days, the following conditions exist: 1) the average daily air temperature is greater than 77°F (25°C) and 2) the air temperature for more than one – half of any 24-hr period is not less than 85°F (30°C). The average daily temperature is the mean of the highest and the lowest temperatures occurring during the period from midnight to midnight

**Initial prestress** – The stress (force) in the tendon immediately after transferring the prestressing force to the concrete.

**Jacking force** – The maximum temporary force exerted by the jack while introducing the

prestressing force into the concrete through the prestressing strand.

**Jig** – A template or device to align parts of an assembly, usually for pre-assembling reinforcing steel and hardware cages, with a minimum of measurement to attain consistent accuracy from one cage to the next.

**J-Ring test** – Test used to determine the passing ability of SCC, or the degree to which the passage of concrete through the bars of the J-ring apparatus is restricted. A J-Ring is an apparatus consisting of a rigid ring supported on sixteen 5/8 inch (16 mm) diameter rods equally spaced on a 12 inch (300 mm) diameter circle 4 inches (100 mm) above a flat surface. See ASTM C1621/C1621M.

**Laitance** – Residue of weak and nondurable material consisting of cement, aggregate fines, or impurities brought to the surface of plastic concrete by bleed water.

**L-Box test** – A test used to test the horizontal and confined flowability of SCC and/or to check that the placement of SCC will not be compromised by unacceptable segregation and jamming or blocking of aggregates. See Appendix 1 TR-6-03.

**Lifting frame** (or beam) – A rigging device designed to provide two or more lifting points of a precast concrete element with a predictable load distribution and pre-arranged direction of pulling force during lifting.

**Mark number** – The individual identifying mark assigned to each precast concrete unit designating its position in the building.

**Master mold** – A mold which allows a maximum number of casts per project; units cast in such molds need not be identical, providing the changes in the units can be simply accomplished as pre-engineered mold modifications.

**Matrix** – The portion of the concrete mixture containing only the cement and fine aggregates (sand).

**Miter** – An edge that has been beveled to an angle other than 90 deg.

**Passing ability** – The ability of SCC to flow under its own weight (without vibration) and completely

fill all spaces within intricate forms/molds, containing obstacles, such as reinforcement.

**Paste** – The fraction of the concrete mixture comprising powder plus water and air and admixture.

**Pattern or positive** – A replica of all or part of the precast element sometimes used for forming the molds in concrete or plastic.

**Placeability** – The ability to place the SCC mixture in the time span associated with the typical production mixing, transport, and placement such that the material remains homogeneous while exhibiting all of the required SCC fresh concrete properties.

**Plastic cracking** – Short cracks often varying in width along their length that occur in the surface of fresh concrete soon after it is placed and while it is still plastic.

**Plastic viscosity** – A material's internal resistance to flow under an applied shearing stress. Once the yield stress of a mixture is overcome, the plastic viscosity dominates flow.

**Powder** – Material of particle size passing the No. 100 sieve (0.15mm).

**Powder additions** – Finely divided inorganic material used in SCC in order to improve certain properties or to achieve special properties. These are additions to the current content of the SCC mixture.

**Post-tensioning** – A method of prestressing concrete whereby the tendon is kept from bonding to the fresh concrete, then elongated and anchored directly against the hardened concrete, imparting stresses through end bearing.

**Precast engineer** – The person or firm that designs precast concrete members for specified loads and may direct the preparation of the shop drawings.

**Pretensioning** – A method of prestressing concrete whereby the tendons are elongated, anchored while the concrete in the member is cast, and released when the concrete has gained sufficient strength to receive the forces transferred from the tendon through bond of the hardened concrete.

**Production drawings** – A set of instructions in the form of diagrams and text that contain all the information necessary for the manufacturer to produce the unit.

**Quality** – (1) The appearance, strength, and durability which are appropriate for the specific product, particular application, and expected performance requirements. (2) The totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs.

**Quality assurance (QA)** – The planned activity and systematic actions necessary to provide adequate confidence to the Owner and other parties that the products or services will perform their intended functions. Quality assurance is a management tool.

**Quality control (QC)** – Those actions related to the physical characteristics of the materials, processes, and services, which provide a means to measure and control the characteristics to predetermined quantitative criteria. Quality control is a production tool.

**Quirk miter** – A corner formed by two chamfered members to eliminate sharp corners and ease alignment.

**R-meter** – An electronic device used to locate and size reinforcement in hardened concrete.

**Retarder** – An admixture which delays the setting of cement paste and therefore of concrete.

**Retarder, surface** – A material used to produce exposed aggregate concrete by retreating or delaying the hardening of the cement paste on a concrete surface within a time period and to a depth to facilitate removal of this paste after the concrete element is otherwise cured.

**Retempering** – The addition of water or admixture and remixing of concrete which has started to stiffen in order to make it more workable.

**Return** – A projection that angles away from the main face or plane of view.

**Reveal** (1) Groove in a panel face generally used to create a desired architectural effect; and (2) The depth of exposure of the coarse aggregate in the matrix after production of an exposed aggregate finish.

**Rheological properties** – Properties dealing with the deformation and flow of fluids, primarily in relation to a fresh SCC mixture.

**Rustication** – A groove in a panel faces for architectural appearance; also reveal.

**Sandwich wall panel** – A prefabricated panel, which is a layered composite, formed by attaching two wythes or skins of concrete separated by an insulating core.

**Scabbing** – A finish defect in which parts of the form/mold face, including release agent, adhere to the concrete. Some probable causes are an excessively rough form/mold face, inadequate application of release agent, or delayed stripping.

**Scouring** – Irregular eroded areas or channels with exposed stone or sand particles. Some probable causes of this finish defect are excessively wet concrete mixture, insufficient fines, water in the form/mold when placing the concrete, poor vibration practices, and low temperature when placing concrete.

**Sealer** – A clear chemical compound applied to the surface of precast concrete units for the purpose of improving weathering qualities or reducing water absorption.

**Segregation** – The unintentional separation of the constituents of concrete or aggregate particles. In concrete, the coarse aggregate and drier material remaining behind and the mortar and wetter material flowing ahead. This also occurs in a vertical direction when wet concrete is overvibrated or dropped vertically into the forms/molds, the mortar and wetter material rise to the top. In aggregate, the coarse particles roll to the outside edges of the stockpile. In SCC, segregation may occur during transport, movement of the SCC within the forms/molds, or after placement.

**Segregation resistance (stability)**—The ability of SCC to remain homogeneous in composition during transport, placement, and after placement.

**Self-consolidating concrete (SCC)** – Concrete that can flow around reinforcement and consolidate under its own weight without additional effort and without exceeding specified limits of segregation.

**Self-leveling concrete** – A subset of SCC for horizontal applications (slabs, floors, surfaces that

will only be minimally finished). This type of SCC will seek a level grade in confined forms/molds and will reach maximum density without vibration.

**Self-stressing form/mold** – A form/mold provided with suitable end bulkheads and sufficient strength to resist the total prestressing force.

**Set-up** – The process of preparing forms/molds for casting, including installation of materials (reinforcement and hardware) prior to the actual placing of concrete.

**Sheathing** – A covering that forms an enclosure around the prestressing steel to avoid temporary or permanent bond between the prestressing steel and the surrounding concrete.

**Shrink-Mixed Concrete** – Concrete that is partially mixed in a stationary mixer then mixed completely and delivered to the casting site in a truck mixer.

**Shrinkage** – The volume change in precast concrete units caused by drying normally occurring during the hardening process of concrete.

**Shop drawings** – (1) Collective term used for erection drawings, production drawings, and hardware details; and (2) Diagrams of precast concrete members and the connecting hardware, developed from information needed for both field assembly (erection) and manufacture (production) of the precast concrete units.

**Slump flow** – Test method used to measure the unconfined flow and stability of SCC. See ASTM C1611/C1611M.

**Specially finished structural precast concrete** – A product fabricated using forms/molds and techniques common to the production of structural elements as defined in MNL-116, Appendix F and having specified surface finishes that require uniformity and detailing more demanding than typically required for structural elements. These surface finish requirements should be clearly specified and verified with appropriate samples and mockups.

**Spread** – The distance of lateral flow of concrete determined as the average diameter of the circular deposit of SCC at the conclusion of the slump flow test. See ASTM C1611/C1611M.

**Spreader beam** – A frame of steel channels or beams attached to the back of a panel, prior to stripping, for the purpose of evenly distributing loads to inserts and for lifting the panel about its center of gravity.

**Stability** – Resistance to segregation and/or settlement of aggregates during transport, placement, and subsequent to placement. The ability of SCC to remain homogeneous in composition by resisting actions which tend to cause the paste and aggregates to separate during transport, placement, and subsequent to placement.

**Static Stability** – The characteristic of a fresh concrete mixture that ensures uniform distribution of all solid particles and air voids once all placement operation are complete and until the onset of setting. Static stability provides a measure of resistance to the tendency to segregate due to gravity effects. This includes resistance to the tendency to settle, air migration within the mixture, and bleeding.

**Stickiness** – The property of concrete that relates to its propensity to adhere to finishing tools and other surfaces.

**Strand** – A group of wires laid helically over a central-core wire. A seven-wire strand would thus consist of six outer wires laid over a single wire core.

**Strand anchor** – A device for holding a strand under tension, sometimes called a strand chuck or vise.

**Static segregation resistance** – That characteristic of a fresh SCC mixture that ensures uniform distribution of all particles and air voids once all placement operations are complete and until the onset of setting, without excessive settlement or bleeding. See ASTM C1610/C1610M.

**Stripping** – The process of removing a precast concrete element from the form/mold in which it was cast.

**Strongback/stiffback** – A steel or wooden member that is attached to a panel for the purpose of adding stiffness during handling, shipping, and/or erection.

**Structural lightweight concrete** – Structural concrete made with lightweight aggregate with an air-dry unit weight of the concrete in the range of 90 to 115 lb/ft<sup>3</sup> (1440 to 1850 kg/m<sup>3</sup>) and a 28-day compressive strength of more than 2500 psi (17.24 MPa).

**Superplasticizer** – A high-range water-reducing (HRWR) admixture that produces concrete of significantly higher slump without addition of water.

**Surface retarder** – A material used to retard or prevent the hardening of the cement paste on a concrete surface to facilitate removal of this paste after curing. This is primarily used to produce an exposed aggregate finish.

**T-50** – A test to determine a relative measure of viscosity of SCC. Measured while performing a slump flow test, T-50 is the time it takes the concrete to reach a 500 mm (19.68 inches) diameter circle. See ASTM C1611/C1611M. Also referred to as the T-20 test when measurements are made in inches.

**Tendon** – A high strength steel element consisting of one or more wires, strands, or bars, or a bundle of such elements, used to impart prestressing forces to the concrete. In post-tensioned applications, a complete assembly consisting of anchorages, prestressing steel (strand), corrosion-inhibiting coating, and sheathing. It imparts the prestressing force to the concrete.

**Thixotropic behavior** – The property of a material that will allow it to exhibit a low viscosity while flowing, but stiffen and resist flowing after a short period at rest.

**Tolerance** – Specified permissible variations from stated requirements such as dimensions, location, alignment, strength, and air entrainment, etc.

**Product tolerances** – Those variations in dimensions relating to individual precast concrete members.

**Erection tolerances** – Those variations in dimensions required for acceptable matching of precast members after erection.

**Interfacing tolerances** – Those variations in dimensions associated with

other materials in contact with or in close proximity to precast concrete.

**Transfer strength** – The minimum concrete strength specified for the individual concrete elements before transfer of the prestressing force. This is sometimes called detensioning strength or release strength.

**Truck-Mixed Concrete** – Concrete that is completely mixed in a truck mixer as it is delivered to the casting site.

**Unbonded tendon** – A tendon in which the prestressing steel (strand) is prevented from bonding to the concrete. When unbonded tendons are used, prestressing force is permanently transferred to the concrete only by the anchorage.

**Unconfined Fluidity** – The mixture's capacity to flow into and completely fill open form/mold, characterize ease of placement (ACI 304).

**Veneered construction** – The attachment of other materials, such as natural stone or clay products, to a concrete panel.

**Viscosity** – One of the rheological constants of fresh concrete, fresh mortar, and fresh paste when they are regarded as Bingham fluids. The magnitude of the change in the applied stress required for changing the unit flow velocity.

**Viscosity modifying agent (VMA)** – A material that, when added to concrete, changes the viscosity and improves the stability of the mixture at a constant fluidity.

**Visual Stability Index (VSI) Rating** – A qualitative visual assessment of the stability of an SCC mixture after performing a slump flow test. See ASTM C1611/C1611M.

**Water to cementitious material ratio (w/cm)** – The ratio of the amount of free water to the amount of cementitious material.

**Water to powder volume** – The ratio of the amount of free water to the amount of solids comprising the paste (material passing the No. 100 [0.15 mm] sieve) in a concrete or mortar mixture.

**Wedges** – Pieces of tapered metal with teeth that bite into the prestressing steel (strand) during transfer of the prestressing force. The teeth are beveled to assure gradual development of the tendon force over the length of the wedge. These are standard internal portions of a strand chuck assembly.

**Wedge set** – The relative movement of the wedges into the anchorage cavity during the transfer of the prestressing force to the anchorage.

**Workability** – That property of freshly mixed concrete or mortar that determines the ease and homogeneity, with which it can be mixed, placed, consolidated, and finished. It is a complex combination of aspects of fluidity, cohesiveness, transportability, compactability, and stickiness.

**Yield stress** – One of the rheological constants of fresh concrete, fresh mortar, and fresh paste when they are regarded as Bingham fluids. The minimum stress required to make the concrete flow.

# ***DIVISION 1 – QUALITY SYSTEM***

## **Standard**

## **Commentary**

### **1.1 Objective**

Quality control shall be an accepted and functioning part of the plant operation. Plant management must make a commitment to quality before quality programs can be effectively adopted or implemented at the operational level. Management shall establish a company standard of quality based on uniform practices in all stages of production, and shall require strict observance of such practices by all levels of personnel. Quality control personnel shall serve to confirm and oversee these practices, and shall report to the General Manager, Chief Engineer, or other non-Production management.

### **C1.1 Objective**

The general objective of this manual is to define the required minimum practices for the production of architectural precast concrete units and for a program of quality control. Overall product quality results from individual as well as company efforts.

Construction project specifications and manuals can prescribe and explain proper quality control criteria for all phases of production consistent with producing products of the highest quality. However, to ensure that such criteria are followed, inspection personnel and a regular program of auditing all aspects of production should be provided.

The individuals in control of operations should have the commitment to produce products of proper quality, and should delegate authority for assignment of the responsibilities necessary to achieve the desired results. Consistent quality can only be achieved if proper procedures are established and then carried out.

While the guidelines in this division address the quality control function, it is recognized that the primary responsibility for quality rests with production personnel. Accordingly, the production personnel should understand the role of quality control and work to ensure effective monitoring, timely responses, corrective actions, and improvement.

Although production personnel are responsible for the quality of products, it is necessary to have a system of checks and balances. Quality control inspections provide this check-and-balance system and consequently are a vital tool for management. The number of persons required to effectively perform the quality control functions will vary with the size and extent of plant operations.

Supervisory personnel are an integral part of the process and should be committed to the quality standards. The production of quality products requires uniformity of management's expectations for all areas of operations and types of products.

### **1.2 Plant Quality Assurance Program**

### **C1.2 Plant Quality Assurance Program**

#### **1.2.1 General**

The plant shall implement and maintain a

#### **C1.2.1 General**

The use of a written QSM requires an initial effort by

documented quality assurance program in addition to this manual. Each plant shall have a unique plant Quality System Manual (QSM) based on operations at that facility.

The QSM shall, as a minimum, cover the following:

- a. Management commitment to quality.
- b. Organizational structure and relationships, responsibilities, and qualifications of key personnel.
- c. Management review of the quality assurance program at regular intervals, not to exceed one year, to ensure its continuing suitability and effectiveness. This review will include handling of nonconformances, corrective actions, and response to customer complaints.
- d. Plant facilities in the form of a general plant layout that notes allocation of areas, services, machinery, and equipment.
- e. Purchasing procedures for quality control compliance that include project specification review for specific requirements.
- f. Identification of training needs and provisions for training personnel in quality assurance procedures and requirements.
- g. Control, calibration, and maintenance of necessary inspection, measuring, and test apparatus.
- h. Uniform methods for reporting (including sample forms), reviewing, and maintaining records. Each precast concrete unit shall be uniquely identified to a specific set of applicable quality control records.
- i. Standards for shop (erection and production) drawings to ensure accuracy and uniform interpretation of instructions for manufacturing and handling.
- j. Procedures for review and dissemination of project-specific requirements to production and quality control personnel.

### **1.2.2 Documented Procedures**

Control of documented procedures and data, relative to the effective functioning of the quality assurance program, shall cover as a minimum:

- a. Inspecting and verifying purchased materials for conformance with

plant management for development of the document. It further requires periodic updating to establish new practice guidelines for addressing the changes in products, procedures, and facilities.

Plant procedures should be documented as specific instructions to operating personnel. This will help to ensure uniformity in daily operations and the training of present and new employees. See Appendix A for developmental guidelines of a QSM.

The best possible design and use of the highest-quality materials do not ensure product quality. Quality is established through adherence to proven production procedures. When possible, procedures with a high degree of variability and that are subject to human error, should be eliminated.

The most important aspects of a quality assurance program are:

- a. Management commitment to supporting the quality assurance program and establishing a uniform standard of quality in the plant.
- b. Clearly defined responsibilities and required functions for each inspector.
- c. Adequate inspection personnel to ensure review of all materials and processes.
- d. Clear and complete records of inspection and testing.
- e. Updating and calibration of testing equipment in a timely manner.

Information gained through quality control inspections should be reviewed in a timely manner with production personnel. This review may be useful in identifying areas that require additional training in proper production procedures, procedures that require modifications, or equipment that needs repair or replacement.

### **C1.2.2 Documented Procedures**

A complete and accurate record of operations and inspection activities is beneficial to a producer if questions are raised during the use of plant-produced products. For additional information, see Division 6, Quality Control.

# ***DIVISION 1 – QUALITY SYSTEM***

## **Standard**

## **Commentary**

specification requirements. Vendors shall be required to submit proof of compliance for both materials and workmanship.

- b. Sampling methods and frequency of tests.
- c. Checking and approval of shop drawings.
- d. Inspecting and verifying the accuracy of dimensions.
- e. Inspecting and verifying adequacy and sealing of the form/mold to produce units in compliance with surface finish requirements.
- f. Procedures for and inspection of batching, mixing, placing, consolidating, curing, and finishing concrete.
- g. Procedures for and inspection of concrete repair, handling, storing, and loading of finished products.
- h. Inspecting the fabrication, placement, and securing of reinforcement and hardware; and quantity, location, and attachment of cast-in items, blockouts, and surface features.
- i. Inspection of tensioning operations to ensure conformance with specified procedures.
- j. Mixture design preparation and evaluation.
- k. Sampling and testing of materials and fresh concrete.
- l. Inspection of detensioning and stripping procedures.
- m. Inspection of finished products for conformance with the shop drawings, and other project requirements, such as approved samples.
- n. Repair procedures for noncompliant conditions.
- o. Preparing and maintaining complete quality control records.
- p. Maintenance and calibration requirements (items and frequency) of plant equipment that may affect product quality.

### **1.2.3 Management Responsibilities**

Plant management shall establish and support fundamental quality control requirements, which include, but are not limited to:

- a. A corporate standard of quality.
- b. A written Plant Quality System Manual

### **C1.2.3 Management Responsibilities**

Plant management should be committed to quality, and this commitment should be demonstrated to all personnel. Quality control inspection functions cannot overcome a lack of dedication to quality by management. Those responsible for producing the

- that establishes a uniform order or practice for all manufacturing operations.
- c. Personnel whose primary function is quality control, with functional responsibility to the general manager or chief engineer.
- d. An acceptance program for finished products prior to shipping.
- e. Uniform methods for reporting, reviewing, and keeping records. Each precast concrete unit produced shall be traceable to a specific set of applicable quality control records.
- f. Engineering operations that ensure compliance with the required codes, standards, specifications, and in-plant performance requirements.

### **1.3 Personnel**

#### **1.3.1 General**

Each plant shall have personnel qualified to perform the functions of the various positions outlined in this section. Personnel responsibilities and the relationships between quality control, engineering, and production shall be established and clearly defined.

At least one individual involved in the testing of fresh concrete or directing such tests shall maintain a current ACI Concrete Field Testing Technician, Grade I Certification or approved equivalent certification.

For plants that do not prestress, at least one individual performing quality control functions shall be certified as Level I in the PCI Plant Quality Personnel Certification (PQPC) program. For plants that prestress, at least one individual performing quality control functions shall be certified as Level II in the PQPC program.

#### **1.3.2 Engineering**

Plants shall have available the services of a registered professional engineer experienced in the design of precast concrete. The precast

product should understand that management requires the production of quality products.

### **C1.3 Personnel**

#### **C1.3.1 General**

In this section, the functional responsibilities of certain basic positions are outlined. Whether one or more of these functions is assigned to one person, or several persons are assigned to a specific function, is the prerogative of management. This is normally dependent on the intended use of the product and the size of the plant.

Proper and responsible performance of persons involved in manufacturing precast concrete products requires specialized technical knowledge and experience. The plant should have appropriate contingency plans in place to provide for the absence of regularly assigned quality control staff.

The PCI Quality Control Personnel Certification program currently outlines three levels of training and certification. It is recommended that all personnel performing precast concrete inspection and testing work, as described in this manual, be certified at the appropriate level. In some operations, the certified individual may perform several tasks, including quality control functions. It is recommended that each plant have at least one Level III–certified employee.

#### **C1.3.2 Engineering**

Engineering personnel should review the design of precast concrete elements. The precast engineer should have the ability to solve problems and devise

# ***DIVISION 1 – QUALITY SYSTEM***

## **Standard**

## **Commentary**

engineer shall prescribe design policies for precast concrete elements and be competent to review designs prepared by others.

methods, as required, for the design, production, handling, and erection of precast concrete products.

The precast engineer shall be responsible for prescribing or approving methods and procedures for tensioning, computations and measurements of elongations, measurements for camber and deflections, compensations for operational stress variations, and any other functions that may affect the integrity of the product.

### **1.3.3 Drafting**

### **C1.3.3 Drafting**

Plants shall utilize experienced personnel competent to prepare shop (production and erection) drawings in general accordance with the current *PCI Drafting Handbook – Precast and Prestressed Concrete*, MNL-119.

Shop drawings should clearly, accurately, and completely detail the requirements of the contract documents in a manner that minimizes the possibility of errors during the manufacturing and erection processes.

### **1.3.4 Production**

### **C1.3.4 Production**

Production personnel shall be qualified to produce units in accordance with the production drawings, the plant's quality control requirements, and other project requirements.

Production personnel have the immediate responsibility of supervising all plant operations involved in the manufacture of products to ensure compliance with production drawings, specifications, and established plant standards.

Production personnel shall receive training in the effects that production methods can have on self-consolidating concrete (SCC) properties.

Production personnel need to understand that each SCC or flowable concrete mixture has been carefully designed to take into account all aspects of material selection, form/mold condition, placement methods, and engineering properties. When expected results in quality are not being achieved, the contribution of knowledgeable production personnel is vital to taking proper corrective action.

### **1.3.5 Quality Control**

### **C1.3.5 Quality Control**

This function shall have lines of communication to engineering, production, and management; however, direct responsibility shall only be to management. Quality control personnel shall not report to production personnel.

Quality assurance is the primary responsibility of the quality control staff. Production personnel should be involved in assuring quality and communicate closely with the quality control staff; however, the delineation of responsibility between production and quality control personnel should be recognized and respected.

The qualifications of personnel conducting inspections and tests are critical to providing adequate assurance that the precast concrete products will achieve the desired level of quality.

Quality control personnel shall be responsible for

Quality control personnel should observe and report

ensuring that the following activities are performed at a frequency adequate to meet plant-specific quality objectives or as addressed in this manual:

- a. Inspecting and verifying the accuracy of dimensions and condition of form/mold
- b. Verifying procedures for batching, mixing, placing, consolidating, curing, and finishing concrete.
- c. Verifying procedures for concrete repair, handling, storing, and loading of finished products.
- d. Verifying the proper fabrication and placement of reinforcement.
- e. Verifying the proper fabrication, quantity, and location of cast-in items, blockouts, and surface features
- f. Inspecting tensioning operations to ensure conformance with specified procedures.
- g. Preparing or evaluating mixture designs.
- h. Taking representative test samples and performing all required testing.
- i. Inspecting finished products for conformance with the shop drawings, approved samples, and other project requirements.
- j. Preparing and maintaining complete quality control records.

Every quality control inspector involved in the production and testing of SCC or flowable concrete shall be trained in the proper testing procedures for the various test methods. In addition to understanding how the tests are to be conducted, quality control personnel shall also be able to evaluate the results of those tests.

## **1.4 Design Responsibilities**

### **1.4.1 General**

The precaster shall be responsible for translating the project requirements into samples, shop drawings, tooling, manufacturing procedures, and installation procedures in accordance with the appropriate provisions of the contract documents.

any changes in plant equipment, working conditions, weather, and other items that have the potential for affecting the quality of products.

The objectives, methods, uniformity of practice, inspection, and record keeping required in production of SCC are no less important than any other facet of the quality control program.

If the desired quality and value of an SCC or flowable concrete mixture is to be realized, the quality control personnel should understand the placement techniques, element characteristics, and raw-material considerations that are used to determine mixture proportions and fresh concrete properties.

## **C1.4 Design Responsibilities**

### **C1.4.1 General**

The responsibilities of the architect/engineer and the precaster are subject to a contractual relationship with the owner, as presented in Appendix B, Design Responsibilities and Considerations. Local practices regarding responsibility for the design of precast concrete units vary widely. Similarly, but to a lesser extent, relevant codes or statutes governing professional design and the responsibility of

# ***DIVISION 1 – QUALITY SYSTEM***

## **Standard**

## **Commentary**

The precast engineer shall analyze all precast concrete units for handling stresses and temporary loadings imposed on the units prior to and during final incorporation into the structure.

The precast engineer shall be responsible for the design of all products for production, handling, and erection stresses.

### **1.4.2 Shop Drawings**

The precaster shall prepare and submit drawings for approval, as required, in general accordance with the current *PCI Drafting Handbook – Precast and Prestressed Concrete*, MNL-119, and the project specifications. Production drawings shall be prepared to convey all pertinent information necessary for fabrication and inspection of the precast concrete products.

## **1.5 Project Samples**

### **1.5.1 General**

Finish samples with the required color and texture shall be prepared and submitted for approval. If the back face of a precast unit is to be exposed, samples of color and texture shall also be submitted. This submittal and approval

manufacturers can also vary widely. Accordingly, the information provided in this section should be evaluated for conditions applicable to the particular location or to individual projects. For additional information, refer to the current *PCI Design Handbook*, MNL-120.

In the interest of both the precaster and architect/engineer, the design responsibilities of each party should be clearly defined, coordinated and consistent. It is recommended that this be done in the contract documents.

A precast engineer should approve the sequence of erection when the sequence may affect the structural stability of the supporting elements. In situations where the engineer of record, or others, provide product design for in-place loading conditions, the precaster should determine any additional requirements imposed by manufacturing and handling procedures.

### **C1.4.2 Shop Drawings**

The primary function of precast concrete shop (production and erection) drawings is the translation of contract documents into usable information for accurate and efficient manufacturing, handling, and erection of the units. The erection drawings provide the architect/engineer with a means for checking the interface between adjacent materials and the precaster's interpretation of the contract drawings. Production drawings should provide effective communications between the engineering/drafting and the production/erection departments of a precast concrete plant.

## **C1.5 Project Samples**

### **C1.5.1 General**

For descriptions of typical surface treatments, refer to Section 2.8, Surface Finishes.

Sample approval should be made in writing directly on the unit with reference to the correct sample code number. Approval of the sample by the architect/engineer should indicate authorization to proceed with production, unless such authorization is

process shall take place before the start of production of the project.

Samples and mock-ups shall be regarded as a standard for performance within the variations of workmanship and materials to be expected.

When specified, or if significant variations in appearance are anticipated, samples showing the expected range of variations shall be supplied for review and approval.

Samples or mock-ups involving the appearance of the surface finish, changes in the source of materials, or changes in the mixture proportions shall require approval of new reference samples.

The concrete placement and consolidation method used to make samples shall be representative of the intended production methods.

expressly withheld.

Mock-ups may be specified for unique elements or features to ensure that proposed construction methods and workmanship produce acceptable results.

Due to differences in sources of supply or different techniques developed in various plants serving the same area, the architect/engineer should not expect to select one sample and obtain exact matching by all precasters.

Samples for approval should be submitted promptly for early acceptance to provide for timely material procurement and production of units.

If the back face of a precast concrete unit is to be visible in the finished structure, samples of the workmanship, color, and texture of the backing should be provided for review and approval.

If the characteristics of submitted prebid samples in any way deviate from the project specifications, the precaster should make this clear to the architect/engineer when submitting the samples.

For proper evaluation and approval of the samples, the precaster should state the reasons for deviations from the specifications. These reasons might include the precaster's concern over controlling variation in color or texture within specified limits. Such color and texture variations should be approved in writing by the specifier.

The production of uniform, blemish-free samples, which demonstrates the abilities of a single master craftsman, will be misleading and may cause difficulties. Such difficulties may arise when the production personnel, using actual manufacturing facilities, try to match the sample.

If small samples are used to select the aggregate color in architectural units, the approving authority (architect or owner) should be made aware that the samples may not be representative of the larger units. Large surface areas of elements will typically contain variations in color and texture.

Color selection should be made under lighting conditions similar to actual service conditions, such as direct sunlight or shadows.

Since some samples are developed for specific projects with particular shapes, limited exposure conditions, or other characteristics, the sample should

# ***DIVISION 1 – QUALITY SYSTEM***

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be clearly marked with respect to limits of application to prevent their selection by the architect/engineer for inappropriate applications.

Examples include:

1. Sandblasted lightweight-aggregate units for exterior applications.
2. Units made from mixtures with lower strength and higher absorption suited for dry, noncorrosive environments.

### **1.5.2 Size and Shape**

The size of samples shall reflect the relationship to the size of aggregate, finish, shape, and casting techniques, such as form/mold types, orientation of exposed surfaces during casting, and consolidation procedures.

### **C1.5.2 Size and Shape**

Samples should reflect the shape of the actual unit. For nonplanar, curved, or other complex shapes, a flat-cast sample may not represent the anticipated appearance of the final product.

Small 12-in.-square (300 mm) samples are generally used for initial color and texture submittals, but larger samples or mock-ups may later be required to adequately represent the actual project requirements.

### **1.5.3 Identification**

All samples shall be clearly identified.

### **C1.5.3 Identification**

A file of sample code numbers with all related data should be maintained by the precaster to ensure future duplication of any sample submitted.

### **1.5.4 Visual Mock-ups, Range Samples, and Initial Production - Approval of Finishes**

Mock-ups and range samples shall be produced using standard production equipment and techniques.

Previously completed project components, mock-ups, or samples that are similar are acceptable for initial production approval of products.

When mock-up units are not used, the precaster shall request the architect/engineer or owner to inspect and approve (sign and date) the initial production components.

When called for by specifications or necessitated by unique color or texture concerns, range samples shall be produced. Range samples shall establish the range of acceptability with respect to color, texture, and surface variations, as well as overall appearance.

### **C1.5.4 Visual Mock-ups, Range Samples, and Initial Production - Approval of Finishes**

When new shapes, materials, or finishes are used, the precaster should consider using mock-ups consisting of a full-scale portion of a unit for initial production approval.

Larger production samples or mock-ups are more representative of the entire structure and will help eliminate uncertainties that the architect/engineer or owner may have

A range of at least three samples of a size sufficient to demonstrate actual planned production conditions may be used to establish a range of acceptability with respect to color and texture variations; uniformity of returns; frequency, size, and uniformity of air-void distribution; surface blemishes; and overall

Samples and mock-ups shall be viewed at a distance consistent with actual viewing distance in the structure, but not less than 20 ft (6 m).

Approved project samples shall be kept at the precaster's facility, adjacent to each other and in an area to allow for proper lighting. These samples shall be used to monitor the acceptability of the production units.

If specifications require mock-ups to be kept at the project site, sufficient additional samples that show equivalent surface features shall be maintained at the plant.

appearance. When specified, the acceptability of repair techniques for chips, spalls, or other surface blemishes should also be established on these samples.

The architect, owner, or owner's representative should visit the precast concrete plant for examination and approval (sign and date) of the mock-up or first production units. It should be clearly stated in the contract documents how long the approved production units or the mock-up structure should be kept in the plant or on the jobsite for comparison purpose.

Some important variables that should be controlled as close to actual production conditions as possible include:

- Retarder coverage rate and method of application
- Mixture design and slump/flow
- Admixtures used
- Temperature of fresh and cured concrete
- Age at which operations are performed
- Vibration methods
- Piece thickness
- Method of exposing the surface

Mock-up panels should contain typical cast-in inserts, reinforcement, and plates as required for the project. Handling the mock-up pieces serves as a check that the stripping methods and lifting hardware will be suitable.

Special details such as reveal patterns and intersections, corner joinery, drip sections, patterns, and other visual characteristics should be demonstrated in large production samples for approval.

Two areas should be patched for approval demonstrating color, texture, and appearance of the repairs.

Changes in aggregate orientation, color tone, and texture can easily be noted on full-scale mock-up panels.

It is important that approval visits be closely coordinated by both the precaster and the architect to avoid delays in the project schedule.

If full sized units are specified in the contract documents for use as visual mockups, it is recommended that the contract documents permit the approved full-sized units to be used in the job installation in the late stages of construction. The

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approval units should remain identifiable even as erected, until final acceptance of the project.

Aesthetic mock-ups can offer the opportunity to evaluate the following factors:

- Acceptable appearance in regard to color, texture, details on the exposed face, and uniformity of returns.
- Desirability of the method of connection in light of handling-equipment limitations and erection procedures.
- Colors and finishes of adjacent materials.
- Dimensional accuracy of the precast concrete work and the constructability of the specified tolerances.
- The acceptability of the precast concrete back finish.
- Available methods for the repair of chips, spalls, or other surface blemishes. The mock-up will also establish the extent and acceptability of defects and repair work.
- Suitability of the selected sealers.

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# DIVISION 2 – PRODUCTION PRACTICES

## Standard

## Commentary

### 2.1 General Objectives and Safety

### C2.1 General Objectives and Safety

#### 2.1.1 General

The plant facility shall be adequate for production, finish processing, handling, and storage of product in accordance with this manual.

#### C2.1.1 General

Plant facilities are the tools of the industry and as such should be maintained in good, clean operating condition. Facilities suitable for the production of precast concrete units will vary from plant to plant. These facilities will be affected by size, weight, and volume of units produced; variety of surface finishes offered; and climate.

#### 2.1.2 Plant Safety

Each operation shall establish and maintain a written program that promotes workers' safety and health.

#### C2.1.2 Plant Safety

A safety program is an important element of any production operation. PCI strongly encourages safety and loss-prevention programs. The *PCI Safety and Loss Prevention Manual*, SLP-100, can be used to start a program. Such programs should outline safety practices as they relate to the precast concrete industry and existing governmental regulations.

A safety program should include the following basic elements:

1. **Policy.** A written statement of plant or company policy for safety that establishes clear lines of authority.
2. **Rules.** The management of each plant should develop a set of safety rules designed to help employees avoid injury. Disciplinary methods should also be established to address situations where safety rules have been compromised.
3. **Training.** Each plant should have a training program to ensure that new and old employees are instructed in safe daily operating procedures.
4. **Accident investigation.** An accident investigation procedure to identify causes or areas needing improvement, better supervision, or employee training.

The details of a safety program are not specified in this manual, but are left to the individual plants to tailor to their facilities, products, and operations.

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### **2.2 Production and Curing Facilities**

### **C2.2 Production and Curing Facilities**

#### **2.2.1 Area Requirements**

#### **C2.2.1 Area Requirements**

The production and curing areas shall be designed for controlled production of quality precast concrete units and be of adequate size in relation to the volume and characteristics of the products manufactured for a well-organized, continuous operation. Consideration for production flexibility and flow patterns shall be made keeping in mind health and safety provisions.

The casting area should provide flexibility in planning and spacing of the form/mold and efficient movement of workers, materials, and equipment involved in placing, initial curing, and stripping of products. Facilities should be provided for prestressing, if required.

Provision should be made to control the temperature with reasonable accuracy, since chemical retarders and form/mold release agents may react differently under varying temperature and humidity ranges. To meet the provisions of Division 4, it may be necessary to provide heating and/or proper ventilation for the casting area and the form/mold, depending on the geographic location of the plant.

The form/mold should be protected against detrimental environmental conditions. The production areas should provide a reasonably uniform ambient environment to maintain the desired concrete temperature. Adequate lighting should be provided for all operations.

All raw materials shall be stored in a manner that will prevent contamination or deterioration and in accordance with applicable manufacturer's recommendations.

#### **2.2.2 Form/Mold Fabrication**

#### **C2.2.2 Form/Mold Fabrication**

Form/mold fabrication facilities shall be tooled to provide for the building of forms/molds to a level of accuracy sufficient to maintain the product within required tolerances.

Form/mold fabrication facilities should be capable of maintaining constant working temperatures above the minimum required for the raw materials and processes utilized. Resins, catalysts, accelerators, acetone, etc., for forms/molds should be stored within the manufacturer's recommended temperature range and away from the production areas.

Forms/molds shall be stored in a manner to protect them from damage that could result in dimensional change or general surface or structural degradation.

The design of prestressing forms/molds and beds should be based on stated factors of safety according to sound engineering principles. The design should take into account the magnitude, position, and frequency of the anticipated applied loading.

For the fabrication of prestressed products, self-stressing forms/molds, bed abutments, and anchorages shall be designed by qualified engineers. Information on the capacity of each bed and self-stressing form/mold in terms of

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allowable prestressing force and its corresponding height of application above the form/mold base shall be kept on file.

Foundations should be designed to prevent undesirable movement.

### **2.2.3 Storage of Release Agents and Other Chemicals**

Release agents and retarders shall be stored in accordance with manufacturer's recommendations, particularly with regard to temperature extremes. Before use, release agents and retarders shall be checked for sediment. If solids are susceptible to settlement, uniformity and original consistency shall be maintained by periodic mechanical mixing or stirring in accordance with the manufacturers recommendations.

Release agents and retarders containing volatile solvents shall be stored in airtight containers to prevent a change in concentration. Release agents shall not be diluted unless specifically permitted by the manufacturer.

### **C2.2.3 Storage of Release Agents and Other Chemicals**

Release agents, retarders, and other chemicals should have a reasonably long and stable storage life, but some, especially emulsions and a few new "green chemicals" may be susceptible to damage from a single freezing storage temperature or simply storage of a few weeks or months.

Certain weather and/or temperature conditions can affect the performance of water-based release agents, retarders, or other chemicals. Generally, they cannot be used in cold weather because they might freeze. Even at temperatures slightly above freezing, some water-based products thicken enough to produce more bugholes and/or reduced performance.

### **2.2.4 Hardware Fabrication and Storage**

Materials shall be handled and stored to avoid distortion beyond allowable variations. Steel without corrosion protection shall be stored on pallets, blocks, or racks, or in containers, as well as protected from contamination.

Stainless steel hardware shall be protected from contamination from other metals during storage and fabrication. Stainless steel hardware shall only be handled with nonmetallic or stainless materials.

Adequate space and equipment shall be provided for the fabrication of hardware. Fabrication equipment for hardware shall be of a type, capacity, and accuracy capable of fabricating hardware assemblies to the required tolerances and quality.

Electrodes used for welding operations shall be bought in hermetically sealed containers. Once containers for low-hydrogen SMAW electrodes are opened, welding electrodes and wires shall be stored in accordance with applicable AWS standards.

### **C.2.2.4 Hardware Fabrication and Storage**

It is necessary to store electrodes in a controlled environment to prevent moisture absorption into the flux from ambient humidity.

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If hardware is fabricated by an outside supplier, that supplier shall furnish records of compliance to specification requirements and mill certificates for the material used.

Periodic review of hardware fabrication shall be performed by quality control personnel.

### **2.2.5 Concrete Handling and Consolidation Equipment**

### **C2.2.5 Concrete Handling and Consolidation Equipment**

The concrete handling equipment shall be such that it will convey concrete from the mixer to the forms/molds:

1. In sufficient quantities to avoid undue delays in placement and consolidation.
2. Without segregation of aggregates and paste.
3. With uniform consistency.
4. With ease of discharge into forms/molds.
5. With equipment capable of being thoroughly cleaned.
6. With consideration for concrete temperatures.

The casting area shall be supplied with equipment in good operating condition for consolidation of the concrete after placement in the forms/molds. The consolidation equipment shall conform to applicable ACI requirements.

Before a vibratory unit is put into use, it shall be checked to verify that it is working properly.

For successful SCC transport and handling, the plant's equipment shall be able to deposit the SCC with acceptable free fall into the forms/molds.

### **2.2.6 Curing and Finishing Areas**

The plant shall be capable of maintaining a minimum concrete temperature of 50 °F (10 °C) and holding a maximum concrete temperature of 104 °F (40 °C) during the initial curing cycle (prior to preset).

When moist curing is used, facilities shall provide

Concrete vibrators may be internal, external, or surface types, depending on the size and shape of the product. These vibrators may be used singly or in various combinations. Provisions should be made to supply adequate and safe power for these units.

Certain modifications to the plant equipment may be necessary to minimize SCC “churning” or agitation, and/or SCC free fall.

### **C2.2.6 Curing and Finishing Areas**

Configuration of curing facilities will depend on the components being made and the method of curing.

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a well-drained area with adequate covering to maintain the required relative humidity and temperature.

The capacity of the heat source for accelerated curing shall be related to the volume of concrete to be cured, the stripping or transfer strength level, the length of the curing cycle, and the effectiveness of the heat enclosure. The heat source and the distribution system shall be protected from operational hazards and shall provide uniform, controlled heat for each unit or series of units being cured. Heat enclosures shall not damage the products nor affect the uniformity of heat distribution to the units.

The finishing areas shall provide for the varying types of finishes to be produced by the plant (see Section 2.8).

In the case where units are to receive no further finish treatment prior to storage and delivery, they shall be protected from damage that cannot be readily removed by cleaning. Products that are to receive a sealer shall be treated and cured as required by the sealer manufacturer.

Provision shall be made for an area to patch flawed or damaged products.

### **2.2.7 Handling Equipment**

The production facilities shall include adequate product handling equipment that is maintained in good working condition. Handling equipment shall be capable of stripping, moving, stacking, retrieving, and loading units without damaging the products.

### **2.2.8 Storage Area for Finished Products**

The storage area shall be of adequate size to allow safe storage and easy access to the products by the handling equipment. The area shall be clean, well-drained, and stabilized to minimize differential settlements under all weather conditions and to minimize soiling, warping, bowing, chipping, or cracking of the product.

Lighting is extremely important in the finishing area and at the point where final inspection is made before transport to the storage area. This is where comparison to the approved samples is made for color and texture. Where possible, indoor lighting should compare to daylight as closely as possible.

### **C2.2.7 Handling Equipment**

The type and capacity of equipment for handling finished products will depend on the product size and configuration and the operating conditions.

### **C2.2.8 Storage Area for Finished Products**

Access should be provided in the storage area to allow for product inspection.

The subgrade in the storage area should be stabilized to avoid soft spots where one end of a member can settle. This settlement creates twisting or tensile stresses that can cause cracking and damage. For example, where units are stored on frozen ground, proper safeguards should be used to prevent

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Storage racks shall be designed to safely store the products. Storage racks, such as horses, A-frames, and vertical racks shall be well constructed to minimize warping, bowing, chipping, or cracking of the products. Storage systems actually carrying products shall be reviewed by the precast engineer for their safe load capacity. Where necessary, such storage equipment shall be protectively coated to avoid any staining or discoloration of the finished products.

settlement when the ground thaws. The storage area should be inspected after hard rains or large snow melts for washouts and other damage.

### **2.3 Welding**

### **C2.3 Welding**

#### **2.3.1 Welding of Structural Steel**

#### **C2.3.1 Welding of Structural Steel**

Welding of steel plates, angles, and other shapes shall be in conformance with current AWS D1.1/D1.1M. All welds shall be performed by welders qualified in accordance with current AWS D1.1/D1.1M. Welding Procedure Specifications (WPS) for structural steel shall be written and qualified in accordance with current AWS D1.1/D1.1M. Welding parameters shall be within the range recommended by the electrode manufacturer (typically shown on the side of the package). The size, length, type, and location of all welds shall conform to those shown on the shop drawings, and no unspecified welds shall be added without approval of the precast engineer. Surfaces to be welded, and surfaces adjacent to a weld, shall be uniform, free from loose or thick scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that can withstand vigorous wire brushing, a thin rust-inhibitive coating, or antisplatter compound may remain.

Temperature-indicating devices, such as temperature sticks or infrared sensors, are frequently used to give an approximate preheat temperature indication. This measurement should be made at approximately 3 in. (75 mm) from the weld joint.

The preheat requirements of insert plates shall be in accordance with Table 2.3.1. Welding shall not be done when the ambient temperature in the immediate vicinity of the weld is below 0 °F (-18 °C). Three in. (75 mm) of the insert plate in each direction around the weld shall be preheated to at least the minimum required temperature.

It is important to verify the carbon equivalent of the structural steel with lab testing or certified mill reports prior to start of welding.

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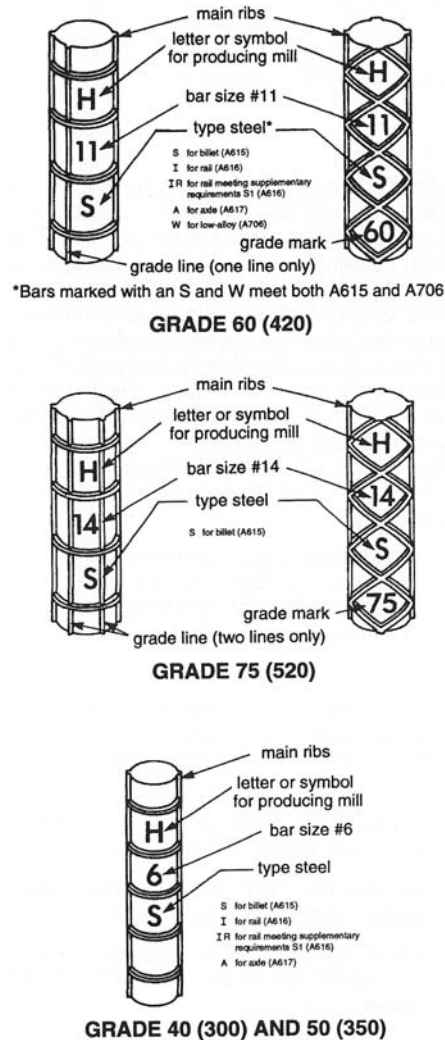
**Table 2.3.1 Minimum preheat temperatures for insert plates**

| Thickest section at point of welding, in. (mm) for A36, A441, A500 (grades A, B), and A572 (grades 42, 50) <sup>1</sup> | Minimum Temperature <sup>1,2,3</sup> , °F (°C) |
|-------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| 1/8 to 3/4 (3 to 19)                                                                                                    | None <sup>4</sup>                              |
| Over 3/4 through 1-1/2 (19 to 38.1 inclusive)                                                                           | 50 (10)                                        |
| Over 1-1/2 through 2-1/2 (38.1 to 63.5 inclusive)                                                                       | 150 (66)                                       |
| Over 2-1/2 (63.5)                                                                                                       | 225 (107)                                      |

1. If the steel specification for the insert plate or welding process being used is not shown in this table, refer to Table 3.2 of current AWS D1.1/D1.1M for preheat requirements.
2. Minimum temperature required when using shielded metal arc welding with low-hydrogen electrodes, submerged arc welding, gas metal arc welding, or flux cored arc welding.
3. This must be compared with the preheat requirements for the reinforcing bar. The higher of the two requirements should be applied.
4. When the insert plate temperature is below 32 °F (0 °C), the plate shall be preheated to a temperature of at least 70 °F (21 °C) and this minimum temperature maintained throughout the entire welding process.

Slag from each pass shall be completely removed before depositing the next pass to avoid porosity and slag entrapment. Slag shall be removed from all completed welds, and the weld and adjacent base metal shall be cleaned with a chipping hammer followed by brushing or other suitable means. Tightly adherent spatter remaining after the cleaning operation is acceptable. Galvanizing on mating surfaces shall be removed prior to welding using qualified procedures. Accessible welds of corrosion-protected (galvanized or painted) material shall be touched up after welding. Zinc-rich paint shall be brush or spray applied to a thickness of greater than 0.004 in. (0.10 mm) over the welded

**Fig. C2.3.1 Identification marks, ASTM standard bars**



For zinc-rich painted steel, welding causes decomposition of the paint film that is burnt off for some distance on each side of the weld. The extent of the repair of the damaged zone will depend on the heat input.

Zinc-rich paints are available that have been specially formulated such that it is not necessary to remove the coating from the weld path prior to welding. A letter should be obtained from the paint manufacturer stating it to be weldable.

It is not uncommon to find small cracks in a fillet weld on galvanized steel, extending from the root

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areas to replace the removed galvanizing or in conformance with current ASTM A780/A780M.

When welding stainless steel plates to other stainless steel or to low-carbon steel, the general procedures for welding low-carbon steels shall be followed, taking into account the stainless steel characteristics that differ, such as higher thermal expansion and lower thermal conductivity. Welding of stainless steel shall be in conformance with AWS B2.1/B2.1M and AWS D1.6/D1.6M. Welding of stainless steel shall be done by qualified welders familiar with the welding requirements of these alloys.

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toward the face of the bead. Whether cracking will occur depends on many factors, such as the silicon content of the weld metal; the degree of penetration of the weld; the gap between metals; the thickness of the base metal that influences restraint of the joint; and the coating weight of the zinc and the microstructure of the zinc coating, which are both influenced by the composition of the base plate, particularly with respect to silicon content. Low-silicon or rutile (non-low hydrogen) base electrodes with low silicon content (0.2 Si or lower) generally reduce cracking.

With proper precautions, zinc can be removed by burning with an oxygen fuel gas torch, shot blasting with portable equipment, or grinding with abrasive discs.

Arc welding with some electrodes and welding of stainless steel may produce hexavalent chromium fumes which are carcinogenic. Engineering controls or respirators may be necessary to reduce exposure.

Stainless steels have many properties that differ from those of carbon or other steels and the differences become more pronounced with higher chromium contents. For example:

1. Their thermal conductivity is much lower, so they are more susceptible to local overheating and to distortion when they are welded.
2. Their thermal expansion is higher and this tends to increase distortion and results in higher stresses on the weld during cooling.
3. They resist oxidation until heated to temperatures around their melting points in the presence of air. Then a highly refractory chromium oxide is formed, preventing these alloys from being cut with an ordinary oxyacetylene cutting torch. In welding stainless steels, the molten metal must be well protected from the air.
4. Some martensitic alloys, as the carbon content increases, are highly hardenable and become brittle when heated and cooled due to excessive grain growth at high temperatures. Other martensitic alloys suffer a loss in corrosion resistance if there is appreciable carbon in the base or weld metal.

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A method for cutting steel, such as thermal or mechanical cutting processes, shall be used that produces a clean, smooth edge.

The edges of a thermally cut weld joint shall be cleaned by machining or grinding to remove surface contamination, particularly iron oxides. Parts to be joined shall also be free of oil, grease, paint, dirt, and other contaminants.

In joining austenitic stainless steels to carbon steels or low-alloy steels, a stainless steel welding rod that is sufficiently high in total alloy content, such as Type 309, shall be used. When, due to service requirements, the depositing of carbon steel or low-alloy steel weld metal on stainless steel is required, the short-circuiting method of metal transfer shall be used.

Welds and the surrounding area on stainless steel shall be cleaned of weld spatter, flux, or scale to avoid impairment of corrosion resistance.

### **2.3.2 Welding of Reinforcement**

Welding procedure specifications for reinforcing bars shall be written and qualified in accordance with current AWS D1.4/D1.4M. Welding of reinforcing bars shall be executed considering steel weldability and proper welding procedures, whether performed in-plant or by vendors.

Because of the relatively high coefficient of thermal expansion [ $9.2 \times 10^{-6}$  in./in. °F ( $16.6 \times 10^{-6}$  m/m °C)] and lower thermal conductivity [9.1 Btu/hr ft °F (15.7 w/mk)] of austenitic stainless steel, precautions are necessary to avoid weld bead cracking, minimize distortion of steel, and avoid cracking of concrete. The following procedures may be used to minimize these problems: lower weld current settings, skip-weld techniques to minimize heat concentration, use of cooling techniques to dissipate heat, tack welding to hold the parts in alignment during welding, and sequence of welding.

Stainless steels cannot be cut smooth with an ordinary oxyacetylene torch.

Cleaning of stainless steel to be welded is important. Contamination from grease and oil can lead to carburization in the weld area with subsequent reduction of corrosion resistance. Postweld cleanup is also important and should not be done with carbon steel files and brushes. Stainless steel wire brushes should be used. Carbon steel cleaning tools, as well as grinding wheels that are used on carbon steel, can leave fine particles embedded in the stainless steel surface that will later rust and stain if not removed by chemical cleaning.

The use of a stainless steel welding rod with high total alloy content will prevent martensite formation while at the same time preserving residual amounts of ferrite, which counteract the tendencies for hot cracking (at the time of welding) even under conditions of severe restraint.

### **C2.3.2 Welding of Reinforcement**

The grade, bar size, and chemical composition of the reinforcing bar should be known prior to welding. Assuming a carbon equivalence higher than what actually exists could result in a more complicated and costly welding process. The weldability of steel established by its chemical analysis limits the

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Striking an arc on the reinforcing bar outside of the weld area shall not be permitted. Quality control or engineering shall review the mill test report to determine the carbon equivalent (C.E.) and the preheat requirements. Minimum preheat and interpass temperatures for welding of reinforcing bars shall be in accordance with Table 2.3.2 using the highest carbon equivalent number of the base metal. Temperature-indicating devices shall be used to determine approximate preheat and interpass temperatures.

For billet-steel bars, conforming to ASTM A615/A615M, the carbon equivalent shall be calculated using the chemical composition as shown in the mill test report, by the following formula:

$$\text{C.E.} = \%C + \%Mn/6$$

If mill test reports are not available, chemical analysis may be made on bars representative of the bars to be welded. If the chemical composition is not known or obtained:

1. For bars No. 6 (19) or less, use a minimum preheat of 300 °F (150 °C).
2. For bars No. 7 (22) or larger, use a minimum preheat of 500 °F (260 °C).
3. For all ASTM A706/A706M bar sizes, use Table 2.3.2 C.E. values of "Over 0.45 to 0.55 inclusive."

Surfaces of reinforcing bars to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease, epoxy coating, or other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that withstands vigorous wire brushing, a thin rust-inhibitive coating, or anti-spatter compound may remain.

The ends of reinforcing bars in direct butt joints shall be shaped to form the weld groove by oxygen cutting, air carbon arc cutting, sawing, or other mechanical means. Bars for direct butt joints that have sheared ends shall be trimmed back beyond the area deformed by shearing.

applicable welding procedures and sets preheat and interpass temperature requirements. Weldability properties are specifically excluded from the ASTM A615/A615M and A996/A996M specifications. Most reinforcing bars that meet ASTM A615/A615M Grade 60 (420) will require preheating. A615/A615M Grade 40 (300) bars may or may not require preheating. ASTM A706/A706M bars are specially formulated to be weldable; hence, the specification contains chemical composition requirements and calculation of the carbon equivalent.

The ASTM specifications for carbon steel, rail steel, axle steel, and low-alloy steel reinforcing bars (A615/A615M, A996/A996M, and A706/A706M, respectively) require identification marks to be rolled into the surface on one side of the bar to denote the producer's mill designation, bar size, type of steel, and minimum yield designation (Fig. C2.3.1).

Minimum yield designation is used for Grade 60 (420) and Grade 75 (520) bars only. Grade 60 (420) bars can either have one single longitudinal line (grade line) or the grade mark 60 (420). Grade 75 (520) bars can either have two grade lines or the grade mark 75 (520).

A grade line is smaller and between the two main ribs that are on opposite sides of all U.S.-made bars. A grade line must be continued at least five deformation spaces. A grade mark is the fourth mark on a bar.

Grade 40 (300) and 50 (350) bars are required to have only the first three identification marks (no minimum yield designation).

AWS D1.4/D1.4M indicates that most reinforcing bars can be welded. However, stringent preheat and other quality control measures are required for bars with high carbon equivalents. Except for welding shops with proven quality control procedures that meet AWS D1.4/D1.4M, it is recommended that carbon equivalents be less than 0.45% for No. 7 (22) and larger bars, and 0.55% for No. 6 (19) and smaller bars.

Welding procedures are critical for reinforcing bars because this steel has relatively high carbon content. The more carbon the steel contains, the more brittle the material and the higher the susceptibility to embrittlement that occurs after a weld begins to cool. As a weld cools, a very brittle form of iron called martensite forms just outside the weld zone. This

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Welding shall not be done when ambient temperature is lower than 0 °F (-18 °C), when surfaces to be welded are exposed to rain, snow, or wind velocities greater than 5 mph (8 km/hr), or when welders are exposed to inclement conditions.

**Table 2.3.2 Welding reinforcing bars (AWS D1.4/D1.4M:2005, Table 5.2)**

| Carbon equivalent <sup>1</sup> range, percent | Size of reinforcing bar     | Minimum preheat and interpass temps. <sup>2,3,4,5</sup> °F (°C) |
|-----------------------------------------------|-----------------------------|-----------------------------------------------------------------|
| Up to 0.40                                    | Up to 11 (36) inclusive     | None <sup>6</sup>                                               |
|                                               | 14 (43) and 18 (57)         | 50 (10)                                                         |
| Over 0.40 to 0.45 inclusive                   | Up to 11 (36) inclusive     | None <sup>6</sup>                                               |
|                                               | 14 (43) and 18 (57)         | 50 (10)                                                         |
| Over 0.45 to 0.55 inclusive                   | Up to 6 (19) inclusive      | None <sup>6</sup>                                               |
|                                               | 7 (22) to 11 (36)           | 50 (10)                                                         |
|                                               | 14 (43) to 18 (57)          | 200 (90)                                                        |
| Over 0.55 to 0.65 inclusive                   | Up to 6 (19) inclusive      | 100 (40)                                                        |
|                                               | 7 (22) to 11 (36)           | 200 (90)                                                        |
|                                               | 14 (43) and 18 (57)         | 300 (150)                                                       |
| Over 0.65 to 0.75                             | Up to 6 (19) inclusive      | 300 (150)                                                       |
|                                               | 7 (22) to 18 (57) inclusive | 400 (200)                                                       |
| Over 0.75                                     | Up to 6 (19) inclusive      | 300 (150)                                                       |
|                                               | 7(22) to 18(57) inclusive   | 500 (260)                                                       |

Notes:

- Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75% except for ASTM A706/A706M bars.
- When reinforcing steel is to be welded to main carbon steel (insert plates or angles), the preheat requirements of the structural steel shall also be considered (see Table 2.3.1). The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables. However, extreme caution shall be exercised in the case of welding reinforcing steel to quenched and tempered steels, and such measures shall be taken as to satisfy the preheat requirements for both. If not possible, welding shall not be used to join the two base metals.

## Commentary

material is subject to fracture upon impact. For example, if a welded assembly that had not been welded using proper procedures is raised to shoulder height and dropped to the floor, it is quite possible the bars would literally break off at the weld point like a shattered piece of crystal. This is due to the formation of brittle martensite.

**Table C2.3.2 Standard identification markings for reinforcing bars**

| Metric bar size | Diameter, mm | Inch-pound bar size | Diameter, in. |
|-----------------|--------------|---------------------|---------------|
| #10             | 9.5          | #3                  | 0.375         |
| #13             | 12.7         | #4                  | 0.500         |
| #16             | 15.9         | #5                  | 0.625         |
| #19             | 19.1         | #6                  | 0.750         |
| #22             | 22.2         | #7                  | 0.875         |
| #25             | 25.4         | #8                  | 1.000         |
| #29             | 28.7         | #9                  | 1.128         |
| #32             | 32.3         | #10                 | 1.270         |
| #36             | 35.8         | 11                  | 1.410         |
| #43             | 43.0         | #14                 | 1.693         |
| #57             | 57.3         | #18                 | 2.257         |

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3. Welding shall not be done when ambient temperature is lower than 0 °F (-18 °C). When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar for not less than 6 in. (150 mm) on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures shall be sufficient to prevent crack formation.
4. After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.
5. Use temperature-sensitive devices for determining approximate preheat and interpass temperatures.
6. When the base metal is below 32 °F (0 °C), the base metal shall be preheated to at least 70 °F (21 °C) and maintained at this minimum temperature during welding.

Preparation for welding on coated base metal shall preferably be made before coating. Welding galvanized metal, without prior removal of the coating, shall be performed in accordance with AWS D1.4/D1.4M or AWS WZC- D19.0. Welding of galvanized metal may also be done after removing all coating from within 2 in. (50 mm) of the weld joint. The welding shall be performed in accordance with AWS D1.4/D1.4 M for uncoated reinforcing bars. With proper precautions, the galvanized coating shall be removed with oxyfuel gas flame, abrasive shot blasting, or other suitable means.

When welding or preheating epoxy coated base metal, the epoxy coating shall be removed from the surfaces to be heated.

After welding, suitable coating protection (zinc-rich or epoxy paint) shall be applied to the finished joint to restore the corrosion-resistant properties of the coated bars.

Tack welds for all reinforcing bars shall be made in conformance with all the requirements of AWS D1.4/D1.4M, preheating, slow cooling, use of proper electrodes, and the same quality requirements as permanent welds.

Tack welding, unless done in conformance with the current AWS D1.4/D1.4M, may produce crystallization (embrittlement or metallurgical notch) of the reinforcing bars in the area of the tack weld. Tack welding seems to be particularly detrimental to ductility, impact and fatigue resistance, and to a lesser extent, static yield strength and ultimate strength. Where a small bar is tack welded to a larger bar, a detrimental “metallurgical notch” effect is developed

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## Commentary

Reinforcing bars which cross shall not be welded unless shown on the approved shop drawings.

Reinforcing bars shall not be welded within two bar diameters of the beginning point of tangency of a cold bend.

in the large bar. Fast cooling under cold weather conditions is likely to aggravate these effects. For assembling ASTM A706/A706M bars into cages, if the holding wires conform to ASTM A82 or A496, electric resistance welds from a fusion process may be used.

There is no metallurgical difference between tack welding and fillet, flare, or flare bevel welding. This is because tack welding produces the same temperature as structural welding.

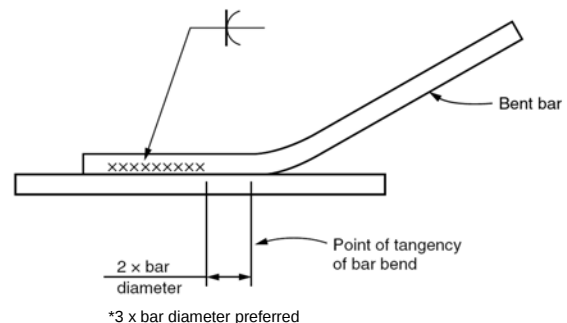
Tack welding should use the same qualification and welding procedures as other structural welding. Tack welding should be limited to straight sections of bars and within the limitations indicated in the shop drawing.

When bars are bent cold without the addition of heat, they become sensitive to heat. Subsequently, the application of too much heat will cause the bars to crystallize and result in unpredictable behavior of the reinforcing bar at the bend. Therefore, as a precaution, it is necessary to keep welds away from cold bends. While AWS D1.4/D1.4M suggests allowing a cold bend at two bar diameters from a weld, experience shows that a minimum distance of 2 in. (50 mm) with 3 in. (75 mm) preferred is better with the small bars commonly used in precasting (Fig. C2.3.2).

When reinforcing steel is welded to structural steel members, the provisions of AWS D1.1/D1.1M shall apply to the structural steel component. When joining different grades of steels, the filler metal shall be selected for the lower-strength base metal.

### 2.3.3 Stud Welding

Headed studs and deformed bar anchors used for anchorage shall be welded in accordance with AWS D1.1/D1.1M and AWS C5.4. The studs and base metal area to be welded shall be free from rust, rust pits, scale, oil, moisture, or other deleterious materials that may adversely affect



**Fig. C2.3.2 Welds at Bends**

### C2.3.3 Stud Welding

The minimum plate thickness requirement is necessary to prevent melt-through occurring and to ensure that the weld is as strong as the stud to utilize the maximum load capacity.

Low-carbon (mild) steels can be stud welded with no

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the welding operation. The base metal shall not be painted, galvanized, or cadmium plated prior to welding. Thickness of plates to which studs are attached shall be at least 1/2 of the diameter of the stud.

When using stud guns, stud length reductions shall meet Table 6.2.3(a) requirements.

The arc shields or ferrules shall be kept dry. Any arc shields that show signs of surface moisture from dew or rain shall be oven dried at 250 °F (120 °C) for 2 hr before use. After welding, arc shields shall be broken free from studs. The completed weld shall have a uniform cross section for the full circumference of the stud.

Stud welding equipment settings shall be based on written welding procedure specifications, past practice, or recommendations of the stud and equipment manufacturer. If two or more stud welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time, so that the power source has fully recovered from making one weld before another weld is started. While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

Stud welding shall not be done when the base metal temperature is below 0 °F (-18 °C), or when the surface is wet or exposed to falling rain or snow.

When studs are welded using prequalified FCAW, GMAW, or SMAW processes, the following requirements shall be met:

### **Commentary**

major metallurgical problems. The upper carbon limit for base plate steel that can be arc stud welded without preheat is 0.30%.

If medium and high-carbon base-plate materials are to be stud welded, it is important that preheat be used to prevent cracking in the heat-affected zones. In some instances, a combination of preheating and postheating after welding is recommended.

Generally, the high-strength, low-alloy steels are satisfactorily stud welded when their carbon content is 0.15% or lower. If the carbon content exceeds 0.15%, it may be necessary to preheat the work to an appropriate preheat temperature to obtain desired toughness in the weld area.

Most classes of stainless steel can be stud welded. Only the 300 series austenitic stainless steels, except 303, are recommended for general applications.

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## **Commentary**

1. Surfaces to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease, or other foreign material that would prevent proper welding or produce objectionable fumes.
2. For fillet welds, the end of the stud shall be clean and the stud base prepared so that the base of the stud fits against the base metal. The minimum size of the fillet weld shall be the larger of those required in Table 5.8 or Table 7.2 of AWS D1.1/D1.1M.
3. The base metal to which studs are welded shall be preheated in accordance with the requirements of Table 2.3.1.
4. SMAW welding shall be performed using low-hydrogen electrodes 5/32 in. or 3/16 in. (4 mm or 5 mm) in diameter, except that a smaller-diameter electrode may be used on studs 7/16 in. (11 mm) or less in diameter for out-of-position welds.

### **2.4 Forms/Molds**

### **C2.4 Forms/Molds**

#### **2.4.1 Materials and Construction**

#### **C2.4.1 Materials and Construction**

All forms/molds, regardless of material, shall conform to the profiles, dimensions, and tolerances indicated by the contract documents and the approved shop drawings.

The overall quality of the project starts with a form/mold capable of allowing the production personnel to make units that meet the specification requirements.

Forms/molds shall be dimensionally stable to produce the required finish and tolerance. Repeated use of forms/molds shall not affect the dimensions or planes of the forms/molds beyond allowable tolerances. Form/mold materials shall not warp or buckle due to any cause, such as temperature change or moisture, which can cause unsightly depressions and uneven swells in the finished surface. The form/mold materials shall be nonabsorbent or properly sealed to prevent excessive moisture absorption to minimize variations in finish due to differential moisture movements resulting from varying degrees of absorbency. When different materials are used to construct the form/mold, they shall not affect the color and texture of the product.

The appearance of the finished surface is directly related to the choice of form/mold material and the quality of the form/mold itself. The in-service life of a form/mold is also a function of the choice of form/mold material, which must therefore be selected with care. Forms/molds for architectural precast concrete can be made of various materials such as wood, concrete, steel, polyester resins reinforced with glass fibers, plasters, plastics, or a combination of these materials. For complicated details, forms/molds of plaster, elastomeric rubber, foam plastic, or sculptured sand may be used. These forms/molds are often combined or reinforced with wood or steel depending on the size and complexity of the unit to be produced.

Form/mold design should account for the special

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Forms/molds shall be coated with release agents that will permit release without damaging or staining the concrete, and without affecting subsequent coating, painting, or caulking operations. Release agents shall be applied in accordance with the manufacturer's directions. Just prior to applying a release agent, the surfaces of the form/mold shall be clean and free of water, dust, dirt, or residues that could be transferred to the surface of the concrete or affect the ability of the release agent to function properly. Excess release agent shall be removed from the form/mold surface prior to casting. Prestressing tendons, anchorages for miscellaneous connections, and reinforcement shall not be contaminated by form/mold release agents.

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requirements of precast concrete products. Sharp angles and thin projections should be avoided whenever possible. Chamfers or radii at inside corners of the form/mold should be incorporated due to the high risk of chipping and spalling at the corners during handling.

In general, the form/mold fabrication and setup tolerances should be one-half of the tolerances of the units they are to produce.

The selection of a release agent should include investigation of the following factors:

1. Compatibility of the release agents with the form/mold material, form/mold sealer, or admixtures in the concrete mixture.
2. Possible interference with the later application of sealants, sealers, or other coatings to the form/mold contact area.
3. Discoloration and staining of the concrete face.
4. Release agents may require a drying or curing period before being used. If too fresh, some of the release agent will become embedded in the concrete. There may also be a maximum time the release agent is on the form/mold before the concrete is to be placed.
5. Amount of time allowed between application and concrete placement and the minimum and maximum time limits for the form/mold to stay in place before stripping.
6. Effect of weather changes and curing conditions on the ease of stripping and appearance of the concrete surface.
7. Uniformity of performance.
8. Current federal, state, and local environmental regulations and OSHA storage regulations, regarding hazardous materials. This includes volatile organic compounds (VOC) flash point, training and other hazardous material compliance rules.

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Forms/molds shall be built sufficiently rigid to provide dimensional stability during handling. The assembled form/mold shall not allow leakage of water or cement paste. Joints or imperfections in the form/mold material shall be made so that they will not be reflected in the concrete surface in excess or larger than those acceptable in the approved samples or mock-ups.

Forms/molds shall be capable of supporting their own weight and the pressure of the fresh concrete, without deflection or deformation that exceeds tolerances. Forms/molds shall be sufficiently rigid to withstand the forces necessary for consolidating the concrete. Forms/molds subjected to external vibration shall be capable of transmitting the vibration over a sufficient area in a relatively uniform manner without flexing or plate fluttering. The form/mold shall be designed to ensure that resonant vibrations that may be imparted into local areas of the form/mold are minimized.

Forms/molds shall permit controlled, fixed positioning or jiggling of hardware and allow for the suspension or placement of the reinforcing cage in a position that maintains the specified concrete cover. Blockouts shall be located and match the size and shape shown on the shop drawings. Blockouts shall be held rigidly in place within tolerance. Form/mold parts shall allow for stripping without damage to the units.

Wood forms/molds shall be sealed with suitable materials to prevent absorption and camouflage wood grain, if desired. The sealer manufacturer's instructions regarding application shall be followed. Surface condition, joints, and coating material shall be visually inspected prior to use.

Applying too much of the release agent can cause excessive surface dusting and bugholes on the finished concrete.

Mineral oil, oil-solvent-based release agents, or paraffin wax should not be used on rubber or elastomeric liners, as the hydrocarbon solvent may soften the rubber. The rubber or elastomeric supplier's recommendations should be carefully followed.

Form/mold seams resulting from jointing of loose parts, such as bulkheads, side or top form/mold, or any form/mold modification pieces should be minimized to the extent required by the finished surface, well fitted, secured, and sealed to prevent leakage.

Forms/molds should have high rigidity, minimum deflection, and minimum movement of the form/mold material between the stiffeners.

Sealing wood form/mold minimizes nonuniformity in concrete surface finish and will stabilize the form/mold dimensions. The manufacturer's instructions regarding application of the sealer should be followed, such as minimum temperature application requirements. An appropriate drying or curing time should be allowed.

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Steel forms/molds shall be visually inspected prior to each use for rust, distortion, and tightness of steel sheet joints. If it is planned to apply a prestressing force by jacking against the form/mold, the form/mold shall be sufficiently strong to withstand the force without buckling or wrinkling and still maintain the required dimensional tolerances.

Concrete forms/molds shall be treated with a coating that renders the concrete nonabsorbent to reduce form/mold damage and to improve the release of the product during the stripping operations.

All forms/molds shall withstand concrete curing temperatures while maintaining their dimensional integrity. The susceptibility of the form/mold to attack by the proposed release agents shall be determined prior to usage. Surface conditions, joints, and gel coat material shall be visually inspected prior to each use.

### **2.4.2 Verification and Maintenance**

The form/mold surfaces and dimensions shall be checked in detail after form/mold construction and before the first unit is made as well as after any modifications. A complete check of the first product from the form/mold shall be performed. Forms/molds shall be cleaned and inspected before each use for dimensions, surface condition, joints, and coatings that will affect product performance or appearance.

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Steel forms/molds should be well braced and frequently examined for bulging or buckling. Dimpling, twisting, or bending may occur if they are not properly stacked for storage. When joining two or more steel sheets by welding, care is required to avoid distortion from the heat of the welding operation. If joining is required, the welds should be ground smooth and coated with an epoxy or similar material to hide the joint. Forms/molds should allow for shortening and movements of the precast concrete units during transfer of prestress, daily temperature cycles and application of heat when accelerated curing is used.

### **C2.4.2 Verification and Maintenance**

When a new form/mold is placed into production, a complete dimensional check should be made, taking into account main dimensions, warping, squareness, flatness, reveals, blockouts, and quality of the surface finish. Fixtures and/or templates can aid in checking. The report of this check should be kept on file.

The forms/molds should be reassembled within the dimensional limitations specified for the product on the shop drawings. The overall length, width, thickness, and other basic dimensions should be checked on all sides of the form/mold. The squareness of the form/mold should be checked by comparing diagonal measurements to the corners of the form/mold. Discrepancies noted in the form/mold dimensional accuracy should be corrected prior to casting.

A basic assessment of the form/mold should be made in advance of each casting. Assessment should ensure that:

1. The form/mold has been assembled/built

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## **Commentary**

Bulkheads, templates, and similar equipment shall be regularly inspected and maintained as necessary. All anchorage locations on the form/mold for holding any cast-in materials to a given position shall be checked for wear. If more than one form/mold is used to produce a given unit, comparative dimensional checks shall be made.

### **2.5 Hardware Installation**

All connection hardware, anchors, inserts, plates, angles, handling and lifting devices, and other accessories shall be checked prior to casting to verify that they are accounted for, of the proper size and type, and accurately located as detailed on the shop drawings.

Hardware shall be firmly held in the correct position and alignment during placement, consolidation, and finishing of the concrete by attachment to the reinforcing cage or by jigs, positioning fixtures, form/mold brackets, or stiffbacks. Hardware shall have provisions (holes, lugs, nuts, etc.) so that it can be secured to the support.

When items cast into units are specified to be plated, galvanized, or of stainless steel, a check shall be made to ensure that the material is of the proper type and/or has the proper coating.

Embedded items placed while the concrete is still plastic shall be properly anchored to develop the design loads. The concrete surface adjacent to the item shall be flat and well finished for proper bearing and the item shall be placed perpendicular to this surface.

Reinforcement shall not be modified, relocated, or eliminated to accommodate hardware without the approval of the precast engineer. If hardware anchors or reinforcing steel cannot be located as shown on the shop drawings, approval for

correctly within specified tolerances.

2. The release agent has been applied satisfactorily and excessive ponding has not occurred in recesses, for example.
3. Concrete splatter, wire ties, dust, etc., have not contaminated the form/mold surface.

### **C2.5 Hardware Installation**

Inserts should be placed accurately because their capacity depends on the depth of embedment, spacing, and distance from free edges. Inserts should also be placed accurately because their capacity decreases sharply if they are not positioned perpendicular to the bearing surface, or if they are not in a straight line with the applied force. It is important to place inserts so that the depth of thread is constant for the same size insert throughout a particular job. Otherwise an erection crew may make mistakes in the field by not always engaging the full thread. Also, a typical size and thread depth for inserts on projects will minimize the possibility of erection crews using the incorrect size and length of bolts.

When approved by the precast engineer, embedded items such as dowels or inserts that either protrude from the concrete or remain exposed for inspection may be installed while the concrete is in a plastic state, provided they are not required to be hooked or tied to reinforcement within the concrete and they are maintained in the correct position while the concrete remains plastic.

Connection hardware or handling inserts should not be plunged or vibrated into concrete already placed in the form/mold without approval of the precast engineer.

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revisions shall be obtained from the precast engineer and all revisions shall be recorded. If approved by the precast engineer, hardware items may be installed after the concrete has been placed, and care shall be taken to ensure that concrete around anchorages has been consolidated and that no displacement of the reinforcing cage has occurred.

Reinforcement that extends out of the units to provide structural connection shall be located within the required tolerance. Paste that adheres to extended reinforcement shall be sufficiently removed to ensure adequate bond of the bars to the subsequent casting.

Where angles are used for connections and fastened to the concrete with bolts and inserts, the concrete surface beneath the angle shall be flat and well finished for proper bearing. The inserts shall be placed perpendicular to this surface. Such angles may also be anchored with studs or welded to plates in the precast concrete units.

The concrete under plates or angles shall be consolidated in a manner to avoid honeycombing or excessive air voids beneath the plate or angle.

Voids in sleeves, inserts, and anchor slots shall be filled temporarily with readily removable material, such as bolts, to prevent entry of concrete during casting. Inserts and sleeves shall be kept clean of dirt or ice by protecting them temporarily with plastic caps or other suitable devices installed in the plant after stripping. Threads on projecting bolts shall be kept free from deleterious materials and shall be protected from damage and rust.

Stainless steel bolts shall be used to connect stainless steel plates or angles. Threaded parts of stainless steel bolts shall be lubricated with an anti-seize thread lubricant during assembly.

Dissimilar metals shall not be placed near or in direct contact in moist or saturated concrete unless experience has shown that no detrimental chemical or electrochemical (galvanic) reactions will occur or the surfaces are permanently protected against corrosion. Sleeves, pipes, or

## **Commentary**

The proper anchorage of the insert or hardware is critical. Careful placement of hardware to required tolerances, including inclination of protruding bars or structural shapes, is important because the bearing surfaces of the panel hardware and the matching hardware on the structure should be parallel to obtain optimum bearing or load transfer.

Exposed epoxy coated bars may require protection from sun exposure until shipped.

Excessive honeycombing beneath the plate or angle may result in diminished structural capacity. After inserting into plastic concrete, the concrete surface next to the plate or angle should be smooth and level.

Dissimilar metals shall not be embedded near or in direct contact in moist or saturated concrete unless detrimental chemical or electrochemical (galvanic) reactions are ensured not to occur.

Aluminum reacts with concrete, and in the presence of

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conduits of aluminum shall not be embedded in concrete unless properly protected to prevent aluminum-concrete reaction or electrolytic action between the aluminum and steel.

The installation of inserts and fastenings by explosive actuated or power-driven tools shall only be allowed where such installation will not damage the structural integrity of the units, such as being too close to reinforcement or strands, or damaging the finish by causing spalling, chipping, or cracking of the unit.

Multiple component lifting devices shall be kept matched to avoid incompatible usage. When grouped in multiples, lifting loops shall be aligned for equal lifting. The projection of the lifting loops shall be maintained within a tolerance consistent with the adjustment capabilities of the lifting hardware.

All inserts that are on an exposed face shall be checked to ensure that they are properly recessed to give adequate cover and permit future patching.

### **2.6 Product Identification**

Precast concrete units shall be clearly marked with a unique identification as shown on the shop drawings. Identification shall be sufficient to distinguish the date of casting and trace the precast unit to associated quality control records.

In all cases the markings shall remain legible for the longest storage period that can be anticipated.

### **2.7 Product Handling**

#### **2.7.1 General**

All precast concrete units shall be handled in a position consistent with their shape, size, and design to avoid either structural or aesthetic damage. Units shall be handled and supported

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chloride ions, may also react electrolytically with steel, causing cracking and/or spalling of the concrete. Aluminum electrical conduits present a special problem since stray electric current accelerates the adverse reaction. Use of aluminum embedments, without a proven protective coating or covering system should not be allowed.

Placing wood in concrete should be avoided since the tendency of wood to swell under moist conditions can cause cracking of the concrete even if the wood is sealed.

### **C2.6 Product Identification**

Product markings may be made in the wet concrete, painted on the units, or by tagging as long as the tags are securely fastened to the units. Markings should be made on the product prior to moving it to storage, ensuring traceability.

### **C2.7 Product Handling**

#### **C2.7.1 General**

Each plant should develop specific unit handling procedures for stripping, lifting, storage, and transport preparations.

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only by appropriate devices at designated locations. Lifting devices shall be checked to ensure that their locations conform to the shop drawings.

Permanent connection hardware should not be used for handling, unless appropriately designed for and shown on the shop drawings. Utilizing permanent connection hardware inappropriately for handling may damage and impair performance.

All lifting from threaded inserts shall be made with appropriate swivel bolt hardware suitable for the insert unless such lifts are made axial with the inserts, such as by direct bolt fastening to lifting beams or frames. If inclined lifting lines are employed, the angle to the horizontal shall not be less than 45 deg unless specifically shown on the shop drawings. The bolts being used in the handling inserts shall be of sufficient length to fully engage all threads plus extending as recommended by the manufacturer beyond the threaded position when coil inserts are used. In addition, bolts shall be inspected for cracks, wear, or deformations and defective bolts discarded.

Lifting can be accomplished by use of threaded inserts, lifting loops, slings, scissor devices, vacuum lifters, or any other proven apparatus.

### **2.7.2 Stripping**

### **C2.7.2 Stripping**

Tests shall be performed to confirm that concrete strength meets or exceeds the required values for stripping.

All removable inserts, fastenings, and form/mold parts shall be released and/or removed prior to stripping.

Care shall be exercised in removing the precast concrete unit from the form/mold to prevent damage. The minimum concrete strength, number and location of lifting points for handling of units, and details of lifting devices shall be shown on the shop drawings. Units shall only be stripped at points indicated on approved shop drawings or as approved by authorized personnel. Initial lifting shall be performed carefully. Equipment for initial release shall have controls allowing such operation.

Proper rigging procedures should be established and documented. Methods of hooking onto different lifting devices and permissible sling angles should be covered in plant procedures. When more than two lifting points are used, the lifting should be rigged to allow the planned distribution of pull on lifting devices.

Uniformity of stripping age from unit to unit should be maintained to minimize concrete color hue differences.

The surfaces of units shall be checked for any dents or marks that may be the result of form/mold wear or deterioration. Also, units shall be checked for voids or excessive air holes that would indicate improper consolidation.

A product that is stripped prior to achieving adequate concrete strength can crack or spall. Significant member stresses are often produced during stripping. Proper care should be taken to minimize stresses and keep them within acceptable limits.

A system for evaluating product deficiencies should be established so that problems and their sources can

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### **2.7.3 Yard Storage**

Storage shall be planned carefully to ensure delivery and erection of the units in an acceptable condition. Units shall be stored on unyielding supports at designated blocking point locations. Units shall be stored on a firm, reasonably level, and well drained surface with identification marks visible.

Dunnage and storage racks, such as A-frames and vertical racks, shall be well constructed and aligned to ensure that the precast concrete units are supported in a given plane to minimize warping, bowing, or cracking of the units and stabilized against potential lateral loads.

Dunnage shall be placed between products themselves as well as between products and storage devices. Such dunnage shall be of a material and type that will not create stacking or staining marks or otherwise cause damage to the finished products. Where necessary, storage apparatus shall be protectively covered to avoid any discoloration or staining of the finished products.

Embedded items and sleeves shall be protected from penetration of water or snow during cold weather.

### **2.7.4 Cleaning**

All surfaces of the precast concrete units to be

be identified. Problems that occur when products are stripped cannot be resolved easily if they are not identified prior to product storage.

### **C2.7.3 Yard Storage**

Units are generally stored with two-point supports spaced approximately at the fifth point. Two-point support is recommended because if support is continuous across three or more points, the member may bridge over one of the supports (because of differential support movement) and result in bowing and cracking.

Proper member support during storage will minimize warping and bowing. Warpage in storage may be caused by temperature or differential shrinkage between surfaces (such as backup vs. face mixture), creep, and storage conditions. Warpage and bowing cannot be totally eliminated, although they can be minimized by providing blocking so that the unit remains plane.

Units stored leaning on one another may induce high stress loads in long storage lanes. A domino effect resulting from cumulative loading should be considered. Units should be stacked against both sides of the supports to equalize loading and to avoid overturning.

Protective material should be provided at points of bearing and contact with exposed surfaces. Care should be taken to prevent surface staining and chipping or spalling of the edges and corners of the units. All blocking, packing, and protective materials should be of a type that will not cause damage, staining, or objectionable disfigurement of the units. Staggered or irregular blocking should be avoided. When setting one unit against another, nonstaining protective blocks should be placed immediately in line with the support of the first unit.

Precast concrete products should be protected from contact with earth, oil, gas, tar, smoke, or other contaminants.

### **C2.7.4 Cleaning**

A small area should be cleaned and evaluated to be

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exposed to view shall be cleaned as necessary prior to shipping to remove dirt and stains. The cleaning procedures shall not detrimentally affect the concrete surface finish.

certain there is no adverse effect on the surface finish before proceeding with the work.

For information on removing specific stains from concrete, reference should be made to *Removing Stains and Cleaning Concrete Surfaces*, IS 214, published by the Portland Cement Association, Skokie, Ill.

### **2.7.5 Loading**

### **C2.7.5 Loading**

Products shall be loaded as necessary:

Protective covering of the units during transportation is normally not required.

1. To permit their removal from the trailer in proper sequence and orientation for erection.
2. With proper supports, blocking, cushioning, and tie-downs to prevent or minimize in-transit damage. Blocking, packing, and protective materials shall not cause staining or physical damage of the products. The blocking points and orientation of the products on the shipping equipment shall be as designated on the shop drawings.
3. With proper padding between units and chains or straps to preclude chipping of edges or damage to returns.

## **2.8 Surface Finishes**

## **C2.8 Surface Finishes**

### **2.8.1 General**

### **C2.8.1 General**

Each plant shall develop quality requirements for all architectural finishes prior to undertaking actual production of such finishes. Such requirements shall include samples and production procedures. A finishing process shall produce an acceptable uniform appearance without detriment to required material properties.

Concrete is a variable material and even after final finishing, there will be a range of color and texture in the surface. Some variations are to be expected. In addition, many finishes cannot be achieved with equal visual quality on all faces of the unit. This is due to factors such as mixture proportions and differences in consolidation techniques, curing temperature and curing duration, particularly in the case of intricate shapes.

It should be recognized that some blemishes or variations in color occur in architectural precast concrete. For example, units containing aggregates or matrices of contrasting colors will appear less uniform than those containing materials of similar colors. Consistency in apparent color of all finishes can be enhanced by color compatibility of materials. If the coarse aggregate, fine aggregate, and cement paste are similar in color, the depth of exposure and patchy

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All finishes of precast concrete units shall be stated on shop drawings. Samples or mock-up units shall be available in the plant so that standards of finish and exposure are maintained.

effects (minor segregation of aggregate) will not be as noticeable in maintaining color consistency. In contrast, if material colors are significantly different, the finish may appear blotchy for the same reason.

Further, smooth-as-cast units may appear less uniform in color and are not recommended. Uniformity in color, even within small units finished with black coloring, and for units using gray cement, may vary from unit to unit. The color of precast concrete can vary between adjacent elements due to daily variations in the water-cementitious ratio and curing conditions for the concrete. This is less pronounced in mixtures using white cement than those using gray cement. Additionally, this color variation will be less pronounced in finishes that have some degree of aggregate exposure. The degree of uniformity normally improves with an increased depth of exposure. When fabrication continues over extended periods, color can vary because of the changes in the physical characteristics of cements, coarse aggregates, and sands, even though they may be from the same sources.

The effect of gravity during consolidation forces the larger aggregates to the bottom and the smaller aggregates, plus the sand and cement content, upward. Consequently, the down face in the form/mold will nearly always be the most uniform and densest surface of the unit. The final orientation of aggregates may also result in differences in exposure between the down face and returns in exposed-aggregate surfaces. Emphasis should be placed on choosing suitable concrete mixtures with aggregates that are reasonably spherical or cubical in shape to minimize differences. For large returns, or situations where it is necessary to minimize variations in appearance, concrete mixtures should be selected where the aggregate gradation can be uniformly controlled and preferably fully graded. Exposures should be medium to deep and color differences between the ingredients of the mixture should be minimal.

Panels with large returns may also be cast in separate pieces and joined with dry joints. This enables all faces to be cast with the same orientation. If this is the indicated production method, attention should be paid to suitable fillets and reinforcement at the corners, and a quirk or architectural feature should be incorporated at the dry joint. Although the dry joint may not show with certain mixtures and textures, a quirk is generally required to help mask it.

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Aggregate exposure shall be no greater than one-third the average diameter of the coarse aggregate particles, and no greater than one-half the diameter of the smallest-sized coarse aggregate.

A demarcation feature shall be incorporated into the surface of a unit having two or more different mixtures or finishes. The different face mixtures shall have relatively similar behavior with respect to shrinkage to avoid cracking at the demarcation feature.

Appearance, color, and texture of surface finish of all units shall be within the acceptable range of the color, texture, and general appearance of the approved sample panels.

### **2.8.2 As-Cast Formed Surface Finishes**

Forms/molds for architectural units shall be carefully made and finished to ensure a smooth, unmarked surface. If air voids are anticipated on return surfaces, a sample shall be used to establish acceptability of such voids with respect to frequency, size, and uniformity of distribution.

As a general rule, a textured surface is more aesthetically pleasing than a smooth surface because the texture of the surface to a very large extent camouflages subtle differences in texture and color of the concrete.

### **C2.8.2 As-Cast Formed Surface Finishes**

A smooth-as-cast finish is perhaps the most difficult to produce, especially when a high level of color uniformity is required. The cement provides the primary color influence on a smooth finish. In some instances the sand may also have some effect. Initially, this is unlikely to be significant unless the sand contains a high percentage of fines or is highly colored. However, as the surface weathers, the sand becomes more exposed and its influence on color becomes more pronounced. The color of the coarse aggregate should not be significant unless the particular unit requires a high degree of consolidation. Under this circumstance, some aggregate transparency may occur, causing a blotchy, nonuniform appearance.

Aggregate transparency or “shadowing” is a condition in which a light-colored, formed concrete surface is marked by dark areas similar in size and shape of particles of dark or deeply colored coarse aggregate in the concrete mixture. When encountered, it usually appears on smooth surfaces.

Forms/molds for smooth-surfaced concrete are perhaps the most critical and the most difficult to control of any type of form/mold encountered for precast concrete, particularly where large single-plane surface areas are involved. Any imperfection in the surface of the form/mold or any misalignment is immediately apparent and becomes the predominant factor in the character of the surface. An impervious surface, such as form/mold liners, steel, overlaid

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plywood, or fiberglass-surfaced plywood will usually result in a lighter color and more uniform appearance if joints have been properly prepared. In general, the joints of the materials used to construct the casting surfaces are difficult to hide.

The smooth surface on the concrete may be susceptible to surface crazing (fine and random hairline cracks) when exposed to wetting and drying. This is, in most cases, a surface phenomenon that will not affect structural properties or durability. In some environments, crazing will be accentuated by dirt collecting in these minute cracks. This will be more apparent in white than gray finishes and in horizontal more than vertical surfaces.

When air voids of a reasonable size (1/8 in. to 1/4 in. [3 mm to 6 mm]) are encountered on return surfaces, it may be more desirable to retain them rather than filling and sack rubbing them in. Color variations can occur when sacking is performed.

Even with good quality control, smooth finished concrete will likely exhibit some negative aesthetic features, such as color variations, air voids, minor surface crazing, and blotchiness, especially on nonprofiled flat panels. Repairs to this finish tend to be even more noticeable after weathering.

#### **2.8.3 Sand or Abrasive Blast**

Uniformly texturing a panel by sand or abrasive blasting requires trained operators. The type and grading of abrasives utilized during the blasting process shall remain the same throughout the entire project.

#### **C2.8.3 Sand or Abrasive Blast**

Sand or abrasive blasting of surfaces is suitable for exposure of either large or small aggregates. Uniformity of depth of exposure between panels and within panels is essential for achieving an acceptable finish. The skill and experience of the operator play a significant role in achieving a uniform finish. As much as possible, the sandblasting crew and equipment used should remain the same throughout the job.

The type and grading of abrasives affects the resulting surface finish. Different shadings, and to some extent color tone, will vary with the degree of aggregate exposure. The age of the panel at time of blasting will also affect the rate of material removal and degree of aggregate exposure. The age and strength of the concrete at time of blasting should be consistent throughout the project to help achieve the desired uniform finish and color from panel to panel.

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The degree of uniformity obtainable in a sandblasted finish is generally in direct proportion to the depth of material removed. Light sandblasting may look acceptable on a small sample, but uniformity is rather difficult to achieve in a full-size unit. A light blast will emphasize visible defects, particularly bugholes, and reveal defects previously hidden by the surface skin of the concrete. The lighter the blast, the more critical the skill of the operator, particularly if the units are sculptured. Small variances in concrete strength at time of blasting may further complicate results. The use of OO sand is recommended for light blasts.

Sculptured units may have air voids on the returns that may be accentuated by a light sandblasted texture. If such air holes are of a reasonable size (1/8 in. to 1/4 in. [3 mm to 6 mm]), it is strongly recommended that they be accepted as part of the finish because filling and sack rubbing may cause color and/or texture variations.

The objective of a brush-blast, which is little more than a uniform scour cleaning that lightly textures the surface skin, is to remove minor surface variations. A brush-blast surface seldom appears uniform at close inspection and should be viewed at a distance for uniformity. Brush-blast is used: (1) on reveals and other small areas for accents due to its nonuniform appearance on large areas or (2) to improve bond of coatings to unit.

Sands used for blasting operations shall be free of deleterious substances, such as fine clay particles. The abrasive used shall not cause any color contamination of the surface.

### **2.8.4 Acid Etched**

Operators shall be trained to produce a uniformly textured surface to match the approved sample when exposing aggregate by acid etching.

In sandwich wall panels, where the insulation is exposed at the edges of the panel, only those methods that prevent damage to the insulation shall be used.

An acceptable range of concrete temperatures and strength levels during the application of the acid shall be established to provide uniform finish quality.

### **C2.8.4 Acid Etched**

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In cases where aggregates are to be exposed to considerable depth, only acid-resistive siliceous aggregates shall be used. The concrete unit shall be well wetted with clean water prior to acid treatment because acids will penetrate faster and deeper into dry concrete. Acid shall not be allowed to lie on the surface longer than 15 min. Deep etch shall be achieved by multiple treatments. After completion of acid etching, the unit shall be thoroughly flushed with water.

Prior to acid etching, all exposed metal surfaces, particularly galvanized metal, shall be protected with acid-resistant coatings.

Touch-up of all exposed galvanized metals cast in the precast concrete units affected by acid

### **Commentary**

Acid etching is most commonly used for light or medium exposure, dissolving the surface cement paste to reveal the sand with only a small percentage of coarse aggregate being visible. Acid etching of concrete surfaces will result in a fine, sandy texture if the concrete mixture and its consolidation have produced a uniform distribution of aggregates and cement paste at the exposed surfaces. Concentration of cement paste and under- and overetching of different parts of the concrete surface, or variation in sand color or content, may cause uniformity problems, particularly when the acid etching is light or used for large, plain surfaces. Carbonate aggregates—for example, limestones, dolomites, and marbles—may discolor or dissolve due to their high calcium content.

With lighter textures, color compatibility of the cement and the aggregates becomes more important to avoid a blotchy effect. White or light colors are more forgiving to the eye and increase the likelihood of better color match from unit to unit.

There is a minimum depth of etch that is required to obtain a uniform surface. To attempt to go any lighter than this will result in a blotchy panel finish. This depth will expose sand and only the very tip of the coarse aggregate. It is difficult to achieve a totally uniform very light exposure on a panel that is highly sculptured. This is due to the acid spray being deflected to other areas of the panel, particularly at inside corners. This may be acceptable if the sculpturing creates differential shadowing.

Prewetting the concrete with water fills the pores and capillaries and prevents the acid from etching too deeply, and also allows all acid to be flushed after etching.

Acid solutions lose their strength quickly once they are in contact with cement paste or mortar. However, even weak, residual solutions can be harmful to concrete due to possible penetration of chlorides. Failure to completely rinse the acid solution off the surface may result in efflorescence or other damaging effects.

Acid-resistant coatings include vinyl chlorides, chlorinated rubber, styrene butadiene rubber (not latex), bituminous paints, enamels, and polyester coatings.

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washing shall be done utilizing a 3 mil thickness of a zinc-rich compound.

### **2.8.5 Retarded**

Surface retarders that are to be used to expose the aggregate shall be thoroughly evaluated prior to use. This involves using the particular type of cement, aggregate, and specific mixture selected for the product.

When using a retarder, the manufacturer's recommendations shall be followed. Surface retarders shall be applied by roller, brush, or spray and care shall be taken to ensure uniform application of retarders to the form/mold surface. Water shall not contact the retarder on the form/mold surface before the concrete is placed to prevent activation of the retarder.

The retarded surface shall be exposed by removing the matrix material to match the approved sample.

### **C2.8.5 Retarded**

Retardation involves the application of a specialized chemical to the concrete surface (normally the form/mold surface) that delays the surface cement paste from hardening within a time period and to a depth depending upon the type or concentration of retarder used.

Chemical retarders are available for face-down or face-up methods of casting, and for horizontal as well as vertical surfaces. Retarders are available for light, medium, and deep exposures. The degree of uniformity normally improves with an increased depth of exposure.

The effectiveness of the retarder will vary, as it is extremely sensitive to changes in the rate of cement hydration due to different temperatures, humidity, or water content of the face mixture. The depth of reveal or retardation will be deeper: (1) the wetter the mixture; (2) the slower the time of set; (3) the more aggregate in the mixture; and (4) the closer together the coarse aggregate.

Retarders function by delaying, not preventing, the set of the surface cement paste in order that the aggregate can be easily exposed. This concept will help in analyzing various mixture designs for depth of retardation. If more sand or coarse aggregate is added to a mixture, with proper consolidation, there will be less cement paste per volume of material at the surface, thus a deeper exposure.

Some retarders are effective for long periods of time while other are active for only a few hours. Water in contact with the retarder before the concrete is placed activates the retarder's action prematurely and may result in a nonuniform surface.

The retarded concrete should be removed the same day that the units are stripped. Any delay in removing the matrix will result in a lighter, less uniform exposure. Preliminary tests should be performed before planning the casting for a large project to determine the most suitable finishing time. The timing of surface finishing operation should be consistent each day, as some retarders cease to delay the hardening process as the product cures.

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### **2.8.6 Tooled or Bushhammered**

Operators shall be trained to produce a uniformly textured surface to match the approved sample when exposing aggregate by tooling or bushhammering.

### **C2.8.6 Tooled or Bushhammered**

Concrete may be mechanically spalled or chipped with a variety of hand and power tools to produce an exposed-aggregate texture. The technique usually is called tooling or bushhammering and is most suitable for flat or convex surfaces. Pneumatic or electric tools may be fitted with a bushhammer, a comb chisel, a crandall, or multiple pointed attachments. The type of tools will be determined by the desired surface effect. Hand tools may be used for small areas, corners, and restricted locations where a power tool cannot reach.

Orientation of equipment and direction of movement for tooling should be kept uniform throughout the tooling process, as tooling produces a definite pattern on the surface. Variations due to more than one person working on the panels may occur with this finish. Care should be exercised to avoid exerting excessive pressure on the tool, especially when starting, so as not to remove more material than either necessary or desirable.

Bushhammering at outside corners may cause jagged edges. If sharp corners are desired, bushhammering should be held back from the corner. It is quite feasible to execute tooling along specific lines. If areas near corners are to be tooled, the work should normally be done by hand because it is difficult to reach into inside corners by mechanical means. A 1 in. (25 mm) minimum chamfered edge is preferred for a bushhammered finish.

### **2.8.7 Honed or Polished**

Care shall be taken to obtain a uniform depth of grind from unit to unit to minimize finish variations. An approved sample unit shall be kept near the grinding operation for comparison and evaluation of the product finish. Air voids in the concrete surfaces shall be filled before each of the first few grinding operations, using a sand-cement mixture that matches the color of the matrix. Careful filling and curing are required and the next grinding operation shall not be performed until the fill material has reached sufficient strength.

### **C2.8.7 Honed or Polished**

The grinding of concrete surfaces produces smooth exposed-aggregate surfaces. Grinding is also called honing or polishing, depending on the degree of smoothness of the finish. In general, honed finishes are produced by using grinding tools varying from about No. 24 coarse grit to a fine grit of about No. 220. This produces a smooth but matte finish free of pits and scratches. Polishing is accomplished after honing. Polishing consists of several successive grinding steps, each employing a finer grit than the preceding step. A buffer brick or felt pad with tin oxide polishing powder is usually used to produce a high gloss polish.

When selecting aggregates, special consideration should be given to their hardness.

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Care shall be exercised in the application of polishing compounds to prevent creating a visually unacceptable halo effect on the surface, particularly if applied manually over a portion of the surface during the blending of imperfections.

The compressive strength of the concrete shall be 5,000 psi (35 MPa) before starting any honing or polishing operations. The concrete shall have a uniform and dense surface.

### **2.8.8 Form/Mold Liner**

Form/mold liners shall be secured in forms/molds by methods that will not permit impressions of nail heads, screw heads, rivets, or the like to be imparted to the surface of the concrete unless this feature is desired. Steps shall be taken to camouflage anomalies within the pattern of the texture.

Form/mold flatness for honed or polished surfaces should be  $\pm 3/32$  in. over 13 ft ( $\pm 2$  mm over 4 m). In addition, panels should be placed onto preleveled blocks with the final alignment carried out using a laser beam, then wedged for final adjustment.

Uniformity of appearance generally is not a problem on flat cast faces but vertical faces are likely to show variations in aggregate density. Careful consideration should be given to manufacturing methods when panel returns do not align with adjacent window glass but abut with flat panels, as this will highlight the textural differences.

When a 90 deg return of a panel is honed or polished, it may prove beneficial to sequentially cast the return in a horizontal position. This will help to create a denser, more uniform surface.

Floor polishers should not be used, as they generally do not provide a flat enough surface for the degree of reflectance required for honed or polished finishes.

### **C2.8.8 Form/Mold Liner**

Form/mold liners may be incorporated in or attached to the surface of a form/mold to produce the desired pattern, shape, or texture in the surface of the finished units. The method of attaching the form/mold liner should be studied for resulting visual effect.

A form/mold liner texture can be of considerable influence in assisting as-cast surfaces to appear more uniform. Form/mold liner material selection depends on the amount of usage and whether or not the pattern has undercut (negative) drafts. Matching joints between liners is often very difficult. Products employing liner finishes should either be limited to widths less than the available width of the liner, or liner joints should be at form/mold edges or be detailed as an architectural feature in the form of a groove, recess, or rib. Elastomeric liners should be

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An investigation shall be made to determine whether staining or discoloration may occur from the liner material, its fastenings, or joint sealers. Care shall be taken to use form/mold release agents and retarders that are compatible with the liner and the liner shall not be subjected to temperatures in excess of those recommended by the manufacturer.

washed with soap and water before use.

### **2.8.9 Veneer Facing Materials**

Quality requirements for finishes derived from materials such as natural cut stone (granite, limestone, marble), brick, ceramic or quarry tile, porcelain, and architectural terra cotta shall be established on the basis of prior experience or sufficient testing of sample and mock-up units. Particular attention shall be paid to the compatibility of materials with respect to differential expansion and contraction caused by thermal and moisture changes. If the materials do not have similar physical properties, the final design shall compensate for interaction of the different materials.

**Natural stone.** Cut stones that are easily stained by oils and rust shall be protected by lining the form/mold with polyethylene sheets or other nonstaining materials.

A complete bondbreaker between natural stone veneer and concrete shall be used. Bondbreakers shall be one of the following: (1) a 6 to 10 mil polyethylene sheet or (2) a 1/8 to 1/4 in. (3 to 6 mm) polyethylene foam pad or sheet. The bondbreaker shall prevent concrete from entering the spaces between pieces of veneer and thereby potentially inhibiting differential movements. Connection of the veneer to the concrete shall be with stainless steel mechanical anchors that can accommodate some relative movement. Preformed anchors with a 5/32 in. (4 mm) minimum diameter, fabricated from Type 302 or 304 stainless steel shall be used. Close supervision is required during the insertion and setting of the anchors. Anchors placed in epoxy shall not be disturbed while the epoxy sets.

When using epoxy in anchor holes, 1/2 in. long (13 mm) compressible 60 durometer rubber or

### **C2.8.9 Veneer Facing Materials**

Color control or blending for uniformity should be done in the stone or brick fabricator's plant since ranges of color and shade, finishes, and markings such as veining, seams, and intrusions are easily seen during the finishing stages. A qualified representative of the owner who understands the aesthetic appearance requested by the owner or architect should perform this color control. Acceptable color of the stone should be judged for an entire building elevation rather than for individual panels.

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elastomeric grommets or sleeves shall be used on the anchor at the back surface of the stone. The epoxy manufacturer's recommendations for mixing and curing temperature limitations shall be followed.

The strength of the stone veneer material and anchorage strength shall be known or determined prior to production by the stone supplier, architect, or owner to ensure adequate strength to resist stresses during handling, transportation, erection, and service conditions.

Veneer joints within a concrete element shall allow for differential movement between materials. In the form/mold, the veneer pieces shall be temporarily spaced with a nonstaining, compressible gasket that will not adversely affect the sealant to be applied later. Shore A hardness of the gasket shall be less than 20 durometer.

The gaskets shall be of an adequate size and configuration to provide a pocket to receive the sealant. It shall prevent any of the concrete backup from entering the joints between the veneer units. Gaskets shall be removed after the panel has been stripped from the form/mold unless a resilient sealant backup is utilized.

When stone veneer is used as an accent or feature strip on precast concrete panels, a 1/2 in. (13 mm) space shall be left between the edge of the stone and the precast concrete to allow for differential movements of the materials. This space shall be caulked as if it were a conventional joint.

**Clay products.** Thin brick embedded in precast concrete panels shall comply with the PCI Standard for Thin Brick. Cast-in bricks with an initial rate of absorption (suction) of less than 30 g per 30 in.<sup>2</sup> per min (30 g per 194 cm<sup>2</sup> per min), when tested in accordance with ASTM C67, are not required to be wetted. However, brick with high suction or with an initial rate of absorption in excess of 30 g per 30 in.<sup>2</sup> per min (30 g per 194 cm<sup>2</sup> per min) shall be wetted prior to placement of the concrete.

Terra cotta units shall be soaked in water for at least 1 hr prior to placement to reduce suction and be damp at the time of concrete placement.

All testing to determine the physical properties of the stone veneer with the same thickness and finish as will be used on the structure should be conducted by the architect or owner prior to the award of the contract. This will reduce the need for potentially costly repairs or replacement, should deficiencies in the stone veneer be found after start of fabrication.

**Clay products.** Whole bricks are generally not used in precasting due to the difficulty in adequately grouting the thin joints and the resultant necessity to use mechanical anchors.

The physical properties of the clay products should be compared with the properties of the concrete backup. These properties include the coefficient of thermal expansion, modulus of elasticity, and volume change due to moisture.

Clay products with high suction or with a high initial rate of absorption should be wetted prior to placement of the concrete to reduce the amount of mixture water

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Because variations in brick or tile color will occur, the clay product supplier shall preblend any color variations and provide units that fall within the color range selected by the architect. Clay products that suffer from various surface defects, such as chips, spalls, face score lines, and cracks, shall be culled from the bulk of acceptable units by the clay product supplier or precaster according to the architect's requirements and applicable ASTM specifications.

The manufacturer of ceramic glazed units shall be consulted for suitable materials and test data backup.

Clay-product-faced units shall have joint widths controlled by locating the units in a suitable template or grid system set out accurately on the form/mold face. When an elastomeric form/mold liner is used, it shall be produced to a tolerance of  $\pm 1/32$  in. ( $\pm 0.8$  mm).

In addition to normal dimensional checks, clay product coursings shall be reinspected for alignment and properly seated against the form/mold face. Clay product units shall be checked for tight fit and wedged if not tightly secured—especially on return sections—to prevent grout leakage to the exposed face of the panel. Concentrations of clay products of the same shade shall be avoided, and chipped or warped units shall be removed as necessary.

Care shall be taken during mortar or concrete placing and consolidation to prevent movement of the individual facing materials, which would upset the appearance of the finished surface.

After the concrete cures and the unit is removed from the form/mold, joints shall remain as cast or be filled, if required by the architect, with pointing mortar or grout carefully formulated for color and texture. Before pointing, joints shall be cleaned and saturated with clean water. After the joints are properly pointed and have become

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absorbed and thus improve bond. Unglazed quarry tile and frost-resistant glazed wall tiles are generally not required to be wetted. Thin brick with an absorption less than 6%, as required by the PCI Standard for Thin Brick, may be wetted to reduce bowing of the panel.

Some bricks are too dimensionally inaccurate for precast concrete applications. They may conform to an ASTM specification suitable for site-laid-up applications, but they are not manufactured accurately enough to permit their use in a preformed grid that is used to position bricks for a precast concrete unit. Individual brick tolerances of  $\pm 1/16$  in. ( $\pm 2$  mm) or greater may usually cause problems. Thin brick units should conform to the PCI Standard and not be less than  $1/2$  in. (13 mm) nor more than 1 in. (25 mm) thick with an overall tolerance of  $+0$  in.,  $-1/16$  in. ( $+0$  mm,  $-1.6$  mm) for any unit dimension 8 in. (200 mm) or less and an overall tolerance of  $+0$  in.,  $-3/32$  in. ( $+0$  mm,  $-2.4$  mm) for any unit dimension greater than 8 in. (200 mm) measured according to ASTM C67. Close tolerances may be obtained by saw cutting each brick, but this substantially increases cost.

When dry-set mortar is used, the necessity of wetting either the concrete surface or clay product is eliminated.

Ceramic glazed units for exterior use may develop craze cracking from freeze-thaw cycles and the bond of the glaze may fail.

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thumbprint hard, they shall be: (1) tooled to a smooth concave surface, which offers the best durability, or (2) struck and troweled flush with the face of the clay units. Initial grout cleanup shall be done within 15 min of pointing to avoid hard setting of the grout on the units. Final cleanup shall be completed within 60 min to 90 min.

When applying thin brick and ceramic tile to a recessed concrete surface, the surface shall be roughened by sandblasting or bushhammering. Dry-set mortar shall conform to ANSI A118.1 included in ANSI A108.1. Latex-portland cement mortar shall conform to ANSI A118.4 included in ANSI A108.1. Installation using either dry-set or latex-portland cement mortars shall conform to ANSI A108.5. Since lattices vary considerably, each latex manufacturer's directions shall be followed explicitly, particularly with regard to curing.

Units shall be grouted and tooled using dry-set or latex-portland cement grouts conforming with material and installation specifications contained in ANSI A118.6 and ANSI A108.1.

### **2.8.10 Sand-Embedded Materials**

Care shall be taken to ensure that the facing aggregate is dense and evenly distributed on all surfaces. When facing materials are of mixed colors, their placement in the form/mold shall be inspected for the formation of unintended patterns or local high incidence of a particular color. If a particular facet of the stone is to be exposed, proper placement shall be inspected before the backup concrete is placed.

### **2.8.11 Unformed Surface Finishes**

For unformed surfaces, visible (exposed) areas shall have finishes that are realistic in relation to the exposure, production techniques, unit

### **C2.8.10 Sand-Embedded Materials**

Bold, massive, rock-like architectural qualities may be achieved by hand placing large-diameter stones (cobble or boulders), fieldstone, or flagstone into a sand bed or other special bedding material.

The sand-embedment technique reveals the facing material and produces the appearance of a mortar joint on the finished panel.

The depth of the bedding material should keep the backup concrete 25% to 35% of the stone's diameter away from the face.

To help achieve uniform distribution and exposure, all aggregate should be approximately the same size. This is particularly important around corners, edges, and openings.

### **C2.8.11 Unformed Surface Finishes**

The back of a precast concrete unit may be given a variety of finishes depending on the intended service or appearance. These may include a screed, light

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configuration, and quality requirements. The finish requirements for all unformed surfaces shall be shown on the shop drawings.

Troweling shall not be done on a surface that has not been floated. Magnesium screeds and floats shall be used with air-entrained or lightweight concrete to minimize surface rippling, tearing, or pullouts.

To obtain a durable surface on unformed concrete, proper procedures shall be carefully followed. Surfaces shall be filled and struck off immediately after concrete placing and consolidation and then rough floated. The operations of screeding, floating, and initial troweling shall be performed in such a manner that the concrete will be worked and manipulated as little as possible in order to obtain the desired result. Overmanipulation of the surface shall be avoided. Overworking of the surface of structural lightweight aggregate concrete shall be avoided even more so than with normalweight concrete.

Each step in the finishing operation, from bull floating to the final floating or troweling, shall be delayed as long as possible to permit the desired grade and surface smoothness to be obtained. If excess moisture or bleed water accumulates, it shall either be removed or allowed to evaporate before the next finishing operation is performed. Under no circumstances shall any finishing tool be used in an area before accumulated water has been removed, nor shall neat cement or mixtures of sand and cement be worked into the surface to dry such areas. When final troweling is required, the surface shall be manipulated only as necessary to produce the specified finish and to close any surface cracks that may have developed.

Prior to initial set of the concrete, an inspection shall be made to ensure that the floating or finishing operation did not result in high areas or ridges around plates or inserts that have been cast into the unit. Screeded areas shall also be inspected to ensure uniform thickness across the entire unit.

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broom, float, trowel, stippled, or water-washed or retarded exposed-aggregate finish.

Overmanipulation of the concrete surface brings excessive fines and water to the top, which impairs the quality of the finished surface, causing such undesirable effects as checking, crazing, dusting, and discoloring.

Excess moisture or bleed water is not as likely to appear and accumulate between finishing operations if proper mixture proportions and consistency are used.

Water added to product surfaces raises the water-cement ratio at the surface, creating a weaker concrete that may result in flaking or a dusty finish. This does not preclude fog-spraying, which is done lightly and serves to replace evaporating surface water.

Normal concrete finishing techniques may be employed with SCC. However, bull floating and finishing should be delayed slightly longer than for conventional superplasticized concrete. The nature of

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### **2.8.12 Applied Coatings**

Whenever concrete is to be painted or stained, only form/mold release agents compatible with the coating shall be permitted unless surface preparation is required to ensure good adhesion between the coating and the concrete.

Coatings applied to exterior surfaces shall be of the breathing type (permeable to water vapor but impermeable to liquid water). The coating manufacturer's instructions regarding mixing, thinning, tinting, and application shall be strictly followed.

Whenever concrete is so smooth that it makes adhesion of some coatings difficult to obtain, such surfaces shall be lightly sandblasted, acid etched, or ground with silicon carbon stones to provide a slightly roughened, more bondable surface.

### **2.9 Repairs**

When noncompliant defects occur, immediate action shall be taken to determine the cause of the defect and establish appropriate mitigating measures for preventing further occurrence. Repairs shall be performed in accordance with detailed written repair procedures. Structural repair procedures shall be approved by the precast engineer.

SCC is such that with a similar amount of bleed water, the surface may dry faster than normal superplasticized concrete. Most SCC surfaces may require only nominal screeding and floating and other surfaces may require a mild vibratory screeding, depending on mixture characteristics.

### **C2.8.12 Applied Coatings**

Paints may be used for purely decorative reasons. See Section 2.11 for discussion on sealers, both clear and pigmented. Every paint and stain is formulated to provide certain performance under specific conditions. Since there is a vast difference in paint or stain types, brands, prices, and performances, knowledge of composition and performance standards is necessary for obtaining a satisfactory concrete coating.

### **C2.9 Repairs**

A certain amount of repair work can be expected. Written repair procedures should clearly define when quality control is required to consult with the precast engineer to determine an appropriate remedial action. Structural repairs should not be attempted until an engineering evaluation is made to determine whether the unit will be structurally sound.

Since the techniques and materials for repairing architectural precast concrete are affected by a variety of factors including mixture ingredients, final finish, size and location of damaged area, temperature and humidity conditions, age of member, surface texture, etc., precise methods of repairing cannot be detailed in this manual.

Repair work requires expert craftsmanship and careful selection and mixing of materials if the end result is to be structurally sound, durable, and aesthetically pleasing. Repairs are acceptable, provided the structural adequacy, serviceability, and appearance of

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Adequate curing methods for repairs shall be implemented as soon as possible to ensure that the repair does not dry out too quickly.

Repairs shall be inspected for acceptability by quality control personnel. The inspection shall ensure that proper repair and curing procedures have been followed and that the results are acceptable. Repairs shall be evaluated after having been properly cured.

### **2.10 Acceptability of Appearance**

The finished face surface shall have no obvious imperfections other than minimal color and texture variations from the approved samples or evidence of repairs when viewed in good typical daylight illumination with the unaided naked eye consistent with the viewing distance on the structure, but not less than 20 ft (6 m). Appearance of the surface shall not be evaluated when light is illuminating the surface from an extreme angle, as this tends to accentuate minor surface irregularities.

the product are not impaired.

Cementitious repair materials should be moist cured to prevent shrinkage or cracking of the repair. Temperature limitations for proper curing of repair materials should be observed.

Repairs should be made at the plant well in advance of shipping to allow for proper curing of the repaired area. Provision should be made to repair damaged products in the finish area of the plant or a special area set aside for this purpose. Repairs should be avoided in the yard storage area or on the truck just prior to shipment. Slight color variations can be expected between the repaired area and the original surface due to the different age and curing conditions of the repair. Time, often several weeks, tends to blend the repair into the rest of the member so that it should become less noticeable. Gross variation in color and texture of repairs from the surrounding surfaces will require removal of the repair material and reapplication of new repair material. Small cracks (under 0.012 in. [0.30 mm]) may not need repair, unless failure to do so can cause corrosion of reinforcement. If crack repair is required for the restoration of structural integrity or member finish, cracks may be filled or pressure injected with a low-viscosity epoxy after evaluation by the precast engineer.

To match specified architectural finishes, repair mixtures should be developed early, following approval of the initial sample. A trial and error process is normally required for each newly developed face mixture to effectively match color and texture.

Corrosion-protected materials should be repaired after completion of curing and acid cleaning.

### **C2.10 Acceptability of Appearance**

It is beyond the scope of this Standard to establish definitive rules for product acceptability on the basis of appearance. Uniformity of color and intensity of shading are generally a matter of subjective individual judgment.

It should be stated in the contract documents who the accepting authority will be—contractor, architect, engineer of record, owner, or jobsite inspector.

At the time the range samples, visual mock-ups, or initial production units are approved and signed by the

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Unless approved otherwise in the architectural sample/ mock-up process (see Section 1.5.4) the following is a list of finish defects that shall be properly repaired, if readily visible when viewed at a 20 ft (6 m) or greater distance.

approving authority, the acceptable range of color, texture, and uniformity should be established.

1. Ragged or irregular edges.

1. It is recommended that all edges of precast concrete products be detailed with a reasonable radius or chamfer, rather than leaving them as sharp corners. Sharp corners chip easily during stripping, handling, and service in the building. When the edge is sharp (less than 45 deg), only fine aggregate collects there, which weakens the edge. Also, voids may occur due to the interference of larger aggregate. Therefore, this edge should have a cutoff or quirk, not less than 1/2 in. (13 mm), with 3/4 in. (20 mm) preferred, nor less than 1.5 times the maximum aggregate size used in the concrete mixture.

2. Excessive air voids (commonly called bugholes) larger than 1/4 in. (6 mm) evident on the exposed surfaces.

2. Products with deep returns and sculptured units may have visible air voids. Air voids (bugholes) become accentuated when the surface is smooth, acid etched, or lightly sandblasted. If the air holes are of a reasonable size (1/8 in. to 1/4 in. [3 to 6 mm]), it is recommended that they be accepted as part of the texture. Filling and sack rubbing could be used to eliminate the voids, but this procedure may cause color differences. Samples or the mock-up panel should be used to establish acceptable air void size, frequency, and distribution.

3. Adjacent, flat, and return surfaces with greater texture and/or color differences than the approved samples or mock-ups.

3. Returns in some finishes will not appear exactly like the front face (down face) due to a number of factors such as mixture proportions, variable depths of concrete, and small differences in consolidation techniques. This is particularly the case with intricate shapes and complex flow of concrete. The effect of consolidation forces the large aggregates downward and the smaller aggregates, as well as the sand and cement paste, upward. Consequently, the down face in the form/mold will generally be more uniform and dense than the returns or upper radius.

4. Casting and/or aggregate segregation lines evident from different concrete placement lifts and consolidation.

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5. Visible form/mold joints, seams, or irregular surfaces in excess of or larger than those acceptable in the approved samples or mock-ups.
6. Rust stains on exposed surfaces.
7. Excessive variation of texture and/or color from the approved samples, within the unit or compared with adjacent units.

6. Rust stains caused by reactive iron pyrites or other contaminants will occur where such contaminants are found as part of the aggregates. Rust stains may also be caused by particles of steel left by the aggregate crusher, pieces of tie wire from the cage assembly, or particles of steel burned off in welding or drilling. These stains (and steel particles) should be removed from the surface. Rust stains due to corrosion of hardware should not occur if the hardware has been protectively coated or where it is entirely behind a weatherproofed joint.

7. It should be recognized that some blemishes or variations in color occur in architectural precast concrete units. Uniformity in color is directly related to mixture ingredients and the production and curing practices. The use of white cement will give better color uniformity than gray cement.

Units containing aggregates and matrices of contrasting colors will appear less uniform than materials of similar color. As the size of the coarse aggregate increases, less matrix is seen, which results in a more uniform color. It is advisable to match color or tone of the matrix to that of the coarse aggregate so minor segregation of the aggregate will not be as noticeable.

Typical color variation in the gray cement is enough to cause noticeable color differences in precast concrete panels. The slightest change of color is readily apparent on the uninterrupted surfaces of smooth-as-cast concrete, and any variation is likely to be regarded as a surface blemish. As a general rule, a textured surface is aesthetically more satisfactory (more uniform) than a smooth surface. The surface highlights and natural variations in aggregate color will, to a large extent, camouflage subtle differences in texture and color of the concrete. The degree of uniformity (different shadings and to some extent, color intensity) between panels and

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- within panels in a sandblasted finish, as in all exposed-aggregate processes, is generally in direct proportion to the depth of exposure. For example, a light sandblasting may look acceptable on a small sample, but uniformity is rather difficult to achieve in the actual units.
- Over time, sunlight and exposure to elements may even out variations to a great extent.
- |                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
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| <p>8. Blocking stains evident on exposed surface.</p> <p>9. Areas where the backup concrete penetrated through the facing concrete.</p> <p>10. Foreign material embedded in the face of the unit.</p> <p>11. Visible repairs at 20 ft (6 m) or greater viewing distance.</p> <p>12. Reinforcement shadow lines.</p> <p>13. Cracks visible at a 20 ft (6 m) or greater viewing distance.</p> | <p>8. Blocking used to separate production units from each other in the storage yard or during shipment should be made of nonstaining material. Blocking should not trap moisture or prevent air circulation that may disrupt uniform curing conditions. Plastic bubble-type pads are well suited for this purpose. Lumber or padding wrapped with plastic should not be used for blocking, unless in an area that is not visible in the final structure.</p> <p>12. Reinforcing steel in some finishes may show up as light shadow lines usually directly over the steel depending on the mixture, concrete cover, vibration of reinforcement, placing, etc. In a few cases, a dark shadow pattern results from the steel within.</p> <p>13. The acceptability of cracks should be determined with respect to actual service condition requirements, structural significance, and aesthetics. Every effort should be made to promptly identify the cause of any cracking and to document the pattern, particularly when several units display similar cracking. Such cracking is often the result of a single design, manufacturing, or handling problem, which can then be rectified to prevent any recurrence.</p> <p>The cement-rich film on smooth concrete may develop a network of fine random</p> |
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hairline cracks (crazing) in an approximate hexagonal or octagonal pattern. A hairline crack is defined as a surface crack of minute width and rarely more than 1/8 in. (3 mm) deep, visible to the naked eye but not measurable by ordinary means.

Crazing is merely a surface phenomenon (penetrates only as deep as the thin layer of cement paste at the surface of the panel) and has no structural or durability significance but it may become visually accentuated when the surface is wetted or dirt settles in these minute cracks. Crazing is more predominant in as-cast or lightly textured finishes. Such crazing cracks are of little structural importance and should not constitute a cause for rejection.

It should be recognized that a certain amount of crazing or cracking may occur without having any detrimental effect on the structural capacity of the member. It is impractical to impose specifications that prohibit cracking.

A key point is cracks do not always result in corrosion of reinforcement. Corrosion depends not only on the width of the crack and whether it reaches the reinforcing steel, but also on the presence of chlorides or low pH in combination with oxygen and moisture. For surfaces exposed to the weather, cracks up to 0.005 in. (0.13 mm) wide have no influence on the corrosion of reinforcement and should be acceptable from an aesthetic viewpoint.

If the crack width is narrow, not over 0.012 in. (0.30 mm), the structural adequacy of the casting will remain unimpaired and the crack will have little influence on the potential for corrosion of the reinforcement. The limitation on crack-size specified is for structural reasons. The aesthetic limitation will depend on the surface texture and the required appearance. On coarse textured surfaces, such as exposed-aggregate concrete, and on smooth surfaces comparable to the best cast-in-place structural concrete, the structural limitation would be aesthetically acceptable. In addition, it should be noted

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that cracks may become more pronounced on surfaces receiving a sandblasted or acid-etch finish.

If crack repair is required for the restoration of structural integrity, cracks may be filled or pressure injected with a low-viscosity epoxy. The acceptability of the crack repairs should be governed by the importance and function of the panel. The decision regarding acceptability must be made on an engineering basis as well as on visual appearance.

#### **2.11 Sealers or Clear Surface Coatings**

If sealers or clear surface coatings are specified, they shall be tested on reasonably sized samples of varying age. The performance shall be monitored over a suitable period of time or be based on prior experience under similar exposure conditions. Sealers shall be applied in accordance with the manufacturer's written recommendations. Clear sealers shall be guaranteed by the supplier or applicator not to stain, soil, darken, or discolor the finish. The sealer shall not cause joint sealants to stain the panel surface or affect the bond of the joint sealant. The manufacturers of both the joint sealant and the sealer shall be consulted regarding compatibility prior to application, or the materials shall be tested before application.

#### **C2.11 Sealers or Clear Surface Coatings**

Sealers or clear surface coatings may be considered for the possible improvement of weathering characteristics. The quality of concrete normally specified for architectural precast concrete, even with minimum practical thickness, does not require sealers for waterproofing.

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### **3.1 Concrete Materials**

### **C3.1 Concrete Materials**

#### **3.1.1 General**

Frequent inspections shall be performed to check and evaluate test results and the appearance of the finished product. An inspector shall check for any change in materials or proportions that will affect the surface appearance, as well as other required mechanical properties.

#### **C3.1.1 General**

Changes in constituent material quantities and properties affect the performance and aesthetics of concrete. For example, a change in aggregate proportions, color, or gradation will affect the uniformity of the finish, particularly where the aggregate is exposed. In smooth concrete, the color of the cement (plus pigment) is the dominant factor in the appearance of the concrete surface. If the concrete surface is progressively removed by sandblasting, retarders, or other means, the color becomes increasingly dependent on the fine and coarse aggregates.

#### **3.1.2 Cement**

The type and kind of cements shall be selected to provide predictable strength and durability as well as proper and consistent color. Cements shall conform to ASTM C150/C150M. Concrete mixtures using cements conforming to ASTM C595/C595M, C845, or C1157/C1157M shall be tested and evaluated for the intended applications.

Each shipment of cement shall be referenced to a certified mill test report that indicates compliance with the specified type of cement and ASTM C150/C150M. The producer shall maintain the mill test reports on file.

To minimize the color variation of the surfaces exposed to view in the finished structure, cement of the same type, brand, and color obtained from the same mill shall be used throughout a given project. The cement used in the work shall correspond to that upon which the selection of concrete proportions and sample approval was based. If a change in cement source is required, new sample approvals are required.

#### **C3.1.2 Cement**

Unless otherwise specified, the producer should have the choice of type and kind of cement to use to achieve the specified physical properties. Different cements have different color and strength development characteristics that affect the desired concrete properties and finish. Copies of the cement strength uniformity tests conducted in accordance with ASTM C917 should be requested from the cement supplier. If the tricalcium silicate varies by more than 4%, the ignition loss varies by more than 0.5%, or the Blaine fineness varies by more than 375 cm<sup>2</sup>/g, problems with uniform strength may result. Sulfate (SO<sub>3</sub>) levels should be maintained with variation limited to ±0.20%. The cement color exerts a considerable influence on the color of the finished product due to its large surface area per unit of weight.

Colored cements conforming to ASTM C150/C150M, which are produced by adding pigments to white cement during the production process, may also be used.

Cement performance can be influenced by atmospheric conditions, and cement has an influence on finishing techniques, mixture design requirements, and casting procedures. Normal production variables such as changes in water content, curing cycles, temperature, humidity, and exposure to climatic conditions at varying strength levels all tend to cause color variation. Color variation in a gray cement matrix is generally greater than those matrices made with white cement. A more consistent gray color may be produced by using white cement with a gray or

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black pigment or a blend of white and gray cement. Uniformity normally increases with increasing percentage of white, but the gray color is dominant.

Hardened concrete containing slag cement may show mottled green or blue-green areas on the surface in the first few days after placement. This temporary condition is commonly called greening. In most concrete made with slag cement, the surface becomes light gray or white within hours after the concrete surface has been exposed to direct sunlight and air. If greening does occur, it usually appears within a week of concrete placement and typically disappears within a week after oxidation (exposure to dry air and sunlight) starts. To minimize greening, slag cement should be limited to 15 to 20% replacement of Portland cement by weight.

The temperatures of the mixing water and aggregates generally have a greater effect in determining the concrete temperature than cement temperature. Loads of “hot” [170+ °F (77+ °C)] cement may arrive at the batch plant and require special considerations prior to use in a concrete batch.

### **3.1.3 Face Mixture Aggregates**

Aggregates shall have proven durability and be free of staining or deleterious materials. They shall be nonreactive with selected cement and available in particle shapes (rounded or cubical rather than slivers) required for workable concrete and appearance.

Final selection of colors shall be made from concrete samples that have the proper matrix and are finished in the same manner as that planned for production.

### **C3.1.3 Face Mixture Aggregates**

The choice of fine and coarse aggregates to be used for face mixtures should be based on a visual inspection of approved samples.

Selection of aggregates should be governed by the following:

1. Some finishing processes change the appearance of the aggregates. If small concrete samples are used to select the aggregate color, the architect/engineer should be aware that the general appearance of large areas after installation tends to be different than indicated by the smaller trial samples.
2. Aggregates with a dull appearance may appear brighter in a white matrix than a gray matrix.
3. Weathering may influence newly crushed aggregate. When first crushed, many aggregates are bright but will dull slightly with time. Similarly, some of the sparkle caused by acid etching or bushhammering may not last more than a few weeks. The architect/engineer should recognize that samples maintained indoors may

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**Fine Aggregate.** Fine aggregates for face mixtures, other than lightweight aggregates, shall consist of high-quality natural sand or sand manufactured from coarse aggregate. Fine aggregates shall comply with ASTM C33/C33M, except for gradation, which can deviate to achieve desired texture. Variations in fineness modulus of fine aggregate shall not exceed  $\pm 0.20$  from the value used for the mixture design and the amount retained on any two consecutive sieves shall not change by more than 10% by weight of the total fine aggregate sample, nor shall more than 45% passing any sieve be retained on the next consecutive sieve.

Fine aggregates shall be obtained from sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete-making properties of the aggregates have been demonstrated by trial mixtures.

**Coarse Aggregate.** Coarse aggregates for face mixtures other than lightweight aggregates shall conform to the requirements of ASTM C33/C33M, except for gradation and the modifications in this manual.

not retain their exact appearance after exposure to weather for a few weeks.

4. The method used to expose the aggregate in the finished product may influence the final appearance.
5. The maximum size of coarse aggregate is usually controlled by (a) the dimensions of the unit to be cast, (b) clear distance between reinforcement, (c) clear distance between the reinforcement and the form/mold, and (d) the desired finish.

**Fine Aggregate.** Fine aggregates have a major effect on the color of white and light buff-colored concrete, and can be used to add color tones. Where the color depends mainly on the fine aggregates, gradation control is required.

For the fine aggregate, the material passing the No. 100 (150  $\mu\text{m}$ ) sieve should not exceed 5%, and the maximum variation of the material passing the No. 100 (150  $\mu\text{m}$ ) sieve from the fine aggregate used in the initial mix design should not exceed 1% to ensure uniformity of concrete mixtures.

**Coarse Aggregate.** Coarse aggregates may be selected on the basis of color, hardness, size, shape, gradation, method of surface exposure, cost, and availability provided levels of strength, durability, and workability are met. Colors of natural aggregates may vary considerably according to their geological classification and even among rocks of one type.

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The nominal maximum size of coarse aggregate in the face mixture shall not exceed:

1. One-fifth of the narrowest dimension between sides of form/mold.
2. One-third of the minimum section thickness.
3. Three-fourths of the minimum clear depth of cover.
4. Two-thirds of the spacing between individual reinforcing bars, bundles of bars, pretensioning tendons, or post-tensioning ducts.
5. The minimum rib size, unless workability and consolidation methods are such that the concrete can be placed without honeycomb or voids.

Coarse aggregates shall be obtained from sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete-making properties have been demonstrated by trial mixtures.

Once a sample panel has been approved by the architect/engineer, no other source of exposed aggregate or facing material shall be used for the project.

The precast concrete manufacturer shall verify that an adequate supply from one source (pit or quarry) for each type of aggregate for the entire job will be readily available and obtain the entire aggregate supply prior to starting the project or have the aggregate supply held by the supplier.

When an aggregate source is specified that does not meet the requirements of this manual, the precaster shall notify the architect/engineer in writing before the start of production.

### 3.1.4 Backup Mixture Aggregates

Aggregates in backup mixture concrete shall comply with ASTM C33/C33M or ASTM C330/C330M. In general, the maximum size of coarse aggregate shall not exceed:

1. One-fifth of the narrowest dimension between

Aggregate size should also be selected on the basis of the total area to be cast and the distance from which it is to be viewed. Aggregates exposed on the face of the precast concrete unit may vary from 1/4 in. (6 mm) up to stones and rubble 6 in. to 7 in. (150 mm to 175 mm) in diameter and larger. When surfaces are a large distance from the main flow of traffic, large aggregate may be required for a rough-textured look. A suggested visibility scale is given in Table C3.1.3.

**Table C3.1.3 - Suggested visibility scale**

| Aggregate size, in. (mm) | Distance at which texture is visible, ft (m) |
|--------------------------|----------------------------------------------|
| 1/4–1/2 (6–13)           | 20–30 (6–9)                                  |
| 1/2–1 (13–25)            | 30–75 (9–23)                                 |
| 1–2 (25–50)              | 75–125 (23–38)                               |
| 2–3 (50–75)              | 125–175 (38–53)                              |

Stockpiling of aggregates for an entire project will help minimize color variation caused by variability of material and will maximize color uniformity. The stockpile may be stored at any convenient location that provides for proper separation from other materials.

Facings of any suitable material, such as natural stone, thin brick, ceramic tile, terra cotta, oversized natural or crushed aggregates, or aluminum or stainless steel sheets or sections may also be used as facing materials. Each of these special facing applications should be properly designed and tested before use both with respect to suitability of the material and to the effect of its relationship with the precast concrete.

### C3.1.4 Backup Mixture Aggregates

The maximum size of aggregates depends on the particular application and is usually limited to 3/4 in. (20 mm).

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- sides of form/mold.
2. One-third of minimum section thickness.
  3. Three-fourths of the minimum clear depth of cover.
  4. Two-thirds of the spacing between individual reinforcing bars, bundles of bars, pretensioning tendons, or post-tensioning ducts.

All backup mixture aggregates shall be from approved sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete making properties have been satisfactorily demonstrated by trial mixtures.

### **3.1.5 Aggregates for Lightweight Concrete**

Lightweight aggregates shall conform to the requirements of ASTM C330/C330M with coarse aggregate absorption less than 11%. Provisions for testing shall be as stipulated in Sections 6.2.2 and 6.2.3 except tests for gradation, unit weight, and impurities shall be made in accordance with requirements of ASTM C330/C330M.

### **3.1.6 Mixing Water**

Water shall be free from deleterious matter that may interfere with the color, setting, or strength of the concrete.

Aggregate particles smaller than 0.005 in. (0.125 mm) contribute to the powder content of the SCC mixture(s).

### **C3.1.5 Aggregates for Lightweight Concrete**

Precasters using lightweight aggregates should be experienced in mixing and placing lightweight concrete mixtures. The effects of the aggregate weight, absorption, and shrinkage characteristics often require special attention to obtain reasonable uniformity in appearance when exposed.

The combination of a normal weight face mixture and a backup mixture with lightweight aggregates may increase the possibility of bowing or warping due to differences in thermal expansion, modulus of elasticity, and creep. Before producing such a combination, pilot units produced and stored under anticipated production conditions are desirable to verify satisfactory performance.

Lightweight aggregates tend to take on moisture and if not saturated will absorb water from the mixture, causing a rapid slump loss, creating problems in handling and placing. The ACI Committee 213 report *Guide for Structural Lightweight Aggregate Concrete* provides a thorough discussion of lightweight aggregate properties, including proportioning and mixing practices.

The moisture condition of lightweight aggregate requires special consideration in the production of SCC.

### **C3.1.6 Mixing Water**

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Water, either potable or nonpotable, shall be free from injurious amounts of oils, acids, alkalis, salts, organic materials, chloride ions, or other substances that may be deleterious to concrete or steel. The water shall not contain iron or iron oxides that will cause staining in light-colored or white concrete.

Water from a source other than a municipal water supply shall be tested on an annual basis as required in Section 6.2.2. The water shall not exceed the maximum concentration limits given in Table 3.1.6.

**Table 3.1.6 Chemical Limits for Nonpotable Mixing Water**

| Substance                                              | Maximum Concentration, ppm | ASTM Test Method <sup>a</sup> |
|--------------------------------------------------------|----------------------------|-------------------------------|
| Soluble carbon dioxide                                 | 600                        | D513 <sup>b</sup>             |
| Calcium plus magnesium                                 | 400                        | D511                          |
| Chloride, as Cl                                        | 500                        | D512                          |
| Iron                                                   | 20                         | c                             |
| Phosphate                                              | 100                        | D4327                         |
| Boron and borates                                      | 100                        | D3082                         |
| Alkalis, as Na <sub>2</sub> O + 0.658 K <sub>2</sub> O | 600                        | D4191 & D4192                 |
| Silt or suspended particles                            | 2,000                      | c                             |
| pH                                                     | 6.0 to 8.0                 | D1067                         |
| Dissolved solids                                       | 2,000                      | C1603                         |
| Sugars and oils                                        | Not detectable             | c                             |

Notes:

- Other methods as used by EPA or water analysis companies are generally satisfactory.
- Alternatively, soluble carbonate and bicarbonate may be determined by appropriate methods (e.g., Hach Chemical Co. procedures and calculated as CO<sub>2</sub>).
- No ASTM method available.

### 3.1.7 Admixtures

If a satisfactory history of admixture performance with the concrete-making materials to be used in a project is not available, a trial mixture program with those materials, particularly the cement,

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Excessive impurities in mixing water not only may affect setting time and strength, but also may cause efflorescence, staining, increased volume change, and reduced durability. Therefore, certain limits should be set on chlorides, sulfates, alkalis, and solids in the mixing water or appropriate tests can be performed to determine the effect the impurity has on various properties. Some impurities may have little effect on strength and setting time, yet they can adversely affect durability and other properties.

The chloride ion content should be limited to a level well below the recommended maximum, if practical. Chloride ions contained in the aggregate and in admixtures should be considered in evaluating the acceptability of total chloride ion content of mixing water.

### C3.1.7 Admixtures

Admixtures used should be materials of standard manufacture having established records of tests to confirm their properties and performance. Expected performance of a given brand, class, or type of

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shall be conducted. The trial mixture program shall demonstrate satisfactory performance of the admixture relative to slump or flow, stability, workability, air content, and strength under the conditions of use, particularly with respect to temperature and humidity typical of production conditions.

Admixtures shall be carefully checked for compatibility with the cement or other admixtures used to ensure that each performs as required without affecting the performance of the other admixtures. Admixture suppliers' recommendations shall be observed subject to plant checking and experience. The effect of variations in dosage and the sequence of charging the admixtures into the mixer shall be determined from the recommendations of the admixture supplier or by trial mixtures.

The same brand and type of admixtures shall be used throughout any part of a project where color uniformity is required.

### **3.1.7.1 Chemical Admixtures**

Air-entraining admixtures shall conform to the requirements of ASTM C260.

Water-reducing, retarding, or accelerating admixtures shall conform to the requirements of ASTM C494/C494M. High-range water-reducing admixtures (HRWRA or superplasticizers) shall conform to the requirements of ASTM C494/C494M Type F or G, or for flowing concrete to ASTM C1017/C1017M, Type 1 or 2.

Admixtures containing chloride ions shall not be used in prestressed concrete or in concrete containing aluminum embedments or galvanized

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admixture may be obtained from one or more of the following sources:

1. Results from jobs that have used the admixture under good technical control, preferably using the same materials and under conditions similar to those to be expected.
2. Technical literature and information from the manufacturer of the admixture.
3. Laboratory tests made to evaluate the admixture.

Trial mixtures can be made at midrange slump and air contents expected or specified for the project. The cement content or water-cementitious ratio should be that required for the specified design strength and durability requirements for the job. Trial mixtures also can be made with a range of cement contents, water-cementitious ratios, slumps, or other properties to bracket the project requirements. In this manner, the optimum mixture proportions can be selected and the required results achieved.

Various results can be expected with a given admixture due to differences in dosage, cement composition and fineness, cement content, aggregate size and gradation, the interaction with other admixtures, addition sequence, changes in water-cementitious ratio, and variations in daily weather.

Differences in setting times and early strength development also can be expected with different types and sources of cement and admixtures as well as differences in initial concrete temperature and ambient temperatures.

### **C3.1.7.1 Chemical Admixtures**

The use of air entrainment is recommended to enhance durability when concrete will be subjected to freezing and thawing while wet.

Use of water-reducing admixtures results in a desirable reduction in water-cementitious ratio for a given consistency (slump) and cement content, an increased consistency for the same water-cementitious ratio and cement content or obtaining specified strength at lower cement content while keeping the water-cementitious ratio the same. The reduction in water-cementitious ratio achieved by eliminating excess mixing water may produce greater strength improvement than a similar reduction obtained by adding cement. Generally, the effect of using these

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reinforcement and/or hardware if their use will produce a deleterious concentration of chloride ions in the mixing water and cause corrosion.

Calcium chloride or admixtures containing more than 0.15% chloride ions by weight of admixture are not permitted. Additionally, each admixture shall not contribute more than 5 ppm, by weight, of chloride ions to total concrete constituents.

To avoid corrosion problems, admixtures containing chloride ions shall be limited to a maximum water-soluble chloride ion (Cl<sup>-</sup>) in prestressed concrete to 0.06% by weight of cement or 0.15% by weight of cement in non-prestressed concrete when tested in conformance to ASTM C1218/C1218M.

Corrosion inhibitors shall conform to ASTM C1582/C1582M and be evaluated for their compatibility with other elements of the concrete mixture.

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materials on the hardened concrete is increased compressive strength and some reduction in permeability and, in combination with adequate air entrainment, improved resistance to freezing and thawing. Water-reducing admixtures also may improve the properties of concrete containing harsh face mixtures, which necessarily have poor aggregate gradation. Dosages required to produce specific results are usually recommended by the manufacturers.

The use of Type F or Type G HRWRA is essential to achieve SCC fluidity. They can also be used in combination with water-reducing admixtures or midrange water-reducing admixtures. There are midrange water-reducing admixtures that may be classified under ASTM C494/C494M as Type A or Type F depending on dosage rate.

Retarding admixtures are used primarily to offset the accelerating and damaging effect of high temperature. In some cases, retarding admixtures may be used to keep concrete plastic for a sufficiently long period of time (retard or control the initial set of the concrete) so that succeeding lifts can be placed without development of cold joints or discontinuities in the unit, for example to achieve good bond between face mixture and backup concrete.

HRWRA can be used to significantly increase slump without adding more water, or to greatly reduce water content without a corresponding loss in slump. Concretes containing these admixtures, particularly those with initial slumps less than 3 in. to 4 in. (75 mm to 100 mm) and low water-cementitious ratios, tend to lose slump and stiffen rapidly. However, some high-range water-reducing retarders can maintain the necessary slump for extended periods at elevated concrete temperatures.

Calcium chloride and admixtures containing chloride ions will promote corrosion of steel reinforcement and galvanized or aluminum embeddings. This material may also cause nonuniformity in color of the concrete surface (darkening and mottling), and may disrupt the efficiency of surface retarders.

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### **3.1.7.2 Mineral Admixtures**

Mineral admixtures or pozzolans meeting ASTM C618, C1240, or C989 may be added for additional workability, increased strength, and reduced permeability and efflorescence, provided no detrimental change is experienced in the desired architectural appearance. If a HRWRA is used with silica fume or any mineral admixture in slurry form, the admixture shall be compatible with that already in the silica fume, if any. The amount of silica fume or metakaolin in concrete shall not exceed 10% by weight of the portland cement unless evidence is available indicating that the concrete produced with a larger amount will have satisfactory strength, durability, and volume stability.

### **3.1.7.3 Coloring Admixtures**

Coloring admixtures or pigments shall conform to the requirements of ASTM C979. All coloring pigments required for a project shall be ordered in one lot or color controlled from lot to lot. The coloring pigment shall be finely ground natural or synthetic mineral oxide or other pigments with test documents to demonstrate that it passes ASTM C979.

ASTM C979 test results shall show that pigments are insoluble in water, free of soluble salts and acids, colorfast in sunlight, resistant to alkalis and weak acids, and virtually free of calcium sulfate. The amount and type of pigment used shall be harmless to concrete setting time or strength. Pigment amounts used shall not exceed 10% by weight of cement.

### **C3.1.7.2 Mineral Admixtures**

Where a particularly smooth surface is desired, the addition of fine minerals or pozzolans conforming to ASTM C618 may be desirable. The use of fly ash or nonwhite silica fume (microsilica) in a concrete mixture will darken the concrete color and may make it difficult to achieve color uniformity. Fly ash should have a maximum loss on ignition of 3%. The color of silica fume depends on carbon content and several other variables. Silica fume from some sources could be almost white in color, while that from another may be black. It is desirable to require the silica fume to meet the optional chemical and physical requirements of ASTM C1240. Metakaolin is a dry white powder and does not darken white or gray concrete.

Viscosity-modifying admixtures (VMAs) are used to increase the segregation resistance of SCC mixtures by increasing their viscosity and to provide mixture robustness by reducing the effect of mixture water variation. However, SCC mixtures can exhibit excellent stability performance without the use of such admixtures when the mixture proportions provide a sufficient level of viscosity to prevent segregation in the casting process.

There are currently no ASTM specifications for VMAs and there is no harmlessness test. Producers should confirm by trial mixtures that VMAs cause no known harmful effects in the hardened concrete.

### **C3.1.7.3 Coloring Admixtures**

Pigments often are added to the matrix to obtain consistent colors that will enhance the colors of the cement and fine aggregate. Variable amounts of a pigment, expressed as a percentage of the cement content by weight, produce various shades of color. High percentages of pigment reduce concrete strength because of the high percentage of fines introduced to the mixture by the pigments. For these reasons, the amount of pigment should be controlled within the limits of strength and absorption requirements. Different shades of color can be obtained by varying the amount of coloring material or by combining two or more pigments. Brilliant concrete colors are not possible with either natural or synthetic pigments due to their low allowable addition rates and the masking effects of the cement and aggregates. White portland cement will produce cleaner, brighter, and more

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consistent colors and should be used in preference to gray cement.

When using pigment dosages of less than 1% by weight of cement, the sensitivity of color intensity to minor pigment quantity variations is very high, causing potential unit-to-unit color variation. When using dosages from 1% to 5%, this sensitivity is much lower, and color variation will be more easily controlled. Addition of synthetic iron oxide pigments above 5% will not increase color intensity, while for natural pigments the saturation points are closer to 10%.

Coloring pigments of iron oxides are generally preferred because of better performance. Green is expensive and quite permanent, except in light shades. Some blues are not uniform or permanent. Cobalt blue should be used to avoid problems. Carbon black, due to its extremely fine particle size, has a tendency to wash out of a concrete matrix and is not recommended. Synthetic black iron oxide will produce a stable charcoal color. Titanium dioxide pigment in quantities of 1 to 3% is sometimes used to increase the opacity or to further intensify the whiteness of white concrete. However, it is doubtful that titanium dioxide would overcome the yellowing effect of yellow or brown sands when used in amounts that would not be detrimental to the strength and durability of the concrete.

Efflorescence deposited on the surface may mask the true color and give the appearance of fading even though the cement paste itself has undergone no change. In addition, weathering of the pigmented cement paste exposes more of the aggregate to view. If the color of the aggregate is in contrast to that of the pigment, a change in the overall color of the surface may be noted. Dark colors have greater tendency to show efflorescence that forms on all concrete surfaces. If the lightening of the color becomes too objectionable, the color can be restored by washing with appropriate cleaning methods.

Architects can best specify the color they desire by referring to the *PCI Architectural Precast Concrete Color and Texture Selection Guide (CTG)*.

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### **3.2 Reinforcement and Hardware**

### **C3.2 Reinforcement and Hardware**

#### **3.2.1 Reinforcing Steel**

#### **C3.2.1 Reinforcing Steel**

Steel reinforcing bars shall be deformed bars of the designated type, size, and grade. The bars shall conform to the following applicable specifications as shown on the production drawings:

- ASTM A615/A615M for Billet-Steel Deformed Bars
- ASTM A706/A706M for Low Alloy Steel Deformed Bars
- ASTM A996 for rail and axle steels

Grades of reinforcing steel required for a specific application are determined by the structural design of the precast concrete units.

The ASTM specifications for steel reinforcing bars (A615/A615M, A706/A706M, and A996) require identification marks to be rolled into the surface of one side of the bar to denote the producer's mill designation, bar size, type of steel, and minimum yield designation (Fig. C2.3.1).

It shall be permissible to substitute a metric bar for the corresponding US Customary Unit bar:

- Metric Grade 300: US Customary Unit Grade 40
- Metric Grade 350: US Customary Unit Grade 50
- Metric Grade 420: US Customary Unit Grade 60
- Metric Grade 520: US Customary Unit Grade 75

Minimum yield designation is used for Grade 60 (420) and Grade 75 (520) bars only. Grade 60 (420) bars can either have one single longitudinal line (grade line) or the number 60 (420) (grade mark). Grade 75 (520) bars can either have two grade lines or the grade mark 75 (520).

A grade line is smaller and between the two main ribs that are on opposite sides of all U.S.-made bars. A grade line must be continued at least five deformation spaces. A grade mark is the fourth mark on a bar.

Grade 40 (300) and 50 (350) bars are required to have only the first three identification marks (no minimum yield designation).

**Variations:** Bar identification marks may be oriented as illustrated or rotated 90 deg. Grade mark numbers may be placed within separate consecutive deformation spaces. Grade lines may be placed on the side opposite the bar marks.

Many mills will mark and supply bars only with the metric designation, which is a soft conversion. Soft

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Zinc-coated (galvanized) reinforcement shall conform to ASTM A767/A767M, which includes the requirement for chromate treatment.

When bars are cut for fabrication after galvanizing, the end of the bar shall be coated with a zinc-rich paint (92% to 95% metallic zinc in the dry film) conforming to ASTM A767/A767M in accordance with ASTM A780/A780M. The maximum damaged areas shall not exceed 2% of surface area in each lineal foot 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.

Epoxy-coated reinforcement shall conform to ASTM A775/A775M or A934/A934M. The maximum damaged areas shall not exceed 2% of surface area in each lineal foot of each bar or the bar shall not be used. The 2% limit on maximum

means that the metric bars have exactly the same dimensions and properties as the equivalent inch-pound designation.

The size of reinforcing bars is often governed by dimensions of the element, required concrete cover over steel, and function of the element. In general, bar sizes should be kept reasonably small even where this will reduce the spacing of the bars. Smaller bars closely spaced will decrease the size of potential cracks and improve the distribution of temperature stresses. The use of additional reinforcing bars as compared with fewer heavier bars becomes more important in thinner concrete sections. Since the sum of potential cracks in concrete is more or less constant for a given set of conditions, the more bars there are, the smaller and less visible the cracks will be.

Where galvanizing of reinforcing bars is required, galvanizing is usually performed after fabrication. The ASTM A767/A767M specification prescribes minimum finished bend diameters for bars that are fabricated before galvanizing. Smaller finished bend diameters are permitted if the bars are stress-relieved. The ASTM A767/A767M specification has two classes of zinc coating weights. Class II [2.0 oz/ft<sup>2</sup> (610 g/m<sup>2</sup>)] is normally specified for precast concrete units. The presence of chromate film on the surface of the galvanized coating is usually visible as a light yellow tint on the surface. ASTM B201 describes a test method for determining the presence of chromate coatings. The purchase order should include a requirement for chromate treatment for all galvanized reinforcement.

Any plant supplying epoxy-coated reinforcement should be a participant in the CRSI Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants.

When epoxy-coated reinforcing bars are exposed to sunlight over a period of time, fading of the color of some epoxy coatings may occur. Since the discoloration does not harm the coating nor affect its corrosion-protection properties, such fading should not be cause for rejection of the coated bars.

ASTM A775, A934 and D3963 give provisions for allowable damage in place epoxy-coated reinforcing bars.

ASTM A775 and A934 state that “when the extent of

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allowed damaged coating area shall include previously repaired areas damaged before shipment, as required by ASTM A775/A775M or A934/A934M. Bars shall be protected from environmental exposure in accordance with ASTM D3963/D3963M or project specifications.

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damage does not exceed 2% of the surface area in any 1 ft length, all damaged coating discernible to a person with normal or corrected vision should be repaired with patching material.” Similarly, ASTM D3963 states: The total damaged surface area (prior to repair with patching material), shall not exceed 2% in any given 1 ft section of coated reinforcement.” It further states that the area does not include sheared or cut ends. ASTM A775 and A934 do not provide a similar requirement, but cautions are provided regarding excess repair material.

To comply with these requirements, a calculation on the bar surface area and a visual estimation of the total damaged area or repair is required. For various bar sizes, allowable damage and repair areas are shown in Table C3.2.1.

**Table C3.2.1: Allowable coating damage and repaired area per linear ft**

| Bar Size | Surface area per linear ft | Allowable damage per linear ft at 2% of area | Allowable repair per linear ft at 5% of area |
|----------|----------------------------|----------------------------------------------|----------------------------------------------|
| Bar #    | (in <sup>2</sup> )         | (in <sup>2</sup> )                           | (in <sup>2</sup> )                           |
| 3        | 14.14                      | 0.28                                         | 0.71                                         |
| 4        | 18.85                      | 0.38                                         | 0.94                                         |
| 5        | 23.56                      | 0.47                                         | 1.18                                         |
| 6        | 28.27                      | 0.57                                         | 1.41                                         |
| 7        | 32.99                      | 0.66                                         | 1.65                                         |
| 8        | 37.70                      | 0.75                                         | 1.88                                         |
| 9        | 42.52                      | 0.85                                         | 2.13                                         |
| 10       | 47.88                      | 0.96                                         | 2.39                                         |
| 11       | 53.16                      | 1.06                                         | 2.66                                         |
| 14       | 63.82                      | 1.28                                         | 3.19                                         |
| 18       | 85.09                      | 1.70                                         | 4.25                                         |

For a #3 bar, a damage site measuring 0.5 x 0.5 in. in each linear foot would be allowable. For a #18 bar, this site can be increased to 1.3 x 1.3 in. in a linear foot.

Bar mats shall conform to ASTM A184/A184M and shall be assembled from the bars described above. If bars other than the types listed above are to be used, their required properties shall be shown on the production drawings. In addition to the ASTM specification requirements, all

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reinforcing bars shall meet the requirements of ACI 318.

The weldability of reinforcing bars including ASTM A706/A706M shall be evaluated according to provisions of AWS D1.4/D1.4M.

Welded-wire reinforcement shall conform to ASTM A1064/1064M.

Galvanized welded-wire reinforcement shall conform to ASTM A1060/1060M and be made from zinc-coated (galvanized) carbon steel wire conforming to ASTM A641/A641M or be hot-dip galvanized and chromate treated or allowed to weather until a whitish coating appears.

Epoxy-coated welded-wire reinforcement shall conform to ASTM A884/A884M, Class A. All damaged areas of epoxy coating shall be repaired (touched up) with an epoxy repair material formulated for repairing damaged epoxy coatings. The maximum damaged area shall not exceed 2% surface area in each lineal foot of each wire or the welded wire reinforcement shall not be used.

Welded-wire reinforcement mesh spacings and wire sizes (gauges) shall be shown on the production drawings. In addition to the ASTM specification requirements, all wire reinforcement shall meet the requirements of ACI 318.

Reinforcement with rust, seams, surface irregularities, or mill scale shall be considered acceptable, provided the minimum nominal dimensions, including minimum average height of deformations and nominal weight of a hand-wire-brushed test specimen, are not less than the applicable ASTM specification requirements.

Plastics for welded wire and bar supports shall be composed of polyethylene, styrene copolymer rubber-resin blends, polyvinyl chlorides, Types I and II, and polytetrafluoroethylene. Plastics shall be alkali resistant, have thermal properties compatible with concrete, and has at least 25% of their gross plane area perforated.

Welded-wire reinforcement may be used as the main reinforcement and, if necessary, reinforcing bars may be added in ribs or other locations to provide the area of steel required. It is recommended that welded-wire reinforcement be purchased in large sheets rather than rolls for better control of flatness.

Galvanized or epoxy-coated reinforcement is generally required when cover over the reinforcement is 3/4 in. (19 mm). In such cases, the use of galvanizing or epoxy coating should be specifically called for in the contract documents and shown on the shop drawings.

Plastic bar supports and spacers have about fifteen times the thermal expansion coefficient of concrete. The plane surface has to be perforated to permit the concrete to weave into the section and restrain movement. This inhibits thermal punching and transverse cracking in thin sections.

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### 3.2.2 Prestressing Materials

### C3.2.2 Prestressing Materials

Strand materials for prestressing shall consist of:

1. Pretensioning
  - a. Uncoated, low-relaxation strand conforming to ASTM A416/A416M, Grade 250 (1725) or Grade 270 (1860).
  - b. Stress-relieved (normal-relaxation) strand, conforming to ASTM A416/A416M, Grade 250 (1725) or Grade 270 (1860).
  - c. Coated, low-relaxation strand conforming to ASTM A882/A882M, Grade 250 (1725) or Grade 270 (1860).
2. Post-Tensioning
  - a. Strand in accordance with pretensioning used as single-strand tendons or multiple-parallel-strand tendons
  - b. Uncoated, stress-relieved wire conforming to ASTM A421/A421M in multiple-parallel-wire tendons
  - c. High-strength, stress-relieved bars conforming to ASTM A722/A722A
  - d. High-strength, stress-relieved large cables.

Mill certificates from suppliers shall be maintained on file by the producer for tendon materials in current use. Modulus of elasticity values provided for strand packs shall be applicable to each individual reel.

A light coating of tight surface rust on prestressing strand is permissible, provided there is no visible evidence of pitting to the unaided eye after the rust is removed with a nonmetallic pad.

Some strand suppliers may provide an average modulus value for all of their strand packs which may cause stressing inaccuracies. For example, a variation of 1,000,000 psi (6,900 MPa) in the modulus of elasticity represents a difference of about 4% in elongation. It is always preferable to use the actual modulus of the strand used on the project when comparing tendon elongation and gauge pressure.

Due to the bond development required of concrete to prestressing strand, bars, or wires, the surface condition of tendons is critical to prestressed concrete. The presence of light rust on a strand has proven to be an enhancement to bond over bright strand. Therefore, it should not be a deterrent to the use of the strand. A pit visible to the unaided eye, when examined as described in "Evaluation of Degree of Rusting on Prestressed Concrete Strand" (Augusto S. Sason, *PCI Journal*, May-June 1992, V. 37, No. 3, pp. 25-30) is cause for rejection. A pit of this magnitude is a stress raiser and greatly reduces the capacity of the strand to withstand repeated or fatigue loading. In many cases,

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Strand chucks for pretensioning shall be capable of anchoring the strand without slippage after seating. Length of grips and configuration of serrations shall be such as to ensure against strand failure within the vise jaw wedges at stresses less than 95% of strand ultimate strength. Steel casings for strand vises shall be verified by the manufacturer as capable of holding at least 100% of the ultimate strength of the strand.

Tendon anchorages for post-tensioning shall meet the following requirements:

1. Anchorages for bonded tendons tested in an unbonded state shall develop 95% of the actual ultimate strength of the prestressing steel, without exceeding anticipated set at time of anchorage. Anchorages that develop less than 100% of the minimum specified ultimate strength shall be used only where the bond length provided is equal to or greater than the bond length required to develop 100% of the minimum specified ultimate strength of the tendon. The required bond length between the anchorage and the zone where the full prestressing force is required under service and ultimate loads shall be sufficient to develop the specified ultimate strength of the prestressing steel. The bond length shall be determined by testing a full-sized tendon. If in the unbonded state the anchorage develops 100% of the minimum specified ultimate strength it need not be tested in the bonded state.
2. Anchorages for unbonded tendons shall develop 95% of the minimum specified ultimate strength of the prestressing steel with an amount of permanent deformation that will not decrease the expected ultimate strength of the assembly.
3. The minimum elongation of a strand under ultimate load in an anchorage assembly tested in the unbonded state shall not be

a heavily rusted strand with relatively large pits will still test to an ultimate strength greater than specification requirements. However, it will not meet the fatigue test requirements.

Strand chuck maintenance should be in force for all elements in use based on guidelines in Article 5.3.5 and Appendix D.

Precast producers should conduct testing as outlined in Division 6.2.2.4 to confirm the threshold for strand bond development.

1. Post-tensioning tendons subject to exposure or condensation, and that are not to be grouted, should be permanently protected against corrosion by plastic coating or other approved means.

3. Elongation based on tests with a gauge length less than 10 ft (3 m) should not be cause for rejection.

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less than 2% when measured in a gauge length of 10 ft (3 m).

Anchorage castings shall be nonporous and free of sand, blow holes, voids, and other defects. For wedge-type anchorages, the wedges shall be designed to preclude premature failure of the prestressing steel due to notch or pinching effects.

Anchorages of any type may be used, provided they are shown by an adequate program of tests to meet the basic requirements listed above.

Sheathing for bonded post-tensioned tendons shall be strong enough to retain its shape, resist unrepairable damage during production, and prevent the entrance of cement paste or water from the concrete. Sheathing material left in place shall not cause harmful electrolytic action or deteriorate. The inside diameter shall be at least 1/4 in. (6 mm) larger than the nominal diameter of single wire, bar, or strand tendons. In the case of multiple wire, bar, or strand tendons, the inside cross-sectional area of the sheath shall be at least twice the net area of the prestressing steel. Sheaths shall be capable of transmitting forces from the grout to the surrounding concrete. Sheaths shall have grout holes or vents at each end and at all high points except where the degree of tendon curvature is small and the tendon is relatively level.

Grout material properties and grouting practices shall be in accordance with current edition of PTI "Specification for Grouting of Post-Tensioned Structures," Post-Tensioning Institute.

Grout shall consist of a mixture of cement, water, and admixtures unless the gross inside cross-sectional area of the sheath exceeds four times the tendon cross-sectional area, in which case fine aggregate may be added to the mixture. Fly ash and pozzolanic mineral admixtures may be added at a ratio not to exceed 0.30 by weight of cement. Mineral admixtures shall conform to ASTM C618, C989, or C1240. Aluminum powder of the proper fineness and quantity or other approved shrinkage-compensating material that is well dispersed through the other admixture may be used to obtain 5% to 10% unrestrained expansion of the grout. Admixtures containing

Different requirements are imposed upon sheathings for bonded and unbonded tendons. In unbonded tendons, the sheathing does not transmit any bond stresses from the prestressing steel to the concrete and therefore has to ensure the freedom of movement of the prestressing steel and form an adequate cover over the coated tendon. In bonded tendons, bond stresses will be transmitted through the sheathing, and it must be of such material and/or configuration to effectively allow this stress transfer.

The void in the concrete in which the tendon is to be located can also be preformed (for example, by inflatable and removable tubes). The tendon is subsequently pulled through the preformed void and no additional sheathing will be required.

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more than trace amounts of chlorides, fluorides, aluminum, zinc, or nitrates shall not be used. Admixtures shall be used in conformance with manufacturers' recommendations. Fine aggregate, if used, shall conform to ASTM C404, Size No. 2, except that all material shall pass the No. 16 sieve. Grout shall achieve a minimum compressive strength of 2500 psi (17.2 MPa) at 7 days and 5000 psi (34.5 MPa) at 28 days when tested in accordance with ASTM C1107/C1107M, and have a consistency that will facilitate placement. Water content shall be the minimum necessary for proper placement, and the water-cementitious ratio shall not exceed 0.45 by weight.

Prepackaged non-shrink grouts shall comply with ASTM C 1107.

Sheathing for unbonded tendons (monostrand post-tensioning system) shall be polypropylene, high-density polyethylene, or other plastic that is not reactive with concrete, coating, or steel. The material shall be waterproof and have sufficient strength and durability to resist damage and deterioration during fabrication, transport, storage, installation, concreting, and tensioning. The sheath shall have a coefficient of friction with the strand of less than 0.05. Tendon covering shall be continuous over the unbonded length of the tendon. It shall prevent the intrusion of water or cement paste and the loss of the coating material during concrete placement. The sheath material shall not become brittle or soften over the anticipated exposure temperature and service life of the structure. The minimum wall thickness of sheaths for noncorrosive conditions shall be 0.04 in. (1 mm). The sheathing shall have an inside diameter at least 0.030 in. (0.76 mm) greater than the maximum diameter of the strand.

Tendons shall be lubricated and protected against corrosion by a properly applied coating of grease or other approved material. The coating shall be a compound that complies with the tests and associated acceptance criteria specified in Table 2.1, ACI 423.7-07. Minimum weight of coating material on the prestressing strand shall be not less than 2.5 pounds (1.1 kg) of coating material per 100 ft (30.5 m) of 0.5-in.-diameter (12 mm) strand, and 3.0 pounds (1.4 kg) of coating material per 100 ft (30.5 m) of 0.6-in.-

Due to variations in the manufacturing process, slight variations may occur concentrically in the wall thickness. The sheathing should provide a smooth circular outside surface and should not visibly reveal the lay of the strand.

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diameter (15.2 mm) strand. The amount of coating material shall be sufficient to ensure essentially complete filling of the annular space between the strand and the sheathing. The coating shall extend over the entire tendon length. Coatings shall remain ductile and free from cracks at the lowest anticipated temperature and shall not flow out from the sheath at the maximum anticipated temperature. Coatings shall be chemically stable and nonreactive to the tendon, concrete, and sheath.

### **3.2.3 Hardware, Lifting Devices, and Miscellaneous Materials**

All hardware, connection items, inserts, lifting devices, or other accessories shall be as shown in the project documents.

Hardware shall be made from materials that are ductile. Plates and angles shall be low-carbon (mild) steel and steel for anchors shall be of a grade and strength similar to the anchored hardware material to minimize welding complications. Brittle materials, such as low-shock-resistant, high-carbon steels or gray iron castings, shall not be used. Malleable cast iron is satisfactory.

Materials used in ferrous items embedded in the concrete, for the purpose of connecting precast elements or attaching or accommodating adjacent materials or equipment, shall conform to the requirements of the following specifications:

### **C3.2.3 Hardware, Lifting Devices, and Miscellaneous Materials**

Precautions should be taken to ensure that hardware elements welded together are compatible.

The degree of protection from corrosion required depends on the actual conditions to which the connections will be exposed in service. The most common condition requiring protection is exposure to climatic conditions. Connection hardware generally needs protection against humidity or a corrosive environment. Corrosion could cause subsequent rusting and marring of adjacent elements or failure of the unit connection. The use of oil-based primers containing lead may be restricted due to local environmental regulations. Protective coatings should be applied in a manner that prevents embrittlement. Also, no loss of connection strength or reinforcement bond loss should occur that was not anticipated and allowed for in the design. Often, final finishing of the products causes the protective finish of the hardware to be damaged. When this occurs, a final touch-up coating of the original protective material is required. This work should be performed in accordance with the recommendations of the coating material manufacturer. Since the final connection of a unit to a structure may require a field weld, the protective coating (zinc-rich or epoxy paint) should be applied according to the manufacturer's requirements after final welding and cleaning of the welded area.

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**Structural Steel:** ASTM A36/A36M (for carbon steel connection assemblies). If this material is to be galvanized, the silicon (Si) content shall be in the range of 0% to 0.04% or 0.15% to 0.20% and phosphorus (P) content in the range of 0% to 0.02%. Steel with chemistry conforming to the formula  $(Si + 0.5P) \leq 0.09$  is also acceptable.

**Stainless Steel:** ASTM A666, Type 304, Type 316, or Type 201 of grade suitable for application.

Stainless steel anchors may be used when resistance to staining merits extra cost.

Some designers specify stainless steel connections to prevent long-term corrosion. While this may appear to be the best possible corrosion protection, users are cautioned that the welding of stainless steel produces more heat than convention welding. The increased heat input, plus a higher coefficient of thermal expansion, may create adverse hardware expansion adjacent to the assembly being welded. This can cause cracking in the adjacent concrete and promote accelerated long-term deterioration. When stainless steel connection plates are used, edges should be kept free from adjacent concrete to allow expansion during welding without spalling the concrete. Heat dissipation can also be facilitated by the use of a thicker plate. In addition, the 300 Series stainless steels are susceptible to stress corrosion cracking when the temperature is over 140 °F (60 °C) and chloride solutions are in contact with the material.

**Carbon Steel Plate:** ASTM A283/A283M, Grade C.

**Malleable Iron Castings:** ASTM A47/A47M, Grades 32510 or 35028.

**Carbon Steel Castings:** ASTM A27/A27M, Grade U-60-30 (Grade 415-205).

**Anchor Bolts:** ASTM A307 (carbon steel) or A325 (high-strength steel for low-carbon steel bolts, nuts, and washers).

**Wrought Carbon Steel Bars:** ASTM A675/A675M, Grade 65.

**Carbon Steel Structural Tubing:** ASTM A500/A500M, Grade B or C (Grade 450).

**High-Strength Low-Alloy Structural Steel:** ASTM A572/A572M. If this material is to be galvanized, the silicon (Si) content shall be in the range of 0 to 0.04% or 0.15% to 0.20% and

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phosphorus (P) content in the range of 0% to 0.02%. Steel with chemistry conforming to the formula  $(Si + 2.5P) \leq 0.09$  is also acceptable.

**Welded Headed Studs:** ASTM A108 Grades 1010 through 1020 inclusive, ASTM A276 (stainless steel) or ASTM A496 with the following mechanical property requirements (Table 3.2.3):

**Table 3.2.3 Minimum Mechanical Property Requirements for Studs**

| Physical property               | Type A<br>AWS<br>D1.1 | Type B<br>AWS<br>D1.1 | Type C<br>ASTM A496<br>(deformed bars –<br>all sizes) | Stainless<br>steel ASTM<br>A276, A496,<br>AWS D1.6 |
|---------------------------------|-----------------------|-----------------------|-------------------------------------------------------|----------------------------------------------------|
| Tensile, psi<br>(MPa)           | 61,000<br>(420)       | 65,000<br>(450)       | 80,000<br>(552)                                       | 75,000<br>(517)                                    |
| Yield, psi (MPa)<br>0.2% offset | 49,000<br>(340)       | 51,000<br>(350)       | —                                                     | 30,000<br>(207)                                    |
| 0.5% offset                     | —                     | —                     | 70,000<br>(485)                                       | —                                                  |
| Elongation<br>% in 2 in., min.  | 17                    | 20                    | —                                                     | 30                                                 |
| % in 5 x dia.<br>min.           | 14                    | 15                    | —                                                     |                                                    |
| Reduction of<br>area, %         | 50                    | 50                    | —                                                     | 40                                                 |

All metallic hardware surfaces that are exposed to or within 1/2 in. (12 mm) of concrete surfaces that are exposed to the weather, corrosive conditions, or condensation shall be protected against corrosion or be made of noncorrosive materials. Hardware shall be properly cleaned prior to application of protective treatment.

Corrosion protection, when required, shall consist of one of the following:

1. **Shop primer paint:** compliance with performance requirements in MPI 79, or SSPC-Paint 25.
2. **Zinc-rich paint** (95% pure zinc in dried film): FS-TT-P-641, Type III, or DOD-P-21035B, self-curing, one component, sacrificial organic coating or SSPC-Paint 20.

Cast steel clamps are typically made out of carbon steel castings.

Completely encased anchors are typically made of wrought carbon steel bars.

Round and shaped tubing is typically made of carbon steel structural tubing.

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3. **Zinc metalizing or plating (electrodeposition):** ASTM B633, SC3, Type 1 or 2.

4. **Cadmium plating:** ASTM B766.

5. **Hot-dip galvanizing:** ASTM A123/A123M or A153/A153M.

4. Cadmium plating is particularly appropriate for threaded fasteners. Cadmium coatings will satisfactorily protect steel embedded in concrete, even in the presence of moisture and normal chloride concentrations. Minor imperfections or breaks in the coating will generally not promote corrosion of the underlying steel.

5. Special care should be taken when galvanized assemblies are used. Many parts of connection components are fabricated using cold rolled steel or cold working techniques, such as bending of anchor bars. Any form of cold working reduces the ductility of steel. Operations such as punching holes, notching, producing fillets of small radii, shearing, and sharp bending may lead to strain-age embrittlement of susceptible steels. This is particularly the case with high carbon content. The embrittlement may not be evident until after the work has been galvanized. This occurs because aging is relatively slow at ambient temperatures but is more rapid at the elevated temperature of the galvanizing bath.

When items of a connection assembly require welding, such as anchor bars to plates, the following recommendations by the American Hot-Dip Galvanizers Association have been found to produce satisfactory results:

- a. An uncoated electrode should be used whenever possible to prevent flux deposits.
- b. If a coated electrode is used, it should provide for “self-slagging” as recommended by welding equipment suppliers. All welding flux residues should be removed per AWS D1.1/D1.1M by wire brushing, flame cleaning, chipping, grinding, needle gun, or abrasive blast cleaning. This is also necessary when galvanizing because welding flux residues are chemically inert in the normal pickling solutions used by galvanizers and may cause rough and incomplete zinc coverage.
- c. A welding process such as metal-inert gas (MIG), tungsten-inert gas (TIG), or CO<sub>2</sub> shielded arc is recommended when possible since they produce essentially no slag.

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### **6. Epoxy coating**

### **7. Stainless steel**

### **8. Other coatings or steels proven suitable by tests.**

Threaded parts of bolts, nuts, or plates shall not be hot-dip galvanized or epoxy coated unless they are subsequently rethreaded prior to use. Connection hardware shall be galvanized, if required, following fabrication. To avoid possible strain-age embrittlement and hydrogen embrittlement, the practices given in ASTM A143/A143M shall be adhered to. Malleable castings shall be heat treated prior to galvanizing by heating to 1250 °F (677 °C) and water quenching.

Care shall be taken to prevent chemicals such as muriatic acid from contacting the hardware and causing corrosion.

The materials of a connection shall be selected and joined in a manner such that embrittlement of any part of the assembled connection will not occur. Nonferrous inserts shall be resistant to electrolytic action and alkali attack. Documentation shall be provided showing satisfactory results over a reasonable period of time. If more than one material is used in a connection, abutting materials shall be selected such that corrosion is not induced. Dissimilar metals shall not be embedded near or in direct contact in moist or saturated concrete unless detrimental chemical or electrochemical (galvanic) reactions are ensured not to occur.

Wooden inserts in the concrete shall be sealed to minimize volume changes during concrete placing, curing, and freezing weather conditions.

7. See page 3.18 and 3.19 for precautions on the use of stainless steel

8. Embedded weathering steels generally do not perform well in concrete containing moisture and chloride. Weathering steels adjoining concrete may discharge rust and cause staining of concrete surfaces.

Nonferrous metals embedded in concrete may corrode in two ways:

1. By direct oxidation in strong alkaline solutions normally occurring in fresh concrete and mortar.
2. By galvanic currents that occur when two dissimilar metals are in contact in the presence of an electrolyte, when an alloy or metal is not perfectly homogeneous, or when different parts of a metal have been subjected to different heat treatments or mechanical stresses.

Aluminum is susceptible to attack when embedded in concrete. Initially, a reaction occurs resulting in the formation of aluminum oxide along with an evolution of hydrogen. The greater volume occupied by the oxidation products causes expansive pressures around the embedded metal and may lead to increased porosity of the surrounding concrete as well as cracking and/or spalling of the concrete.

A wood sealer should be applied to prevent moisture migration from concrete into the wood. The high volume change of lumber that occurs even with changes in atmospheric humidity may lead to cracking of the concrete. Also, the embedment of lumber in concrete has sometimes resulted in leaching of the wood resins by calcium hydroxide with subsequent deterioration of the wood.

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### **3.2.4 Embedded Handling and Lifting Devices**

Since lifting devices are subject to dynamic loads, handling and lifting devices shall be fabricated from ductile material. Reinforcing bars shall not be used as lifting devices. If smooth bars are required for lifting, ASTM A36/A36M steel of a known steel grade bent to correct size and shape shall be used, provided adequate embedment or mechanical anchorage exists. Each bar size and configuration shall be substantiated by testing to ensure that it meets load and handling requirements. The diameter shall be such that localized failure will not occur by bearing on the lifting device. Coil rods and bolts shall not be welded when used in lifting operations. Connection hardware shall not be used for lifting or handling unless carefully reviewed and approved by the precast engineer.

To avoid overstressing one lifting loop when using multiple loops, care shall be taken in the fabrication to ensure that all strands are similarly bent and positioned so that even distribution of load occurs between loops.

Shop drawings shall clearly define insert dimensions and location for fabrication and placement or refer to standard details. Corrosion protection shall be considered where such hardware is left in the units.

Lifting devices shall be capable of supporting the element in all positions planned during the course of manufacture, storage, delivery, and erection. Safe loads for lifting inserts or devices shall be established by full-scale tests to failure performed by a licensed professional engineer or supplied by the manufacturer of proprietary devices. Information also shall be supplied by the manufacturer on the use and installation of the devices to ensure proper performance.

### **3.3 Insulation**

Insulation shall conform to ASTM standards as specified in the project documents. The ASTM standards present quality control minimums for each product matrix and are as follows:

### **C3.2.4 Embedded Handling and Lifting Devices**

The most common lifting devices are prestressing strand or cable loops projecting from the concrete, threaded inserts, or proprietary devices.

Deformed reinforcing bars should not be used as the deformations can result in stress concentrations from the shackle pin. Also, reinforcing bars may be hard grade or rerolled rail steel with little ductility and low impact strength at cold temperatures. Strain hardening from bending the bars may also cause embrittlement. Smooth bars of a known steel grade may be used if adequate embedment and mechanical anchorage are provided. The diameter must be such that localized failure will not occur by bearing on the shackle pin.

Strands undergo physical changes when bent into loops; therefore, care should be exercised with multiple bending. Multiple-strand loops should be bent together in a conduit to facilitate even load distribution.

Locating handling and lifting inserts in finished surfaces should be avoided to minimize patching.

Lifting anchors should be capable of supporting at least four times the maximum load throughout all directions of the lift. The lifting hardware should have a five-to-one safety factor.

### **C3.3 Insulation**

Cellular (rigid) insulations used in the manufacturing of sandwich panels come in two primary forms: thermoplastic and thermosetting. The thermoplastic insulations are known as molded expanded polystyrene (beadboard) and extruded polystyrene

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### **Expanded Polystyrene**

ASTM C578 — Type I, II, VIII, IX, XI

(extruded board). Thermosetting insulations consist of polyurethane, polyisocyanurate, and phenolic.

### **Extruded Polystyrene**

ASTM C578 — Type IV, V, VI, VII, X

### **Polyurethane**

ASTM C591 — Type 1, 2, 3

### **Polyisocyanurate**

ASTM C591 — Type 1, 2, 3

All relevant information on properties of insulating materials used in the production shall be on file at the plant. Any discontinuity or blockouts in the insulation shall be as detailed on the production drawings. Connectors to be used through the insulation shall either be of a proprietary type or specifically designed by the precast engineer. In either case, the location, type, spacing, and required embedment shall be as detailed on the production drawings.

Although there are many insulation types on the market today, sandwich panels generally use a cellular (rigid) insulation due to the material properties needed to perform between two independent layers of concrete. These properties include, but are not limited to, low thermal and vapor transmission characteristics, low moisture absorption, high dimensional stability, low coefficient of expansion, and adequate compressive and flexural strengths.

Because the insulation is generally placed in direct contact with the fresh concrete, excessive dewatering of the fresh concrete may occur with the use of highly absorbent insulation. This could prevent the cement from hydrating properly. The insulating quality of a material will also diminish if it absorbs moisture. For this reason, a material that is not absorbent, or has suitable vapor barriers, should be selected. Some insulating materials such as expanded polystyrene are highly absorbent.

Care shall be exercised when the insulation is exposed to temperatures greater than 140 °F (60 °C). The insulation manufacturer's recommendation shall be known and considered in choosing the insulation.

## **3.4 Welding Electrodes**

## **C3.4 Welding Electrodes**

Electrodes for shielded metal arc welding (SMAW) shall conform to the requirements of AWS D1.1 or AWS D1.4 (AWS A5.1 or A5.5). All welding electrodes shall be of a type suitable for the chemistry of the steel being welded (see Table 3.4.1). Electrodes for welding galvanized steel shall have a silicon content less than 0.3%.

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**Table 3.4.1. Filler metal requirements**

| Base Metal                                             | Electrode Classifications for Welding Process                                   |                                                            |
|--------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------|
|                                                        | Shielded Metal-Arc<br>Low-Hydrogen Electrodes                                   | Flux-Cored Arc                                             |
| ASTM A615/A615M<br>Grade 40 (300)                      | AWS A5.1 or A5.5<br>E70XX*                                                      | AWS A5.20<br>E7XT-X<br>(Except -2, -3, -10, -GS)           |
| ASTM A706/A706M<br>Grade 60 (420)                      | AWS A5.5<br>E80XX-X                                                             | ASW A5.29<br>E8XTX-X                                       |
| ASTM A615/A615M<br>Grade 60 (420)                      | ASW A5.5<br>E90XX-X                                                             | AWS A5.29<br>E9XTX-X                                       |
| ASTM A615/A615M<br>Grade 75 (520)                      | AWS A5.5<br>E100XX-X                                                            | AWS A5.29<br>E10XTX-X                                      |
| ASTM A36/A36M<br>ASTM A500/A500M<br>Grade A<br>Grade B | AWS A5.1 or A5.5<br>E60XX<br>E70XX<br>E70XX-X                                   | AWS A5.20<br>E6XT-X<br>E7XT-X<br>(Except -2, -3, -10, -GS) |
| ASTM A572<br>Grade 42 (290)<br>Grade 50 (350)          | AWS A5.1 or A5.5<br>E7015, E7016<br>E7018, E7028<br>E7015-X, E7016-X<br>E7018-X | AWS A5.20<br>E7XT-X<br>(Except -2, -3, -10, -GS)           |
| ASTM A572<br>Grade 60 (420)<br>Grade 65 (450)          | AWS A5.5<br>E8015-X, E8016-X<br>E8018-X                                         | AWS A5.29<br>E8XTX-X                                       |

\*XX = 15 or 16.

The electrodes and the shielding for flux-cored arc welding (FCAW), for producing weld metal with minimum specified yield strengths of 60 ksi (415 MPa) or less, shall conform to the requirements of AWS A5.20 or AWS A5.29.

Design tensile capacity of lap welds is determined by length and size of welds and filler metal strengths and not by compatibility of base metal tensile strength. However, the chemical composition of the materials should be compatible.

Electrodes for welding reinforcing bar lap splices in contact or lap welds with splice plates or angles are not required to comply with Table 3.4.1. The length and size of such welds shall be as shown on the shop drawings.

Weld metal having a minimum specified yield strength greater than 60 ksi (415 MPa) shall conform to the following requirements:

1. The electrodes and shielding for gas metal arc welding used to produce weld metal with a minimum specified yield strength greater than 60 ksi (415 MPa) shall conform with AWS A5.28.
2. The electrodes and shielding gas for flux-cored arc welding used to produce weld metal with a minimum specified yield strength greater than 60 ksi (415 MPa) shall conform to AWS A5.20 and A5.29.

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3. The plant shall have on file the electrode manufacturer's certification that the electrode will meet the above requirements of classification.

When a gas or gas mixture is used for shielding in gas metal arc or flux-cored arc welding, it shall be of a welding grade having a dew point of -40 °F (-40 °C) or lower. The plant shall have on file the gas manufacturer's certification that the gas or gas mixture will meet the dew point requirement. When mixing at the welding site, suitable meters shall be used for proportioning the gases.

All low-hydrogen electrodes conforming to AWS A5.1/5.1M shall be purchased in hermetically sealed containers or shall be dried for at least 2 hr at a temperature between 500 °F (260 °C) and 800 °F (430 °C) before they are used, if the container is damaged or the seal is broken.

All low-hydrogen electrodes conforming to AWS A5.5/A5.5M shall be purchased in hermetically sealed containers or shall be dried at least one hour at temperatures between 700 °F (370 °C) and 800 °F (430 °C) before being used, if the container is damaged or the seal is broken.

Electrodes shall be dried as specified above prior to use if the hermetically sealed containers are damaged or improperly stored or for any reason the electrodes are exposed to high-moisture conditions. Immediately after removal from hermetically sealed containers or drying ovens, electrodes shall be stored in holding ovens and held at a temperature of 250 °F (120 °C) above ambient temperature.

Electrodes exposed to the atmosphere for periods greater than permitted in D1.1/D1.1M Table 5.1 shall be returned to a holding oven maintained at 250 °F (120 °C) for a minimum period of 4 hr before they are reissued. Electrodes exposed for a greater period shall be baked as noted above after being placed in an oven at a temperature not exceeding one-half of the specified baking temperature for a minimum of 1/2 hr prior to increasing the temperature to

Low-hydrogen and stainless steel shielded metal arc electrode coverings should be protected from moisture pickup. Normally, electrodes packaged in hermetically sealed containers can be stored for several months without deteriorating. However, after the container is opened, the coating begins to absorb moisture. Depending on the ambient air condition, the rods may need to be reconditioned after only 4 hr of exposure; otherwise porosity may result, especially at arc starts.

Only low-hydrogen welding rods (EXX-X5, 6, or 8) should be kept in an oven once removed from their airtight container. Although they must not get wet, the coating of other rods (60-11) will be damaged if heated.

Storage temperatures for E6010 and E6011 (high cellulosic type) electrodes are not critical but temperatures exceeding 125 °F (52 °C) should be avoided since these electrodes depend on a high percentage of moisture (6% to 7%) for favorable arc characteristics; overbaked or dried-out cellulosic electrodes result in low arc force, low penetration, incomplete slag coverage, and porosity.

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the final specified baking temperature. Electrodes shall be dried only once for any reason. Electrodes that have been wet shall not be used.

When joining different grades of steels, the electrode shall be selected for the lower-strength base metal. If the weld joint in a low-carbon, unalloyed steel cannot be completely cleaned of mill scale, rust, paint, moisture, or dirt and when approved by the precast engineer, an E6010 or E6011 electrode shall be used except for steels with yield strengths in excess of 70 ksi (485 MPa).

When welding stainless steel, welding rods that provide weld filler material having corrosion resistance properties as nearly identical to the base material as possible shall be used.

The maximum diameter of electrodes shall be:

1. 5/16 in. (8.0 mm) for all welds made in the flat position, except root passes.
2. 1/4 in. (6.4 mm) for horizontal fillet welds.
3. 1/4 in. for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and with a root opening of 1/4 in. or more.
4. 5/32 in. (4.0 mm) for welds made with low-hydrogen electrodes in the vertical and overhead positions.
5. 3/16 in. (4.8 mm) for root passes of groove welds and for all other welds not included above.

The characteristics of the weld metal are primarily dependent on the alloy content of the filler metal and to a lesser extent on the degree to which the molten weld metal is protected from the environment. This protection is provided by the shielding gases used in certain welding processes or by the action of chemical fluxes applied to welding rods. The greater amount of chromium and nickel in certain alloys, Type 308 for example, is useful for welding Types 302 and 304 base metals and hence is standard for all the lower chromium-nickel base metals. While the same principle applies to Type 316 in that the minimum chromium is higher in the weld metal than the base metal, the designation of the filler metal is the same.

The baking procedure does not apply to the EXX10 and EXX11 classes of electrodes. They will be irreversibly damaged if baked at these temperatures.

Only low-hydrogen welding rods (EXX-X5, 6, or 8) should be kept in an oven once removed from their airtight container. The E6010 and E6011 electrodes are sources of large amounts of hydrogen and in high-strength steels, hydrogen-induced cracks may occur.

All low-hydrogen and stainless steel shielded metal arc electrode coverings should be protected from moisture pickup. Electrodes packaged in hermetically sealed containers can be stored for several months without deteriorating. However, after the container is opened, the coating absorbs moisture and, depending on the ambient air condition, may need to be reconditioned after only 4 hr of exposure.

Welding with “moist” electrodes leads to hydrogen-induced cracking, increased arc voltage, spatter loss, undercutting, and poor slag removal, in addition to porosity, underbead cracking, and general rough welds.

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### **4.1 Mixture Proportioning**

### **C4.1 Mixture Proportioning**

#### **4.1.1 General**

The properties of concrete mixtures and the color and texture of the unit shall be as required for the project.

#### **C4.1.1 General**

There are three categories of concrete based on consistency: conventional, flowable, and self-consolidating (SCC).

Much of the skill, knowledge, and technique of producing quality precast concrete depend on proper proportioning of the concrete mixture. Before a concrete mixture can be properly proportioned, several factors must be known. The finish, size, and shapes of units to be cast should be considered. The method of consolidation should be known to help determine the required workability of the mixture. The consistency requirements for proper placement of concrete in the elements being cast should be known to determine the required fresh concrete properties. The maximum size of the coarse aggregate should be established. The required compressive strength affects the amount of cement to be used as well as the maximum water allowed. The required surface finish will frequently control the ratio of coarse to fine aggregate. The extent of exposure to severe weather or other harsh environments will affect the durability requirements of the concrete mixture design.

Concrete mixtures are usually divided into two groups: face and backup. Face mixtures are usually composed of special decorative aggregates, and are frequently made with white cement and pigments, where exposed-aggregate surface finishes are desired. Backup mixtures are usually composed of more-economical local aggregates with gray cement and are used to reduce material costs in large units with face mixtures. Backup concrete mixtures are also used where exposed aggregate or other special finishes are not required, and where the size and distribution of aggregate are not critical. Depending on the setback of windows or in precast concrete units of complicated shapes and deep narrow sections, the face mixture may be used throughout the member if procedures for separating the face and backup mixtures become too cumbersome.

Since the introduction of SCC into precast plants, many producers are choosing to use flowable concrete mixtures that have many of the properties of SCC but are not fully self-consolidating. Slump flow of these mixtures may vary from 18 in. to 24 in. and bridge the consistency gap between conventional and SCC

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### 4.1.2 Qualification of Concrete Mixtures

Concrete mixtures for precast concrete shall be established initially by laboratory methods. The proportioning of mixtures shall be done either by a qualified commercial laboratory or qualified precast concrete technologist. Mixtures shall be evaluated by trial batches prepared in accordance with ASTM C192/C192M and production tests under conditions that simulate as closely as possible actual production and finishing. Tests shall be made on all mixtures to be used in production of units. When accelerated curing is to be used, it is necessary to base the mixture proportions on similarly cured test specimens.

Concrete mixtures shall comply with the requirements for the applicable exposure class assigned from Chapter 4 of ACI 318.

Each SCC mixture shall be evaluated to ensure its ability to tolerate the water dosage variation consistent with the ability of the plant equipment to control total mixture water without showing excessive bleeding or segregation.

Each concrete mixture used shall be developed using the brand and type of cement, the source and gradation of aggregates, and the brand of admixture proposed for use in the production mixtures. If these variables are changed, the proportions of the mixture shall be re-evaluated.

Concrete mixtures shall be proportioned and/or evaluated for each individual project to satisfy

mixtures. These flowable mixtures are chosen because they typically can be placed and consolidated with some mechanical vibration with a wider slump flow range than SCC. Flowable concrete with a wider acceptable slump flow range may be preferable when mixture water control is difficult due to variations in aggregate free surface moisture.

### C4.1.2 Qualification of Concrete Mixtures

Accepted methods of selecting mixture proportions are described in detail in the following publications:

1. Portland Cement Association:
  - a. *Design and Control of Concrete Mixtures* (EB001).
2. American Concrete Institute:
  - a. *Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete* (ACI 211.1).
  - b. *Standard Practice for Selecting Proportions for Structural Lightweight Concrete* (ACI 211.2).
  - c. *Standard Practice for Selecting Proportions for No Slump Concrete* (ACI 211.3R).
  - d. *Specifications for Structural Concrete* (ACI 301).
  - e. *Building Code Requirements for Structural Concrete and Commentary* (ACI 318)
3. PCI:
  - a. *Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants* (TR-6-03).

Experienced admixture suppliers can be of assistance when it comes to SCC mixture design.

An architectural precast concrete mixture has demanding criteria, as appearance will be a governing

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project requirements and service conditions such as strength, absorption, volume change, and resistance to freezing and thawing, as well as desired surface finish (color and texture uniformity). The mixture shall have adequate workability for proper placement and consolidation.

The three levels of tests that shall be considered when qualifying a concrete mixture are as follows:

1. Laboratory testing
2. Production trials
3. Quality control testing

The fresh performance of all SCC mixtures shall be designed to exhibit filling ability, stability, and passing ability.

In addition to conventional concrete testing for qualification, SCC qualification shall include:

1. Slump Flow/T-50 (ASTM C1611/C1611M)
2. Visual Stability Index (VSI) (ASTM C1611/C1611M)
3. J-Ring Test (ASTM C1621/C1621M)
4. Column Segregation Test (ASTM C1610/C1610M)
5. Static Segregation Resistance Test (ASTM C1712)

criterion in addition to strength and durability. Mixture design factors that influence appearance are selection and proportioning of fine and coarse aggregate, color of cement, and use of pigments. Often several aggregates must be blended and the properties of the mixture considered in proportioning the mixture. Typically a larger portion of the mixture will be coarse aggregate, which affects consistency, finishability, and strength. Careful selection of aggregate sizes and gradation, colors, and mixture proportions is necessary to ensure that the desired aesthetics of the matrix or the exposed surface texture are achieved. Such considerations can vary significantly with respect to proportioning for strength and durability. Accordingly, the use of samples for assessing aesthetic characteristics becomes a necessary step in the mixture design process.

SCC requires a greater awareness of quality control, aggregate gradation variation, mixture water control, and the use of highly advanced HRWRAs and/or viscosity modifiers. Wait times between consecutive loads should be minimized.

Laboratory testing of the mixture should be used to determine the initial mixture characteristics and confirm the hardened properties of the basic mixture design.

Qualification testing is necessary to qualify the mixture in the production environment. This includes qualification of the batching, mixing, transporting, placing, finishing, and curing processes.

Quality control of the fresh concrete properties and confirmation testing of the hardened concrete properties is also necessary.

The required filling ability (fluidity) is obtained by carefully managing the mixture design, dosage of water, and dosage of superplasticizers. Filling ability can be measured by the slump flow/T-50.

Examine the slump flow at which the mixture becomes unstable, taking into consideration the fact that some HRWRAs will lose slump flow more rapidly than others. Batch a mixture and measure slump flow and determine the Visual Stability Index (VSI) rating, add successive amounts of HRWRA measuring slump flow, and VSI at each addition.

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Once a suitable mixture has been developed, the level of fluidity (slump flow variation window) at which the mixture becomes unstable shall be determined, because the level of fluidity has a direct impact on the stability of an SCC mixture. The water sensitivity (fluctuations in raw material moisture contents and thus total mixture water content) of the production SCC shall be determined.

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Record at what level of slump flow the mixture becomes unstable. Use this information to aid in controlling stability during daily production.

Once a mixture has been developed, determine the sensitivity to water fluctuations by batching a mixture and adding successive amounts of water to the batch. At each of these additions, measure the slump flow and VSI. The mixture stability—static as well as dynamic—should also be demonstrated for mixtures within the fluidity window. The viscosity, as well as the yield stress of the SCC, plays a major role in its overall stability.

SCC mixtures are high-performance concrete mixtures; therefore, they are more sensitive to constituent material consistency and quantity fluctuations during production. Fluctuations in raw materials, such as gradations and moisture contents, can have dramatic influence on the stability of the SCC mixtures. Batching fluctuations can also significantly affect both stability and fluidity. Because of the potential variation in stability and the resulting potential for segregation, consideration should be given to methods to confirm uniformity distribution of coarse aggregate and the reduction of voids in the finished product.

Mixture design parameters of SCC include water-cementitious ratio, percent air entrained, mineral addition replacement, dosage of HRWRA and VMA, aggregate ratios, 28-day strengths, and other requirements that relate to special applications.

In the event that satisfactory production performance of SCC cannot be obtained with laboratory trial mixtures, then consideration should be given to fundamental redesign of the mixture. Depending on the apparent problems, the following courses of action may be appropriate:

- a. The use of additional or different types of filler.
- b. Modification of the proportions or gradation of sand or the coarse aggregate.
- c. The use of a viscosity-modifying agent, if not already included in the mixture.
- d. Adjustment of the dosage of the superplasticizer (and/or viscosity-modifying agent).
- e. The use of alternative types of superplasticizer (and/or viscosity-modifying agent), which may be more compatible with local materials.
- f. Revision of dosage rates of admixtures to modify

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The qualification of SCC mixtures shall include the type of mixing equipment, material, batching sequence, mixing cycle time, transportation and handling techniques, placement methods and conditions, and horizontal placement and free fall distances.

the water/powder ratio.

Plant conditions (temperature and humidity variations, moisture variations in aggregates as a result of weather, etc.) may have a significant effect on SCC mixtures that requires adjustment to the mixture.

Typical adjustments should be qualified in advance because mixture adjustments to SCC mixtures may be more complex than similar adjustments to normal high-performance concrete.

There are seven basic member characteristics that should be considered in the determination of SCC mixture parameter requirements:

1. Coarse aggregate content
2. Reinforcement amount and spacing
3. Element depth
4. Element length
5. Element thickness
6. Element shape intricacy
7. Surface finish

The initial step in this process is to rank the level of difficulty associated with each member characteristic as low, medium, or high.

The next step in the process is to identify the controlling parameters associated with the element-specific ratings made for each of the seven element characteristics.

### **Production mixing qualification for SCC**

An important qualification procedure for SCC mixtures is to run trial batches from production mixers and adjust the mixture as necessary to attain desired properties.

To appropriately determine the value SCC brings to the project, performance should be optimized with respect to the application.

It is strongly recommended to rely on a qualified concrete technologist experienced in SCC mixture design to establish the mixture design with respect to the specifications and concrete placing conditions. Experienced admixture suppliers can also be of great help when it comes to developing SCC mixture designs.

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### **Fresh Performance of SCC**

In conventional high-performance concrete, the consolidation process (localized vibration) can be adjusted in intensity to compensate for most variations of the fresh concrete properties. With the elimination of the consolidation operations, the properties of fresh SCC (viscosity, yield stress, and thixotropy) need to be adequately optimized and remain consistent during the concrete placement process. An experienced SCC technologist can be helpful in successfully optimizing a mixture for a given application.

#### **a. Qualifying mixing equipment capability**

Rated mixing times for normal concrete may vary with SCC mixtures and thus must be confirmed with actual trial mixtures in the production mixers that will be used in the plant.

#### **b. Qualifying material batching sequence**

For each SCC mixture, an acceptable sequence that produces SCC of the desired fresh properties shall be developed. Once established, this should be employed for all SCC batches.

#### **c. Qualifying mix cycle time**

For each SCC mixture, an acceptable mixing time, sequence, and duration to produce SCC of the desired fresh properties should be developed. Once established, this mix cycle time should be employed for all SCC batches.

The placement qualification of SCC mixtures should include transportation and handling techniques, placement methods and conditions, and horizontal placement and free fall distances.

#### **a. Transportation/handling techniques**

Any method of transportation used should be qualified as not resulting in unacceptable segregation of the SCC.

The transport method should be confirmed as providing SCC at the point of placement that is sufficiently homogeneous to allow

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successful placement in the precast elements involved. This determination should be based on the SCC qualification tests.

### **b. Placement methods/conditions**

Placement methods for substantially different elements should be qualified as producing acceptable elements.

Appropriate placement guidelines to minimize the possibility of segregation should be determined.

The transportation and placement procedure should be observed for all placements of SCC for each particular element type.

Procedures should be used to ensure avoidance of segregation, cold joints, and seams.

If concrete pumping is used to transport the SCC, the ability to successfully move the mixture through the hoses or pipes must be qualified for use in production.

### **c. Distance of flow from point of placement**

SCC placement methods should be qualified at the placement distance representative of the production placement situation.

### **d. Free-fall distance**

Determination of maximum free-falling distances through reinforcement should be qualified through the use of production mock-ups or by other means to ensure acceptable uniformity in the production element. It is the task of the producer to select the appropriate test methods for qualification of the SCC mixtures.

While the properties of fresh SCC differ significantly from those of conventional fresh concrete, the quality in terms of strength, durability, and performance of the hardened SCC should be equal to or better than that of a similar specified conventional concrete mixture.

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### **Qualification of placement methods of SCC**

This method helps to quantify the ease-of-placement level provided by the concrete. T-50 is the method that measures the time for the spread to reach a diameter of 50 cm (19.68 in.), providing an indication of the relative viscosity of the mixture. Note: in the United States, the T-20 time is frequently used. This is the time for the spread to reach a diameter of 20 in. (50 cm).

The Abrams cone may either be upright or inverted for this test. The smoothness and duration time of the cone lifting should conform to ASTM C143/C143M for consistency.

A combination of the slump flow and T-50 time can provide a clear indication of relative SCC viscosity.

VSI ratings of 2 or 3 should lead to some action in the adjustment of the SCC mixture. The production qualification testing should define rejection limits for SCC batches. The results of the VSI test should form a part of the definition of rejection limits.

Considerable experience and careful judgment are needed to accurately and reliably rate production of SCC mixtures using VSI ratings. It is used in combination with the slump flow and T-50 tests.

SCC can be produced with various performance levels. The two main production issues that will affect the SCC properties are the characteristics of the element being cast and the placement techniques.

It should be noted that experience and judgment regarding SCC mixture development are of value in assessing these characteristics and using them appropriately to guide mixture design modifications.

There may be significant differences in the fresh performance of SCC mixed in small lab mixers as part of the mixture design process and the same mixture produced in a production mixer in the precast plant.

While most mixers in use in production can successfully mix SCC, some mixer types handle SCC more efficiently than others.

Batching sequence for SCC mixtures may be more important than for non-SCC mixtures. This is especially true of the batching sequence of

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admixtures, powders, and water.

Elements of the cycle time (time mixed for different elements of the batching cycle) may have a significant effect on SCC properties.

Some SCC mixture properties may vary substantially with variation in mixing time. Thus, once a successful mixing time is determined, all batches should be similarly mixed.

SCC should be transported to the point of placement in a continuous and timely manner. Placing may be faster, especially if a pump is used, but it is still essential to ensure that delivery and placement can be completed within the workability-retention time of the concrete.

Mixer trucks have proven to be the best method of delivery of mixed SCC when transporting over rough yard terrain or long distances. Any method of transport can be employed as long as segregation (as determined by the VSI test) is kept to acceptable levels.

Some SCC has a thixotropic nature. This tendency to gel when the material has been at rest for a short period must be considered in the transportation and handling techniques used for the material.

More-efficient placement is one of the important advantages of SCC. Different types of precast elements may require differing approaches to placement.

Placement of SCC, while requiring less manpower on the form/mold, may require advance planning to ensure acceptable finishes without seam lines or visible flow lines on the surface of the element.

Unexpected production stops can result in consistency variations that adversely affect the end result. Although SCC normally bonds well with previously placed concrete, the likelihood of damage resulting from a cold joint may not be able to be mitigated by vibration, as with normal concrete.

The producer should ensure that SCC placement methods are adequate. Placement methods may need to be varied for different types of elements.

Concrete pumping is a very efficient and reliable

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As with normal high-performance concrete, capacities for strand lifting loop configurations used for lifting products fabricated from SCC shall be qualified by testing. See Section 3.2.4 for more information.

When required by specification, the modulus of elasticity of SCC shall be determined in accordance with ASTM C469.

When required by specification, shrinkage of SCC shall be determined in accordance with ASTM C157/C157M.

### **4.1.3 Specified Concrete Strength**

Concrete strengths shall be determined on the basis of test specimens either at time of stripping, at transfer of prestress, or at a specified age—usually 28 days, although other ages may be specified. A minimum acceptable strength at time

method of placing SCC concrete, due to its ability to be placed without vibration and its ability to flow. An SCC mixture design with higher fine content makes it an ideal choice for pumping.

Selecting deposition locations and determining the optimal length of flow are two of the parameters to be determined from test placements. If pumped, the length of the pumping line is a variable that could affect the flow characteristics of the material.

The detailed nature of the element being produced will determine the acceptable lateral flow distance from the charging point. Thus, this is something that should be investigated through the use of production mock-ups or by other means to ensure acceptable uniformity in the production element.

In some instances, precast elements of significant size and length can be placed from one concrete deposition point with SCC.

Some SCC can be allowed to free fall a greater distance than normal concrete. Free falling through reinforcement in a form/mold, however, is a very severe test that may tend to cause segregation.

Properly designed and qualified SCC mixtures can in some instances free fall in excess of 10 ft (3 m) without segregation.

In some instances, the modulus of elasticity of SCC may be lower than that for normal high-performance concrete.

Because some SCC mixtures may have a higher potential for shrinkage than normal concrete, increased attention may be required to ensure that specified shrinkage limits are attained.

### **C4.1.3 Specified Concrete Strength**

A minimum design strength for concrete should be determined by the architect/engineer based on in-service requirements. Consideration for production and erection are the responsibility of the precaster. The mixture is generally proportioned for appearance,

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of stripping shall be established by the precast engineer and shall be stated on the drawings. When members are prestressed, the concrete shall have a specified compressive strength suitable for transfer of the prestress force. The 28-day strength shall be as required by the specifications, unless otherwise specified by the precast engineer.

### **4.1.4 Statistical Concrete Strength Considerations**

For commonly used concrete mixtures such as backup mixtures, or for face mixtures where the size of the project warrants, a plant shall maintain up-to-date documentation of the compressive strength variability. Based on this information, a design strength shall be chosen for the concrete that will comply with the statistical interpretation of the strength requirements given in ACI 318.

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with strength considered secondarily. Except for load-bearing units, stresses on units are usually higher during fabrication and erection than those anticipated in the structural design for in-service conditions. Production requirements for early stripping of units or early prestress transfer and subsequent rapid reuse of forms/molds require high early compressive strength. The minimum transportation and erection strength levels are dependent on the shape of the unit; handling, shipping, and erection techniques; and the delivery schedule. These factors often require such high early strength that the resulting 28-day strengths far exceed the specified design strengths.

In cases where the typical 28-day strength of 5,000 psi (34.5 MPa) is not structurally necessary and is difficult to attain due to the use of special cements or aggregates, sufficient durability and weathering qualities may be obtained by ensuring proper air entrainment and minimizing absorption limits at a strength level as low as 4,000 psi (27.6 MPa).

### **C4.1.4 Statistical Concrete Strength Considerations**

Concrete strength test evaluation should follow methods outlined in ACI 214R.

Strength tests failing to meet these criteria may occur occasionally (probably about once in 100 tests), even though strength level and uniformity are satisfactory. Allowance should be made for such statistically normal deviations in deciding whether or not the strength level being produced is adequate.

Mixture designs and concrete proportions may be selected on the basis of established records for the concrete production facility if the concrete is made from the same sources of cement, aggregates, and admixtures. The better the control, as measured by the coefficient of variation or standard deviation, the more economical the selected mixture may become. Under the best control, there still are many variables that can influence concrete strength, such as variations in ingredients, batching, and testing. Concrete for which all specimens can be expected to show strengths above the specified minimum strength is generally impractical, and evaluation of strength tests should recognize this fact.

Concrete for background tests to determine standard deviation is considered to have been similar to that

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The strength level of the concrete shall be considered satisfactory if the average of each set of any three consecutive strength tests equals or exceeds the specified strength and no individual test falls below the specified strength by more than 500 psi (3.5 MPa) or more than 10% of the specified strength when specified strength is more than 5,000 psi (35 MPa).

required if the mixtures were made with the same general types of ingredients under no more restrictive conditions of control over material quality and production methods than will exist on the proposed work, and if its specified strength did not deviate more than 1,000 psi (6.9 MPa) from the required strength. A change in the type of cement or a major increase in the required strength level may increase the standard deviation.

Adequate statistical records are based on at least 30 consecutive strength tests obtained within the past year representing similar materials and conditions to those expected. The 30 consecutive strength tests may represent either a group of 30 consecutive batches of the same class of concrete or the statistical average for two groups totaling 30 or more batches.

Average strengths, used as the basis for selecting proportions, should exceed the specified strength by at least:

400 psi (2.76 MPa) if the standard deviation is less than 300 psi (2.07 MPa).

550 psi (3.79 MPa) if the standard deviation is 300 psi to 400 psi.

700 psi (4.82 MPa) if the standard deviation is 400 psi to 500 psi (2.76 MPa to 3.45 MPa).

900 psi (6.20 MPa) if the standard deviation is 500 psi to 600 psi (3.45 MPa to 4.14 MPa).

These values are based on ACI 318 equations for required compressive strength  $f'_{cr}$ . ACI 318 requires that mixtures be proportioned for  $f'_{cr}$  as defined by the larger of the two equations in Table C4.1.4.

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**Table C4.1.4. Specified and required compressive strength**

| Specified compressive strength $f'_c$ , psi | Required average compressive strength $f'_{cr}$ , psi                                            |
|---------------------------------------------|--------------------------------------------------------------------------------------------------|
| $f'_c \leq 5,000$                           | Use the larger value computed:<br>$f'_{cr} = f'_c + 1.34s_s$<br>$f'_{cr} = f'_c + 2.33s_s - 500$ |
| $f'_c > 5,000$                              | Use the larger value computed:<br>$f'_{cr} = f'_c + 1.34s_s$<br>$f'_{cr} = 0.90f'_c + 2.33s_s$   |

Where:

$f'_c$  = specified compressive strength (psi)

$s_s$  = standard deviation (psi)

If the standard deviation exceeds 600 psi (4.14 MPa) or if a suitable record of strength test performance is not available, mixture proportions should be selected to produce an average strength of 1,200 psi (8.27 MPa) greater than the specified strength for required strengths of 5,000 psi (34.5 MPa) and below, and 1,400 psi (9.66 MPa) for required strengths above 5,000 psi (34.5 MPa).

### 4.1.5 Proportioning to Ensure Durability of Concrete

Concrete strength and durability shall be achieved through proper consideration in the mixture design of air, water and cement contents, and workability. Low water-cementitious ratios shall be used to provide specified strength, durability, and low absorption. Drying shrinkage characteristics shall be controlled by aggregate size, gradation, mineralogy, aggregate-cement ratio, cement factor, paste content, water-cementitious ratio, additives, and admixtures.

Combinations of cement and aggregates shall be selected on the basis of known compatibility determined through performance history or testing. Incompatible combinations that will result in unacceptable volume changes, cracking, or deterioration, such as the use of high-alkali cement with alkali-reactive aggregates, are prohibited.

These precautions are particularly necessary in

### C4.1.5 Proportioning to Ensure Durability of Concrete

Selection of fine and coarse aggregate affects both density and appearance. The high quality of the aggregate does not necessarily by itself ensure a good mixture design, but it does relate to quality of concrete as evidenced by its durability. If the aggregate material is not durable, deterioration can be expected in areas where the concrete is in contact with corrosive atmospheres, salts, excessive moisture, and/or severe temperature changes.

Achieving low absorption rates for the surface of the concrete demands a high density of the concrete surface.

Aggregates subject to pop-outs, rusting, staining, or other surface deterioration should be avoided.

Shrinkage, as well as creep, will tend to increase as the paste content increases. To limit shrinkage and creep, it is important to avoid an excess of paste. Because the paste content plays a major role in

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areas subject to freezing and thawing or in locations where salt or sulfate exposures are expected.

### 4.1.6 Special Considerations for Air Entrainment

Units subject to freezing and thawing shall be air entrained. For gap-graded facing mixtures, where a given percentage of air cannot be reliably measured, the dosage of air-entraining agent shall produce an 8% to 10% air content when tested in accordance with ASTM C185 but using only the mortar (material passing the No. 4 [4.75 mm] sieve) portion of the mixture or provide 19%  $\pm$  3% of entrained air in the paste when tested according to ASTM C185. Once established for the mixture, the corresponding entrained air content of the total concrete mixture can be determined, and that value shall be used in production control.

When a specific level of air content is to be maintained in concrete units exposed to freeze-thaw, deicer, and wet-dry conditions, air content at the point of delivery shall conform to the requirements of Table 4.1.6. For specified compressive strength greater than 5,000 psi (34.5 MPa), a reduction of air content by 1.0% as indicated in Table 4.1.6 shall be permitted.

**Table 4.1.6 Total air content for various sizes of coarse aggregate for normal weight concrete**

| Nominal maximum size of aggregate, in. (mm) | Total air content percent, by volume <sup>1</sup> |                   |
|---------------------------------------------|---------------------------------------------------|-------------------|
|                                             | Severe exposure                                   | Moderate exposure |
| Less than 3/8 (9)                           | 9                                                 | 7                 |
| 3/8 (9)                                     | 7-1/2                                             | 6                 |
| 1/2 (13)                                    | 7                                                 | 5-1/2             |
| 3/4 (19)                                    | 6                                                 | 5                 |
| 1 (25)                                      | 6                                                 | 4-1/2             |
| 1-1/2 (38)                                  | 5-1/2                                             | 4-1/2             |

1. Air content tolerance is  $\pm$ 1-1/2%.

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achieving the fresh concrete performance, SCC mixture designs must balance fresh concrete properties with specification requirements for shrinkage and creep limits.

### 4.1.6 Special Considerations for Air Entrainment

Air-entrained concrete should be able to withstand the effects of freezing as soon as it attains a compressive strength of about 500 psi (3.45 MPa), provided there is no external source of moisture. Because of the gradation characteristics of most gap-graded facing mixture concrete or for mixtures with high cement contents and low slumps, a given percentage of air may not be reliably measured for many mixtures.

Increased air entrainment can result in increased slump and potentially reduced strength, if all other parameters remain constant.

Air is entrained in the mortar fraction of the concrete; in properly proportioned mixtures, the mortar content decreases as maximum aggregate size increases, thus decreasing the required concrete air content for both workability and durability.

Typical plant control practice only involves measurement of air volume in freshly mixed concrete. Although measurement of air volume alone does not permit full evaluation of the important characteristics of the air-void system, air entrainment is generally considered effective for freeze-thaw resistance when the volume of air in the mortar fraction of the concrete (material passing the No. 4 sieve) is about 9%  $\pm$  1%.

In SCC mixtures that involve a higher paste content than that used in normal high-performance concrete, higher air content than typical for normal high-performance concrete may be required to achieve the same air distribution in the paste.

For a given water-cementitious ratio, the addition of air entrainment may result in a reduction in concrete strength. This reduction can be partly overcome if the air entrainment improves the workability of the mixture sufficiently to facilitate a reduction in the water content.

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The properties of the concrete-making materials, the proportioning of the concrete mixture, and all aspects of mixing, handling, and placing shall be maintained as constant as possible to help ensure that the air content will be uniform and within the range specified for the work.

### **4.1.7 Compatibility of Face and Backup Mixtures**

To ensure compatibility between face and backup mixtures, the following characteristics of each mixture shall be investigated for their consequences on the unit design: (1) relative shrinkage characteristics, (2) relative thermal coefficients of expansion, and (3) relative modulus of elasticity.

Special attention shall be given to mixture compatibility when normal-weight face mixtures are combined with lightweight backup mixtures.

### **4.1.8 Proportioning for Appearance of Concrete Surface**

The face mixture for architectural concrete units shall be designed to produce the desired appearance, taking into account the technique for obtaining the surface finish.

## **Commentary**

The production of high-strength concrete (6,000 psi [41 MPa] or greater) may be adversely affected by air entrainment due to a potential loss of strength. Unless the environmental exposure is severe, it may be more appropriate, easier, and more economical to achieve the high strength requirements without air entrainment.

### **4.1.7 Compatibility of Face and Backup Mixtures**

Face and backup mixtures should have water-cementitious and cement-aggregate ratios within 10% of each other and should be proportioned to minimize variations in shrinkage, thermal coefficient of expansion, and modulus of elasticity such that finished products meet the tolerance requirements for bowing and warping. To minimize the potential for compatibility concerns, such mixtures should have similar water-cementitious and cement-aggregate ratios.

The combination of a normalweight face mixture and a backup with lightweight aggregates may increase the possibility of bowing or warping. Before using such a combination, sample units produced, cured, and stored under anticipated production conditions should be made to verify satisfactory performance.

### **C4.1.8 Proportioning for Appearance of Concrete Surface**

The type of finish is the key factor for determining the necessary quantity of coarse aggregate for use in the concrete face mixture. The material requirements will vary with the depth and amount of surface removed. The shallower the reveal, the more visual influence the aggregate fines and cement will have; and the deeper the reveal, the more visual influence the coarse aggregate will have.

Proportioning of fine and coarse aggregate is of importance to workability of the mixture and, thus, to final appearance. When producing an exposed-aggregate finish, high volumes of coarse aggregate may be required to achieve the desired visual effect. Coarse aggregate content is one of the main issues controlling passing ability; this must be taken into consideration when proportioning the SCC mixture. The type of coarse aggregate (crushed or round) and aspect ratio of the coarse aggregate particles are also mixture design considerations.

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### **4.1.9 Mixture Proportioning for Concrete Made with Structural Lightweight Aggregate**

Lightweight concrete proportions shall be selected to meet the specified limit on maximum air-dry unit weight as measured in accordance with ASTM C567.

1. Special attention is required in the mixture design optimization process to keep the lightweight aggregate SCC from segregating.
2. Because there is no standardized method to evaluate the dynamic and static segregation resistance of lightweight aggregate SCC, a careful visual inspection shall be executed in the first production tests, as well as on a regular basis throughout normal production.

#### **4.1.9.1 Lightweight Aggregates – Absorption and Moisture Content**

Lightweight aggregates shall be dampened prior to batching, and the absorbed water shall be accounted for in the mixture-proportioning procedure. The supplier of the particular aggregate shall be consulted regarding the

In general, where appearance and color uniformity are of prime importance, mixtures may have considerably higher cement content than required for achieving the specified strength. If the cement is the main contributor to the color of concrete, the color will become more intense or darker with increased cement content or decreased water-cementitious ratio.

With SCC, improved surface appearance is generally obtained with higher levels of fluidity with controlled viscosity.

### **4.1.9 Mixture Proportioning for Concrete Made with Structural Lightweight Aggregate**

Mixture proportioning methods for structural lightweight aggregate concrete (ACI 211.2) generally differ somewhat from those for normalweight concrete. The principal properties that require modification of proportioning and control procedures are the greater total water absorption and rate of absorption of lightweight aggregates, plus their low weight. The absorption of water by the aggregate has little effect on compressive strength, provided that enough water is supplied to saturate the aggregate. The moisture content of the aggregate should be known and adjustments should be made from batch to batch to provide constant cement and air contents, similar slumps or flow spreads, and a constant volume of aggregates.

1. In any SCC made with lightweight aggregates, the tendency for the lightweight aggregates to segregate will increase as the size of the lightweight aggregate increases.
2. Should segregation occur, the lightweight aggregates will migrate to the upper portion of the concrete mass. This will lead to varying unit weights across the concrete section and strength heterogeneity in the concrete element.

#### **C4.1.9.1 Lightweight Aggregates – Absorption and Moisture Content**

When concrete is made with lightweight aggregates that have low initial moisture contents (usually less than 8% to 10%) and relatively high rates of absorption, it may be desirable to mix the aggregates with one-half to two-thirds of the mixing water for a

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necessity for predampening and mixing requirement.

When producing trial batches in the laboratory using the specific-gravity method to address lightweight aggregate moisture content, the specific gravity of the lightweight aggregate shall be determined at the moisture content anticipated prior to use.

### **4.1.9.2 Lightweight Aggregates – Gradation**

Differences in the bulk specific gravity of the lightweight aggregate fractions retained on the different sieve sizes shall be taken into account in the mixture proportioning for lightweight aggregate concrete.

### **4.1.9.3 Water-Cementitious Material Ratio for Lightweight Aggregate Concrete**

Lightweight aggregate concrete shall be proportioned by the weight method (ACI 211.2) on the basis of an approximate water-cementitious relationship when the absorption of the lightweight aggregate is known or to be determined.

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short period prior to the addition of cement and air-entraining admixture to minimize slump or slump flow spread loss.

### **C4.1.9.2 Lightweight Aggregates – Gradation**

For normalweight aggregates, the bulk specific gravity of fractions retained on the different sieve sizes is nearly equal. Percentages retained on each size in terms of weight give a true indication of percentages by volume. However, the bulk specific gravity of the various size fractions of lightweight aggregate usually increases as the particle size decreases. This is due to the tendency of some coarse aggregate particles that may float on water, whereas the No. 100 sieve (0.15 mm) material typically has a specific gravity similar to that of normalweight sand. Accordingly, it is the volume occupied, not the weight of the material retained on each sieve, that should be used in determining the percentage of voids and paste content.

Therefore, lightweight aggregates require a larger percentage of material by weight retained on the finer sieve sizes than do normalweight aggregates to provide an equal aggregate size distribution by volume.

### **C4.1.9.3 Water-Cementitious Material Ratio for Lightweight Aggregate Concrete**

If trial mixtures are proportioned by procedures other than the weight method, the net water-cementitious ratio of most lightweight concrete mixtures cannot be established with sufficient accuracy for use as a basis of mixture proportioning. This is due to the difficulty of determining how much of the total water is absorbed in the aggregate and consequently unavailable for hydration of the cement.

When the weight method is not employed, lightweight aggregate concrete mixtures are usually established by trial mixtures proportioned on a cement and air content basis at the required consistency.

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### **4.1.9.4 Air Entrainment for Lightweight Aggregate Concrete**

The volumetric method of measuring air entrainment, as described in ASTM C173/C173M, shall be used to determine air content in lightweight aggregate concrete mixtures.

### **4.1.10 Proportioning for Concrete Workability**

The slump or slump flow and workability of a mixture shall be suitable for the conditions of each individual job—that is, to permit the concrete to be worked readily into the forms/molds and around reinforcement under the conditions of placement to be used, without excessive segregation or bleeding.

In color-sensitive units, the slump shall be as low as possible and consistent between batches to

### **C4.1.9.4 Air Entrainment for Lightweight Aggregate Concrete**

Air entrainment of at least 4% has beneficial effects on the workability of lightweight aggregate concrete. Entrained air also lowers the unit weight of the concrete.

The amount of entrained air recommended for lightweight aggregate concrete that is exposed to freezing and thawing or deicer salts is 4% to 6% when the maximum aggregate size is 3/4 in. (19 mm) and 4.5% to 7.5% when the maximum aggregate size is 3/8 in. (9.5 mm).

The strength of lightweight concrete may be reduced by high air contents. At normal air contents (4% to 6%), the reduction in strength is small if slumps are 5 in. (127 mm) or less and cement contents are as recommended in ACI 211.2, *Standard Practice for Selecting Proportions for Structural Lightweight Concrete*.

### **4.1.10 Proportioning for Concrete Workability**

It is difficult and unnecessary to establish limits for slump for typical precast concrete production. Very stiff mixtures require more labor to place and special vibration techniques.

Required workability is related to the shape of the precast concrete unit and the method of consolidation. Methods of consolidation using mechanical equipment require fewer fines for workability. The lower the percentages of fines, the lower the specific surface area of the aggregates and the lower the water and cement requirements of the mixture, which leads to a higher quality potential of the concrete. However, mixtures with very low fine content may bleed excessively and require a high water content for workability.

Workability under the influence of a properly selected vibrator, not slump, is the important consideration. Workability of freshly mixed concrete is the property that determines the ease and homogeneity with which it can be mixed, placed, compacted, and finished.

Slump is a measure of concrete consistency. However, it is not by itself a measure of workability. Other

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ensure uniformity of color in the end product. Slump tolerances of  $\pm 1$  in. ( $\pm 25$  mm) prior to the addition of high-range water reducer shall be maintained for mixture consistency and color control.

When superplasticized concrete or SCC falls below the specified slump or slump flow due to a delay, it shall be retempered with superplasticizing admixtures rather than additional water.

### **4.1.11 Water-Cementitious Ratio**

#### **4.1.11.1 General**

The water-cementitious ratio (w/cm) shall not exceed 0.45 by weight with an allowable variation during production of  $\pm 0.02$ . The allowable variation (tolerance) of the w/cm shall be determined during the SCC qualification testing. In all mixture designs for precast concrete production, the importance of a low w/cm shall be recognized, but this ratio shall also be evaluated in relation to the workability required for satisfactory placing and consolidation techniques for the actual mixture application. Water shall be limited to the minimum needed for proper placing

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considerations, such as cohesiveness, harshness, segregation, bleeding, ease of consolidation, and finish ability, are also important and these properties are not entirely measured by slump.

The consistency of concrete as measured by the slump test is an indicator of the relative water content of the same concrete mixture. Additional water increases the water-cementitious ratio and has the undesirable effect of reducing the cohesion within the mixture and increasing the potential for segregation and excessive bleeding.

Excessive water will affect strength, shrinkage, density, absorption, and uniformity of color.

Concrete slumps in color-sensitive architectural panels should not exceed 3 in. (75 mm) in most instances prior to the addition of high-range water reducer. Exceptions to this are gap-graded mixtures, which generally should not have slumps greater than 2 in. (50 mm).

Retempering with water increases the water-cementitious ratio and has the undesirable effect of lightening the concrete color, reducing strength, increasing shrinkage, reducing the cohesion within the mixture, and increasing the potential for segregation and excessive bleeding.

Because of the high fluidity of SCC, retempering should only be done in production situations after test evaluation of the consequences of retempering on both the mixture stability in the fresh state and the effects on the hardened concrete properties.

### **C4.1.11 Water-Cementitious Ratio**

#### **C4.1.11.1 General**

With given materials, the optimum mixture proportions use the least amount of total water per unit volume of concrete to obtain the required slump and workability. The w/cm for SCC mixtures is generally more stringent than that of conventional concrete mixtures. With respect to a fixed w/cm, material costs are reduced by using mixtures having the least paste. The cement in the paste is typically the most costly ingredient of the concrete; therefore, using more paste than required adds unnecessarily to the cost of the concrete. However, when using extremely high-priced aggregates, the cost of paste should be balanced

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and consolidation by means of vibration. Low w/cm shall be accompanied by controls on total water content.

The water portion, in which solution admixtures are dispersed, becomes a part of the mixing water in the concrete and shall be considered in the calculation of the w/cm.

### **4.1.11.2 Relationship of Water-Cementitious Ratio to Strength, Durability, and Shrinkage**

Since the w/cm is one of the fundamental keys governing the strength and durability of the concrete the proportioning of the concrete mixture design shall minimize the w/cm to the maximum extent possible consistent with acceptable workability of the concrete mixture in the intended application. Low w/cm shall be accompanied by controls on total water content to limit shrinkage.

### **4.1.11.3 Relationship of Water-Cementitious Ratio to Workability**

The w/cm shall not be increased for reasons of improving workability. Use of suitable workability-improving admixtures shall be employed if additional workability is needed in concrete mixtures that are already proportioned at the maximum allowable w/cm.

against the aggregate cost.

Most water-reducing admixtures are provided as water solutions. The proportional volume of the solids included in the admixture is so small in relation to the size of the batch that it can be neglected in the mixture design calculations.

### **C4.1.11.2 Relationship of Water-Cementitious Ratio to Strength, Durability, and Shrinkage**

A reasonable balance should be established between a maximum cement content for stripping and service strength requirements and a minimum cement content to diminish the negative qualities of high-cement-content mixtures, such as shrinkage and a matrix hardness lower than that of the aggregates.

In addition to controlling the w/cm to a low level, the cement content should be held to the practical minimum amount needed to achieve stripping, transfer of prestress, and service strength requirements.

Minimizing the paste is desirable because water in the paste is the primary cause of shrinkage as the concrete hardens and dries. The more water (and therefore the more paste), the greater the drying shrinkage. Also, cement produces heat as it hydrates. Therefore, high cement contents may produce an undesirable temperature rise during curing and crack-producing temperature differentials.

### **C4.1.11.3 Relationship of Water-Cementitious Ratio to Workability**

The required water content of concrete is influenced by a number of factors: aggregate size and shape, slump or slump flow, w/cm, air content, cement content, admixtures, and environmental conditions. Increased air content and aggregate size, reduction in w/cm and slump, rounded aggregates, and the use of water-reducing admixtures reduce water demand. On the other hand, increased temperatures, increased cement contents, increased slump, increased w/cm, increased aggregate angularity, and a decreased proportion of coarse aggregate to fine aggregate increase water demand.

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### **4.1.12 Use of Admixtures**

Admixtures shall be materials of standard manufacture having well-established records of tests to confirm their properties and their short-term and long-term effects on the properties of both fresh and cured concrete. The manufacturers' recommendations shall be followed in their use.

When more than one admixture is used in a concrete mixture, it shall be verified prior to production that each material performs as required without adversely affecting the performance of the other.

To avoid corrosion problems in prestressed concrete, admixtures containing chloride ions shall be limited so that the maximum water-soluble chloride ion (Cl<sup>-</sup>) does not exceed 0.06% by weight of cement, determined in accordance with ASTM C1218/C1218M. Reference ACI 318 for maximum chloride ion content limits in reinforced concrete.

When supplementary cementitious materials are to be included in the concrete mixture, the mixture proportioning shall be established by trial mixtures.

Provisions shall be made for controlling the quantity and uniform introduction of all admixtures with other concrete components to ensure that they are uniformly distributed into the mixture.

### **C4.1.12 Use of Admixtures**

The development of admixtures to modify and improve the properties of fresh and hardened concrete is one of the most rapidly changing areas of concrete technology. Some concrete admixtures have been in successful service for many years and are considered to be proven performers with no adverse side effects. New admixtures should be well supported by research and testing prior to use in precast concrete elements.

High-range water reducers (superplasticizers) should be carefully tested with production materials and other admixtures under anticipated production conditions to establish the desired characteristics of the concrete.

Calcium chloride and admixtures containing chloride ions will promote corrosion of steel reinforcement and galvanized and aluminum embedments, and may cause nonuniformity in the color of the concrete surface (darkening and mottling). Chloride ions may also disrupt the efficiency of surface retarders.

In the absence of prior information regarding proportions for supplementary cementitious materials and for preparing estimated proportions for a first trial batch or a series of trial batches in accordance with ASTM C192/C192M, the ranges are provided in ACI 211.1. The percentages are based on the total weight of cementitious material used in the batch. For curing requirements, see Section 4.9.5.

Recommended maximum limits for cementitious materials used in architectural mixtures are as follows:

- Class F or C fly ash: 20% maximum
- Natural pozzolans: 10% maximum
- Ground granulated blast-furnace slag (GGBF): 20% maximum
- Silica fume: 10% maximum

Fly ash and gray silica fume will cause color variations. White silica fume is available and will minimize color variations.

The optimum amount of cementitious materials can be determined by evaluating the effect on color, strength, water requirement, time of set, and other important properties.

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When fly ash is used as an admixture, it should be tested in accordance with ASTM C311. An important criterion for fly ash is a low loss on ignition (LOI), as determined by ASTM C 114. The LOI is a measure of unburned carbon. As the percentage of LOI increases, air entrainment and concrete performance are adversely affected.

The hydraulic properties of GGBF may vary. The ASTM C989 grade classifications provide guidance on the relative strength potential of 50% GGBF slag mortars with respect to 100% portland cement at 7 and 28 days. GGBF slag is graded as 80, 100, and 120 in order of increasing strength potential to designate the percent strength with respect to the control (100% portland cement).

### **4.1.13 Strand Bond**

Producers shall provide evidence that the prestressing strand used in the prestressed products has been accepted through an approved strand bond quality control program. Producers shall provide evidence that the strand they use will satisfactorily bond with the specific concrete mixes used for the fabrication of their products.

### **C4.1.13 Strand Bond**

Plants producing prestressed concrete products should perform tests to assure the bond of prestressing strand with the plant's concrete mixture designs. A proposed beam bond test now under evaluation by PCI committees requires the manufacture and testing of a single strand beam, 6 in. deep by 8 in. wide by 11'-6" long, which is described in the article entitled "A Simple Quality Assurance Test for Strand Bond" and published in the Spring 2009 PCI Journal and revised in May 2009. Refer to the PCI web site for additional important information.

## **4.2 Storage and Handling of Concrete Materials**

## **C4.2 Storage and Handling of Concrete Materials**

### **4.2.1 General**

Concrete batching plants and operational procedures shall conform to ASTM C94/C94M. Concrete batch plants shall be capable of producing concrete of the quality required for architectural precast concrete members and shall be properly equipped, maintained, and operated. Batching and mixing facilities shall be capable of producing concrete under typical ambient temperature extremes. There shall be an adequate water supply with constant or regulated pressures to prevent interference with accuracy of measurement.

### **C4.2.1 General**

Because of the importance of proper concrete batching and mixing to the proper production of precast concrete elements, the producer should ensure that as much quality control oversight is being provided on off-site sources of concrete as required of the precast producer.

Concrete supplied by an off-site batch plant shall meet the same requirements of on-site batch

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plant facilities. Evidence of conformance shall be certification of the outside plant by NRMCA (National Ready Mixed Concrete Association).

### **4.2.2 Storage and Handling of Aggregates**

Each aggregate shall be handled and stored by methods that will minimize variability in grading and moisture content upon arrival at batch weighing equipment. Rehandling of aggregates shall be minimized to avoid aggregate segregation, which can occur as a result of each handling operation.

Wet or moist aggregates shall be stockpiled in advance of use to allow for proper drainage and establishment of a uniform moisture content. The required amount of time necessary to establish a uniform moisture content depends primarily on the grading and particle shapes of the aggregate, and shall be verified by moisture tests or measurements.

**Stockpiles.** When aggregates are to be stockpiled, the use of aggregate bins is preferred; failing this, it is imperative that a hard, clean, and well-drained base shall be provided for each aggregate stockpile. If contamination from underlying material cannot be avoided, the area shall be planked or paved. Stockpiles shall be built up in horizontal or gently sloping thin layers. Conical stockpiles or any unloading procedures involving the dumping of aggregate down sloping sides of piles shall be prohibited. A front-end loader or reclaimer shall remove slices from the edges of the pile so that every slice will contain a portion of each horizontal layer. Trucks, bulldozers, or other vehicular or track equipment shall not be operated on the stockpiles because in addition to breaking the aggregate, dirt is frequently tracked onto the piles. Intermixing of different materials shall be prevented by suitable walls or ample distance between piles.

Fine aggregate shall be handled in a damp state to minimize the separating of dry fine aggregate by wind. Stockpiles shall not be contaminated by spillage from swinging aggregate-filled buckets, conveyor belts, or clams over the various stockpiled aggregate sizes.

### **C4.2.2 Storage and Handling of Aggregates**

Procedures for handling and storage of aggregates are outlined in further detail in ACI 221R and ACI 304R.

Unless uniformity of aggregates as batched is ensured, production of uniform concrete is unlikely. When aggregates are to be stockpiled, the use of aggregate bins helps to ensure that the aggregate remains clean, prevents segregation, and protects against contamination from adjacent stockpiles.

**Stockpiles.** Stockpiles of coarse aggregate inevitably tend to accumulate an excess of fines near their bases. This material should be periodically removed and discarded to ensure that aggregates are uniform and clean to help ensure production of uniform concrete.

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**Bins.** When bins are used for storing aggregates, separate compartments shall be provided for fine aggregates and for each required size of coarse aggregate. Each compartment shall be capable of receiving and storing material without cross-contamination. Bins shall be filled by material falling vertically, directly over the outlet. Each compartment shall be designed to discharge freely and independently into the weigh hopper. Bins shall be kept as full as practicable at all times.

Storage bins shall have the smallest practicable equal horizontal dimensions. To avoid accumulation of fines in dead storage areas, bottoms of circular bins shall slope at angles not less than 50 deg from the horizontal toward center outlets. The bottom surface of rectangular bins shall slope at angles not less than 55 deg from the horizontal.

**Bags.** When bagged aggregates are used, the individual sizes shall be stored on pallets in a well-drained, reasonably dry area. Bagged fine aggregate shall be stored under dry conditions. Bagged aggregate shall be weighed prior to use.

### 4.2.3 Storage and Handling of Cement

Cement that develops hard lumps (due to partial hydration or dampness) that cannot be reduced by light finger pressure shall not be used, unless tested for strength and loss on ignition.

**Bulk cement.** Bulk cement shall be stored in weathertight bins or silos that exclude moisture and contaminants. Storage silos shall be drawn down frequently—at least once per month—to prevent cement caking in the bins or silos. Each brand, type, and color of cement shall be stored separately.

**Silos and bins.** Compartments shall be designed to discharge freely and independently into the weighing hopper. The interior of a cement silo

**Bins.** Aggregate bins in cold climates may have to be appropriately heated in winter.

Chuting the aggregate into a bin at an angle and against the bin sides will cause it to segregate. Baffle plates or dividers will help minimize segregation. Round bins are preferred.

By keeping bins full, breakage and changes in grading will be minimized as the materials are drawn down.

**Bags.** If stored outside, aggregates bagged in burlap should be protected with a weather-protective cover to prevent deterioration of the bags from moisture in wet regions. If aggregates are to be stored in polypropylene bags, the bags should be protected from sunlight to prevent deterioration of the bags. Long periods of storage may require rebagging or other means to prevent breaking of bags when handled. Storage should be such that there is no mixing of sizes if some bags break and the aggregate is recovered.

### C4.2.3 Storage and Handling of Cement

Cement can be supplied in bags or in bulk. Portland cement has great affinity for water and, if left exposed to the atmosphere, will gradually absorb water vapor from the air and begin to hydrate (develop small lumps). If kept dry, it can retain its quality for an extended period of time.

**Bulk cement.** Contamination of cement typically occurs during shipping and handling. It is generally caused by use of trucks and rail cars that have not been properly cleaned. Changes in color, changes in texture, or the presence of coarse particles may be evidence of a problem.

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shall be smooth, with a minimum bottom slope of 50 deg from the horizontal for a circular silo and 55 deg for a rectangular silo. Silos not of circular construction shall be equipped with features to loosen cement that has settled tightly into corners.

Bin compartments from which cement is batched shall include a separate gate and conveyance system. This system shall provide for a constant flow and precise cutoff to ensure accurate automatic batching and weighing of cement. Procedures shall be in place to avoid cement being transferred to the wrong cement silo, either by faulty procedures or equipment.

**Bagged cement.** Cement in bags shall be protected from wet weather and stacked on pallets or similar platforms to avoid contact with ground moisture and allow for proper air circulation. Bags shall be stored clear of wall areas where condensation may occur. Bags to be stored for long periods of time shall be covered with waterproof coverings and stacked to ensure that the oldest cement is used first.

### **4.2.4 Storage and Handling of Admixtures and Pigments**

The storage, handling, and batching of admixtures shall be in accordance with the manufacturer's recommendations. Adequate storage facilities shall be provided to ensure uninterrupted supplies of admixtures during batching operations. Liquid admixtures shall be stored separately in weathertight containers or tanks that are clearly labeled by the type, brand, and manufacturer of the admixture.

Provision shall be made for proper venting that ensures against foreign materials entering the storage tanks or drums. Venting is required to ensure that tanks or drums do not become air bound, restricting the admixture flow. Facilities for straining, flushing, draining, and cleaning the storage tanks shall be provided. Fill nozzles and other tank openings shall be capped when not in use to avoid contamination.

In addition to mechanical or electromechanical dispensing systems used for measuring and charging of the admixtures to the concrete batch,

**Bagged cement.** Portland cement should be kept sealed in its original bags and well protected from water or humidity until use. When bagged cement is used, batches should be sized to use full bags of cement when possible. If it is necessary to store partially used bags of cement, they should be folded closed and then enclosed in a polyethylene bag. Old cement that has absorbed even small amounts of moisture may reduce the strength of the concrete.

### **C4.2.4 Storage and Handling of Admixtures and Pigments**

The requirements for storage of powdered admixtures are generally the same as those for storage of cement.

Admixture manufacturers usually furnish complete storage and dispensing systems or at least information regarding the degree of agitation or recirculation required for their admixtures. Timing devices are commonly used to control recirculation of the contents of storage tanks to avoid settlement or polymerization.

High-volume liquid admixtures, such as nonchloride accelerators or silica fume slurries, may not use a calibrated holding tank. They may be metered directly

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volumetric dispensing systems shall include a device or devices that shall either detect and indicate the presence or absence of flow of the admixture, or detect and indicate the presence or absence of the admixture, or provide a convenient means of visually observing the admixture in process of being batched or discharged.

All admixture dispensers shall provide for diversion of the measured dosages for verification of the batch quantity. Batching accuracy shall be checked at least every 90 days. Calibrated sight tubes shall be vented so that they do not become air bound and restrict flow. Piping for liquid admixtures shall be free from leaks and properly fitted with valves to prevent backflow or siphoning and to ensure that measured amounts are completely discharged.

Volumetric admixture dispensers shall be provided with visual indication or interlock cutoff when the liquid admixture supply is depleted. Dispenser control panels shall be equipped with timer-relay devices to ensure that all admixtures have been discharged from the conveying hoses or pipes.

Tanks, lines, and dispensing equipment for liquid admixtures shall be protected and configured to prevent freezing, contamination, dilution, and evaporation. Tanks shall have a means for preventing settlement or separation of the admixtures. To prevent freezing, storage tanks shall be heated or placed in heated environments. The manufacturers' instructions regarding the effects of heating or freezing admixtures shall be observed.

Separate dispensers shall be used for each admixture. If properly isolated to prevent cross-contamination of admixtures, the use of common dispensing controls for the dispensing of different admixtures is permitted. Compatible admixtures may be stored in the same calibrated holding or checking tank after batching and prior to introduction into the mixer. If the same dispensing equipment is used for incompatible admixtures, the dispenser shall be flushed at the end of each cycle.

into the mixer through accurately calibrated metering devices.

Some admixtures become quite viscous at lower temperatures, which might cause difficulty unless properly heated prior to use. Freezing can cause ingredients of some liquid admixtures to separate, adversely affecting performance of the admixture.

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Storage areas for pigments shall be adequately clean and dry. Pigments shall remain in sealed containers until used, and all opened packages shall be protected from contamination.

Pigments are packaged in bags (dry powder pigments) and drums (liquid pigments).

Silica fume slurry will stiffen or gel during storage and shall be remixed prior to use. Bulk slurry storage tanks shall be equipped with a mechanical agitation device or a recirculation system that is designed to appropriately remix the silica fume.

Silica fume is provided in bulk, bags, or drums (slurry).

Metakaolin shall be handled and stored in a similar manner to cement.

Metakaolin is provided in a powder form in bags or bulk.

### 4.3 Batch Plant

### C4.3 Batch Plant

#### 4.3.1 Batching Equipment Tolerances

#### C4.3.1 Batching Equipment Tolerances

Batching equipment shall be maintained and operated in accordance with ASTM C94/C94M.

The quantities of ingredients used for each batch shall be recorded separately for each batch.

When measuring by bulk volume, batching shall be in accordance with ASTM C685/C685M with the weight tolerance waived.

Graphical recorders shall register scale readings within  $\pm 2\%$  of total scale capacity. Digital recorders shall reproduce the scale reading within  $\pm 0.1\%$  of scale capacity.

For ingredients batched by weight, the accuracy tolerances required of the batching equipment shall be applicable for batch quantities between 10% and 100% of scale capacity.

The range of tolerance control, weight control limitations of batching equipment, and batching controls are covered in *Concrete Plant Mixer Standards*, published by the Concrete Plant Manufacturers Bureau.

For water or admixtures batched by volume, the required accuracy tolerances shall be applicable for all batch sizes from minimum to maximum, as determined by the associated cement or aggregate batcher rating.

Operation and maintenance of batching equipment shall be provided in such a manner that ensures that the concrete ingredients are consistently measured.

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For individual batching equipment, the following tolerances shall apply based on the required scale reading:

**Cementitious materials:**  $\pm 1\%$  of the required weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, whichever is greater.

**Aggregates:**  $\pm 2\%$  of the required weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, whichever is greater.

**Water:**  $\pm 1\%$  of the required weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, or  $\pm 10$  lb, whichever is greatest.

**Admixtures:**  $\pm 3\%$  of the required weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, or  $\pm$  the minimum dosage rate for one 94 lb (43 kg) bag of cement, whichever is greatest.

Pigments in powder form are used in extremely small dosages and shall be batched by hand from premeasured containers packaged in amounts sufficient for proper dosages per unit volume of concrete. Pigments shall be weighed to the nearest  $\pm 1\%$  of the required weight.

For cumulative batching equipment without a tare-compensated control, the following tolerances shall apply to the required cumulative scale reading:

**Cementitious materials or aggregates:**  $\pm 1\%$  of the required cumulative weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, whichever is greater.

**Admixtures:**  $\pm 3\%$  of the required cumulative weight of material being weighed, or  $\pm 0.3\%$  of scale capacity, or  $\pm$  the minimum dosage rate for one 94 lb (43 kg) bag of cement, whichever is greatest.

For **volumetric batching equipment**, the following tolerances shall apply to the required volume of material being batched:

**Water:** Plants should use caution with small batches where these water quantity tolerances will not produce acceptable results.

**Admixtures:** Dispensers for liquid admixtures may measure by volume or weight. Generally, better results are obtained from admixtures in liquid form. Modern liquid admixture batching equipment that incorporates effective controls and interlocks is so accurate that it has virtually eliminated the need for weighing admixtures in the powdered state.

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**Water:**  $\pm 1\%$  of the required weight of material being batched, or  $\pm 1$  gal (3.8 L), whichever is greater. For batch sizes less than  $2 \text{ yd}^3$ , water volume shall be controlled to  $\pm 1/2$  gal (1.9 L) to meet the water-cementitious ratio tolerance requirements.

**Admixtures:**  $\pm 3\%$  of the required volume of material being batched but not less than  $\pm 1$  oz (30 gm) or  $\pm$  the minimum recommended dosage rate per 94 lb (43 kg) bag of cement, whichever is greater.

**Aggregates:** When measuring lightweight aggregate by bulk volume, batching shall be in accordance with ASTM C685/C685M with the weight tolerance waived.

**Aggregates:** In some instances, the accurate control of concrete with lightweight aggregate is more feasible when measuring by bulk volume than by weight.

### 4.3.2 Scale Requirements

Scales in the plant shall consist of a suitable system of levers or load cells that weigh consistently within specified tolerances. Loads shall be indicated either by means of a beam with balance indicator, a full-reading dial, or a digital readout.

For all types of batching systems, the batch operator shall be able to read the load-indicating devices from the operator's normal station. Where controls are remotely located with respect to the batching equipment, monitors or scale-follower devices shall repeat the indication of the master scale within  $\pm 0.2\%$  of scale capacity.

Separate scales shall be provided for weighing cement and other cementitious materials.

The reading face capacity or the sum of weigh-beam capacities of a scale on a cement batcher shall be not less than  $660 \text{ lb/yd}^3$  ( $390 \text{ kg/m}^3$ ) of rated batcher capacity.

Fine and coarse aggregates shall be weighed on separate scales or on a single scale, which will first weigh one aggregate, then the cumulative total of aggregates. The reading face capacity or the sum of weigh-beam capacities of a scale on an aggregate batcher shall be not less than  $3300 \text{ lb/yd}^3$  ( $1,966 \text{ kg m}^3$ ) of the rated batcher capacity.

All scales shall be maintained to provide

### C4.3.2 Scale Requirements

Accurate weighing of the batch ingredients is critical to ensure that the characteristics of the mixture, as designed and proven in the trial mixture process, are achieved in production.

Since variations in cement and cementitious material batch weights are more important to the overall performance of the mixture than are small variations in aggregate weights, separate scales should be used so that potential errors in cement weights are readily apparent.

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accuracy within 1% of loads weighed under operating conditions or within  $\pm 0.20\%$  of scale capacity throughout the range of use. For direct digital read-out, the tolerance shall be increased to  $\pm 0.25\%$  when the digital readings are limited to whole-number values that cannot reproduce weight indications closer than  $\pm 0.05\%$  of capacity. All exposed fulcrums, clevises, and similar working parts shall be kept clean. Beam-type scales shall be checked to zero load with the bins empty each time the mixture is changed, and at least once during each day of operation. Scales shall register loads at all stages of the weighing operations from zero to full capacity.

For calibration of scales, standard test weights aggregated to at least 500 lb (227 kg) (each accurate within  $\pm 0.01\%$  of indicated values) shall be used. Calibration of scales shall be performed at intervals not greater than six months, and whenever there is reason to question accuracy. Scale calibration certificates and charts shall be prominently displayed at the batch control location.

### **4.3.3 Requirements for Water Measuring Equipment**

The reading face capacity or the sum of weigh-beam capacities of a scale on a water batcher shall be not less than 320 lb/yd<sup>3</sup> (145 kg/m<sup>3</sup>) or 38 gal/yd<sup>3</sup> (188 L/m<sup>3</sup>) of rated batcher capacities.

If water is to be measured by volume, the water measuring device shall be arranged so that variable pressures in the water supply line will not affect the measurements.

Calibration of water measuring devices shall be performed at intervals not exceeding three months for volumetric measurement or six months for weight measurement, or whenever there is reason to question accuracy.

### **4.3.4 Requirements for Batching and Mixing Plants**

#### **4.3.4.1 General**

The batch plant shall be capable of providing sufficient quantities of concrete to ensure continuous casting operations. The concrete

Confirmation of accurate scale performance can only be determined by proper calibration checks. This is an important aspect of overall concrete quality control.

### **C4.3.3 Requirements for Water Measuring Equipment**

Water meters should conform to the Standards of the American Water Works Association.

In the case of truck mixers used to supply the plant, and if wash water is permitted to be used as a portion of the mixing water for backup mixtures, it should be measured accurately in a separate tank and accounted for in determining the amount of additional water required.

Measuring tanks for water should be equipped with outside taps and valves to provide for checking the meter calibration. Volumetric tank water batchers should be equipped with a valve to remove overloads.

### **C4.3.4 Requirements for Batching and Mixing Plants**

#### **C4.3.4.1 General**

It is not the purpose of this section to specify any particular type of concrete plant.

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ingredients shall be properly proportioned and mixed to the desired uniformity and consistency. Batching equipment used for dispensing and weighing cement, aggregates, water, and admixtures (if measured by weight) shall consist of suitable containers freely suspended from scales and equipped with necessary charging and discharging mechanisms. Batch equipment shall be capable of receiving the rated load and maintaining a separation distance to prevent contact of the weighted material with the charging mechanisms.

Charging or dispensing devices shall be capable of controlling the rate of flow and stopping the flow of material within the weighing tolerances. Charging and discharging devices shall not permit loss of materials when closed. Batching systems shall contain interlocks that prevent charging and discharging from occurring simultaneously and in the event of electrical or mechanical malfunctions to ensure that materials cannot be overbatched. Provision shall be made for removal of material overloads.

The batch plant shall be equipped with provisions to aid in the smooth and complete discharge of the batch. Vibrators or other appurtenances shall be installed in such a way as not to affect accuracy of weighing. Wind protection measures shall be sufficient to prevent interference with weighing accuracy.

Batching equipment used to meter cementitious materials shall be provided with a dust seal between batching and charging mechanisms. The seal shall be installed in such a manner that it will not affect weighing accuracy. The weigh hopper shall be vented, self-cleaning, and fitted with mechanisms to ensure complete discharge of the batch.

### **4.3.4.2 Requirements for Concrete Mixers**

Mixing equipment shall be of sufficient capacity and type to produce concrete of uniform consistency and provide for uniform distribution of materials as required by ASTM C94/C94M.

## **Commentary**

Concrete batching plant types include simple manual equipment in which the operator sets batch weights and discharges materials manually; semiautomatic plants in which batch weights are set manually and materials are discharged automatically; and fully automated, electronically controlled plants in which mixtures are controlled by means of selectors, punch cards, or computer memory.

When batch plants of outside suppliers are used, the plants should be reviewed regularly to confirm compliance with the plant certification requirements of the National Ready Mixed Concrete Association and other applicable requirements of this division.

Any of the methods described are acceptable as long as concrete is of consistent quality and operations are performed in accordance with ASTM C94/C94M.

### **C4.3.4.2 Requirements for Concrete Mixers**

An important measure of mixer performance is uniformity of the concrete between batches. Visual observation of the concrete during mixing and discharge from the mixer aids in monitoring the uniformity of the mixture.

The consistency meter (amp meter, watt meter, etc.) should be correlated for each mixture design so as to

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High-intensity stationary mixers of the vertical or horizontal shaft type capable of producing uniform low-slump concrete shall be used for architectural concrete face mixtures. Backup mixtures may be mixed by any of the methods listed in Section 4.6.6.2.

Mixers with a rated capacity of 1 yd<sup>3</sup> (0.76 m<sup>3</sup>) or larger shall be in accordance with the requirements of the *Concrete Plant Mixer Standards* of the Concrete Plant Manufacturers Bureau, Plant Mixer Manufacturers Division. Truck mixers shall conform to the requirements of the *Truck Mixer and Agitator Standards* of the Truck Mixer Manufacturers Bureau. Truck mixers shall be equipped with revolution counters.

### 4.3.4.3 Mixer Placard Requirements

The capacity of the drum or container, in terms of the volume of mixed concrete, shall be maintained on file for each mixer and agitator.

A mixer shall not be used for mixture quantities greater than the quantity recommended by the mixer manufacturer. The rate of the drum or blades for truck or stationary mixers shall be in accordance with the manufacturer's recommendations.

### 4.3.4.4 Maintenance Requirements for Concrete Mixers

All mechanical aspects of mixers or agitators, such as water measuring and discharge apparatus, condition of blades, speed and

determine as precisely as possible the mixing duration necessary to obtain a homogeneous mixture. Consistency meters of the digital type, such as those operating from the amperage draw on the electric motor drives for revolving drum mixers, are recommended. Conventional analog or dial-type meters may lack the necessary accuracy for producing consistent SCC. However, the most effective measure for monitoring concrete uniformity is a regularly scheduled program of fresh concrete tests. Such tests include unit weight, air content, slump or slump flow, coarse aggregate content, and temperature.

For a description of the various mixer types, refer to the *Concrete Plant Standards* of the Concrete Plant Manufacturers Bureau, Plant Mixer Manufacturers Division.

While most mixers in use in production can successfully mix SCC, some mixer types handle SCC more efficiently than others.

### C4.3.4.3 Mixer Placard Requirements

Low-slump concrete may require smaller loads than the rated mixer capacity.

### C4.3.4.4 Maintenance Requirements for Concrete Mixers

A preventive maintenance program for concrete mixers and associated equipment is critical to the production of uniform quality concrete.

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rotation of the drum or blades, general mechanical condition of the units, and cleanliness, shall be checked daily. Mixers shall be examined daily for accumulation of hardened concrete or wear of blades. Accumulations of hardened concrete shall be removed.

Mixer blades shall be replaced or repaired in accordance with the manufacturer's recommendations regarding blade wear or damage.

### **4.4 Concrete Transportation Equipment**

#### **4.4.1 General**

Bottom dump buckets or hoppers shall be designed to allow placement of concrete at the lowest practical slump that can be adequately consolidated with vibrators. Discharge gates shall have a clear opening no less than one-third the maximum interior horizontal area or five times the maximum aggregate size in the mixture. If dump buckets are used, the side slopes of transportation containers shall be no less than 60 deg measured from the horizontal. Controls on the gates shall permit opening and closing during any portion of the discharge cycle. Oil shall not be used to keep mixers or weigh hoppers clean and care shall be taken to avoid contamination of the concrete or aggregate by oil spillage or leakage.

All conveying equipment shall be thoroughly cleaned prior to casting, between different mixtures, and at frequent intervals during prolonged castings.

Concrete transportation equipment shall be considered during the SCC mixture qualification.

#### **4.4.2 Requirements for Concrete Delivery Equipment**

Agitators, truck mixers, or truck agitators shall be capable of maintaining the concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity. All types of mixers and agitators shall be capable of discharging concrete

Cement lumps in the mix may indicate ineffective mixing caused by worn blades or a dirty mixer.

### **C4.4 Concrete Transportation Equipment**

#### **C4.4.1 General**

Efficient concrete transportation equipment should be used to minimize the time between mixing and placing of the concrete. This will help to ensure optimum workability at the time of placement. Prior to the start of production that requires low-slump/workability mixtures, the condition of the transportation equipment should be verified.

Segregation or leakage may be a problem using conventional transportation equipment for SCC mixtures.

#### **C4.4.2 Requirements for Concrete Delivery Equipment**

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at its specified slump. Low-slump concrete shall be batched and mixed in smaller batches if required to ensure efficient discharge of the concrete from the mixer.

Centrally mixed concrete may be transported in suitable nonagitating equipment, provided the following requirements are followed:

1. Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that will permit control of the concrete discharge.
2. Covers shall be provided for protection against inclement weather.
3. The concrete shall be delivered without segregation, thoroughly mixed, and discharged with a satisfactory degree of uniformity as defined in ASTM C94/C94M.
4. SCC shall not be transported in nonagitating equipment unless prior testing in accordance with ASTM C94/C94M has shown no segregation of coarse aggregate.

### **4.5 Placing and Handling Equipment**

Placing and handling equipment shall be adequate for depositing and consolidating the required type of concrete. The assessment of the acceptability of any special method or procedure shall be based on the uniformity and the quality of the end product.

Chutes, hoppers, buckets, or gates on placing and handling equipment shall not restrict the use of a specified low water-cementitious ratio, low-slump concrete, or SCC. Chutes shall not cause moisture loss or segregation.

Travel times, speed of travel, load size, concrete temperature, and other factors will influence how the SCC responds to transportation.

### **C4.5 Placing and Handling Equipment**

Adequate attention to placing and handling equipment is necessary to allow efficient handling of relatively low-slump concrete, particularly gap-graded concrete, which may not readily flow out of placement equipment but can otherwise be properly consolidated with vibration.

Proper planning and testing should be performed to verify that the placing and handling equipment is adequate for low-workability mixtures or SCC.

Chutes should have a round bottom, be rigid, and be protected from overflow. Chutes should be sloped at an angle between 30 deg and 45 deg, measured from the horizontal.

Chutes with a length greater than 20 ft (0.3 m) or a slope greater than 45 deg from the horizontal should only be used if the concrete materials are recombined by a hopper or other suitable means prior to placement.

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### **4.6 Batching and Mixing Operations**

### **C4.6 Batching and Mixing Operations**

#### **4.6.1 General**

#### **C4.6.1 General**

All concrete shall be accurately batched and properly mixed to a uniform consistency.

Consistency and accuracy in all phases of batching and mixing are essential to ensuring a high-quality, uniform mixture. Each mixture should be batched in the same sequence and mixed the same length of time.

Care shall be taken to ensure that the weighed materials are properly sequenced and blended during charging of the mixers to maintain uniformity between batches and obtain the desired fresh properties. Materials shall enter the mixer at a location which will allow for uniform distribution of materials. Once a batching sequence is qualified, it shall be maintained for all batches of concrete until requalification.

Proper batching and mixing procedures should produce uniform concrete with the required material proportions. Continuous monitoring and adjustment of aggregate and water batch quantities for aggregate free-surface moisture is consistent with production of all high-quality concrete, including SCC. Aggregate gradation, shape, and moisture content is more critical for SCC.

Information on mixture designs, batching, and mixing procedures shall be recorded and maintained as required in Division 6 for quality control records.

Batching sequence for SCC mixtures may be more important than for non-SCC mixtures. This is especially true of the batching sequence of admixtures, powders, and water.

Ready-mixed concrete delivered to the plant in transport trucks from off-site batching locations shall be accompanied with batch tickets that show the batch quantities, type of admixtures, mixture designation, design slump, and time of batching.

It is important to keep the batching equipment clean, especially when batching different concrete mixtures that have the potential for contamination from the previous batch.

Partial bags of material shall not be used unless weighed.

#### **4.6.2 Batching of Aggregates**

#### **C4.6.2 Batching of Aggregates**

Under normal conditions, all of the aggregates shall be charged into the mixer after an initial amount of the mixture water has been charged.

Maintaining batch consistency requires consistent aggregate gradation and diligent monitoring and adjustment for aggregate free-surface moisture. Sand with intermediate amounts of surface moisture can bulk and occupy more space in a bin or stockpile than very dry or very wet sand. It is for this reason that fine aggregates are batched by weight.

Batch weight of normalweight aggregates shall be based on the required weight of either oven dry or saturated, surface dry aggregate that is corrected for the moisture conditions at the time of batching. For systems using in-line moisture meters, the moisture meter shall be able to detect changes of at least 1% in the moisture content of fine aggregate. For SCC, in-line aggregate moisture meters shall be able to detect changes of at least 0.5% in the moisture content of both

During production of SCC, tests of aggregate grading and moisture content should be carried out more frequently than usual because SCC is more sensitive than normal concrete to variations in these parameters. There should be no assumptions or approximations made concerning the amount of free moisture present

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coarse and fine aggregates. Moisture meters shall be positioned so that moisture values are representative of the aggregate being placed in the mixer. The batch weight tolerance shall apply to the weight of the aggregates that have been corrected for the moisture conditions at the time of batching.

If in-line moisture meters are not used, the free moisture of the fine aggregate shall be determined at least daily, or for SCC, at the beginning of each batching operation and at 4 hr intervals during continuous batching operations or anytime a change in moisture content becomes apparent. Batching weight corrections based on the results of the tests shall be made. Moisture testing shall be performed in accordance with ASTM C70 and ASTM C566. Samples for moisture determination shall be taken from aggregate that is representative of the aggregate being placed in the mixer.

Refer to Section 4.6.6.7 for batching of lightweight aggregate.

### **4.6.3 Batching of Cementitious Materials**

Cement shall be batched in a manner that ensures uniform distribution in the mixture. Cement shall be charged with the fine and coarse aggregates but shall enter the stream after an amount of the aggregates is in the mixer. When heated water is used to warm the mixture, the addition of the cement shall be delayed until most of the water and aggregate have been charged into the mixer.

Free fall of cement shall not be permitted. Cement shall flow from its hopper into the stream of aggregates through a suitable enclosed chute.

If batching by bag, the weight of full bags shall be checked at a frequency of 1 per every 10 bags to confirm that the batch tolerances are met.

### **4.6.4 Batching of Water**

When mixing normalweight concrete, a portion of the mixing water shall precede, and a like quantity shall follow the charging of other constituent materials into the mixer. The remainder of the water shall be introduced

in any aggregate. Actual measurement of free moisture should be made and used for the adjustment of required batch weights.

### **C4.6.3 Batching of Cementitious Materials**

When heated water is used in cold weather, the order of charging the mixer may require modification to prevent possible rapid stiffening of the mixture as a result of combining hot water directly with cement. Geographic climate variations and experience may dictate minor differences in methods.

Of all the constituent elements of the concrete mixture, the proportion of cement in the mixture is the most important. Cement can fluff up as much as 35% when aerated for bulk handling. It is for this reason that batching of cement is done by weight.

### **C4.6.4 Batching of Water**

Next to the proportion of cement, the amount of water in the concrete mixture has the most significant effect on the properties of the concrete. Because of the adverse consequences associated with excess water in the mixture, stringent controls on the handling,

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uniformly with other materials. For mixes of 1 yd<sup>3</sup> (0.76 m<sup>3</sup>) capacity or less, the aggregates may be placed into the mixer first, with the cement and water introduced subsequently and at the same time.

Water batch quantities shall be calculated at the beginning of each batching operation accounting for the actual aggregate free-surface moisture. The required water batch quantity shall be recalculated any time the aggregate free-surface moisture changes.

Water shall be introduced into the mixer in the sequence developed in the qualification procedure for each mixture design.

### **4.6.5 Batching of Admixtures**

Admixtures shall be batched in accordance with the manufacturer's recommendations. Solution admixtures shall be considered part of the mixing water. A procedure for controlling the timing and addition rate of the admixture to the concrete batch shall be established and followed. Admixtures shall be uniformly distributed throughout the concrete mixture during the charging cycle.

Admixtures shall be introduced into the mixer in the sequence developed in the qualification procedure for each SCC mixture design.

Tanks, conveying lines, and ancillary equipment shall be drained and flushed on a regular basis per manufacturers' recommendations. Calibration tubes shall have water fittings installed to allow the plant operator to water flush the tubes so that divisions or markings can be clearly seen at all times.

measurement, and introduction of water to the mixture should be observed.

The sequencing in the introduction of batch water to the mixer should be reviewed and revised as needed in the production of SCC mixtures.

Variation in total mixture water has a greater effect on the properties of fresh SCC than it does on other concrete mixtures.

### **C4.6.5 Batching of Admixtures**

Most admixtures are furnished in liquid form and often do not require dilution or continuous agitation to maintain their solution stability. For ease of handling and increased precision in batching, liquid admixtures are preferable.

If the admixture is supplied in the form of powder, flakes, or semisolids, a solution should be prepared prior to use in accordance with the manufacturer's recommendations. When this is done, mixing drums or storage tanks from which the admixture will be dispensed should be equipped with agitating or mixing equipment to keep solids in suspension.

Because small quantities of admixtures, and combinations of admixtures, can create large changes in the properties and performance of concrete, the recommendations concerning handling, storage, and measurement of admixtures addressed herein should be carefully observed.

Admixtures should be charged into the mixer in the same sequence for every batch. Changing the timing or sequence in which the admixture is added during mixing may vary the effectiveness of the admixture. This may cause the water demand to vary, which may cause inconsistent finish and color. Varying dosage rates in different batches may cause color variations. Regardless of whether they are in liquid, paste, or powdered form, the introduction of admixtures should generally be at a rate proportional to that of the other concrete components to ensure uniform distribution into the mixture. Liquid chemical admixtures should

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A manually operated admixture dispenser system shall have a valve with a locking mechanism to ensure that no extraneous admixture is dispensed.

Pigments shall be batched in a manner that ensures uniform distribution to the mixture. Dry pigments shall be preweighed and batched from packages that are sized for a single batch. Pigments may also be in liquid form.

When finely divided mineral admixtures are used in bulk, the weighing sequence shall be cement first and admixture or pigment second, followed by the aggregates. This procedure shall be followed when cement and finely divided mineral admixtures are weighed cumulatively on the same scale beam. Mineral admixtures shall not be charged into a wet mixer ahead of the other materials, or at the same time as the mixing water.

Centrally mixed concrete containing silica fume shall have the silica fume added after (or if ribbon fed, along with) all other ingredients. For truck-mixed concrete that incorporates silica fume slurry, the silica fume shall be added to the truck before any other ingredients, as it contains much of the batch water needed for the mixture.

Metakaolin shall be added to the batch with the cement or after all other ingredients have been charged.

### **Commentary**

not be added directly to cement or to dry, absorptive aggregate. Liquid admixtures should, in most cases, be charged with the last portion (final 5% to 10%) of mixture water. The entire amount of nonretarding admixtures should be added prior to the completion of the addition of the mixing water. The addition of retarding admixtures should be completed within 1 min after addition of water to the cement has been completed, or prior to the start of the last three-fourths of the mixing cycle, whichever occurs first.

If two or more admixtures are used in the concrete, the admixtures should be added separately to avoid possible adverse interaction. This practice should be followed unless tests indicate that there will be no adverse effects, or unless the manufacturer's recommendations permit intermixing of admixtures.

Although admixture batching systems usually are installed and maintained by the admixture producer, plant operators should thoroughly understand the system and be able to make adjustments and perform maintenance. Prior to installation of the dispenser, the system should be analyzed to determine the possibility for batching errors that may occur with the system. The necessary steps for avoiding such errors should be established and followed.

Mineral admixtures have a tendency to stick to the sides of a wet mixer drum when charged ahead of other materials. Such admixtures also have a tendency to ball up when charged into the mixer at the same time as the mixing water.

Adding dry, densified silica fume to a truck mixer after the other ingredients may result in inadequate dispersion into the mixture. This may lead to nonuniform consistency throughout the mixture.

Care should be taken when adding metakaolin after all other ingredients have been charged to ensure that the mixer is not overloaded and the slump of the concrete is greater than 4 in. (100 mm).

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### **4.6.6 Mixing of Concrete**

### **C4.6.6 Mixing of Concrete**

#### **4.6.6.1 General**

#### **C4.6.6.1 General**

Mixers shall be capable of thoroughly combining the concrete materials into an acceptable and uniform consistency.

Concrete of satisfactory quality requires the materials to be thoroughly mixed until there is a uniform distribution of the materials and the mixture is uniform in appearance. The necessary mixing time will depend on many factors, including batch size, workability of the batch, size and grading of the aggregate, type of mixer, condition of blades, and ability of the mixer to produce uniform concrete throughout the batch and from batch to batch. Some mixtures require longer mixing times to improve workability and reduce the potential for surface voids and other consistency related problems.

Mixing procedures shall be established to ensure that the weighed materials are properly sequenced and blended during charging of the mixer. All concrete materials shall be discharged into the mixer while the drum or blades are rotating. The minimum mixing time or number revolutions shall be established to ensure that the necessary level of uniformity and consistency is obtained. Once determined, this mixing time shall be observed for all batches of a given SCC mixture.

Varying the mixing time from batch to batch may cause different degrees of dispersion of cement or coloring pigment, if used, and therefore, different shades of color. This is particularly important when using white cement with or without color pigments and when the colors of the sand and cement are different. Some SCC mixture properties may vary substantially with variation in mixing time. Thus, once a successful mixing time is determined, all SCC batches should be similarly mixed.

#### **4.6.6.2 Methods of Concrete Mixing**

#### **C4.6.6.2 Methods of Concrete Mixing**

Concrete shall be mixed by one of the following methods:

1. Central mixing.
2. Shrink mixing.
3. Truck mixing.

Truck mixing is only suitable for backup mixtures because it usually results in insufficient uniformity for uniform visual appearance in architectural units.

All requirements for mixing of concrete, as given in this section, are valid for both normalweight aggregates as specified in ASTM C33/C33M and for lightweight aggregates as specified in ASTM C330/C330M.

The practice of adding superplasticizer to counteract slump loss must be carefully monitored to avoid potential uniformity problems.

The time from the start of concrete mixing to placement shall not exceed 1 hr. Retempering with water of concrete that has started to stiffen shall not be allowed. The practice of adding superplasticizer to counteract slump loss shall be

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carefully monitored to avoid potential uniformity problems.

When colored concrete or white cement mixtures are used in conjunction with gray concrete (such as with facing and backup mixtures), separate mixers and handling arrangements are required. Alternatively, the equipment shall be flushed with water until it is completely cleaned to remove all concrete residue before being used for producing a different color mixture.

### **4.6.6.3 Mixing Time and Concrete Uniformity**

Mixing time shall be measured from the time all cement and aggregate are charged into the mixer. All water shall be in the mixer by the end of the first quarter of the established mixing time.

The mixing time required for each batch shall be based on the ability of the mixer to produce uniform concrete throughout a given batch and between batches. For each type of mixer, the optimum mixing time shall be established by the manufacturer's recommendations.

Mixing time for air-entrained concrete shall be verified and controlled to ensure the specified air content.

When uniformity sampling is performed in accordance with ASTM C94/C94M, slump flow tests taken at the point of discharge shall be made to check the relative degree of uniformity. If the slumps differ more than the specified values in Table 4.6.6.3a or Table 4.6.6.3b, the mixer or agitator shall not be used unless corrective measures are taken.

The allowable variation in slump flow between batches of SCC mixtures shall be established by specifications or by parameters set during mixture qualification testing.

### **C4.6.6.3 Mixing Time and Concrete Uniformity**

Both overmixing and undermixing are to be avoided. Undermixing will result in concrete of variable consistency and low strength. Overmixing may result in a reduction of air in air-entrained mixtures, grinding of aggregates, and loss of workability. Concrete mixing procedures should be established for each type of mixer. Variations in mixture designs (such as those for lightweight concrete) and the use of superplasticizers may require adjustments to standard mixing procedures.

For a given dosage of air-entraining admixture, the amount of entrained air will vary with the type and condition of the mixer, the amount of concrete being mixed, mixing speed, and mixing duration. The entrained air content will generally increase as mixing conditions are optimized. Poor mixing conditions will not facilitate the full potential of air entrainment, and an excessive rate of mixing may reduce the entrained air content. The amount of entrained air generally increases with mixing times up to about 5 min, beyond which it slowly decreases. However, the air void system, as characterized by specific surface and spacing factors, generally is not harmed by prolonged agitation.

Mixers should not be loaded above the rated capacities and should be operated at the speeds recommended by the mixer manufacturer. It may prove beneficial to reduce the batch size below the rated capacity to ensure more-efficient mixing. Increased output should be obtained by using a larger mixer or additional mixers, rather than by speeding up or overloading the mixer. If the blades of the mixer become worn or coated with hardened concrete, the mixing action will be less efficient. Badly worn blades should be replaced, and hardened concrete should be removed

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periodically, preferably after each production day.

Elements of the cycle time (time mixed for different elements of the batching cycle) may have a significant effect on SCC properties.

Some SCC mixture properties may vary substantially with variation in mixing time. Thus, once a successful mixing time is determined, all batches should be similarly mixed.

**Table 4.6.6.3a. Requirements for uniformity of concrete (from ASTM C94/C94M)**

| Test                                                                                   | Maximum allowable deviation between samples |
|----------------------------------------------------------------------------------------|---------------------------------------------|
| Weight per cubic foot calculated to an air-free basis, lb/ft <sup>3</sup>              | 1.0                                         |
| Air content, volume % of concrete                                                      | 1.0                                         |
| Slump, in.:<br>If average slump is 4 in. or less                                       | 1.0                                         |
| If average slump is 4 in. to 6 in.                                                     | 1.5                                         |
| If superplasticizers are used in mixture                                               | 2.5                                         |
| Coarse aggregate content, portion by weight of each sample retained on No. 4 sieve, %  | 6.0                                         |
| Unit weight of air-free mortar based on average for all comparative samples, tested, % | 1.6                                         |

When SCC is used, the slump requirements in Table 4.6.6.3a are replaced by slump flow requirements noted in Table 4.6.6.3b.

**Table 4.6.6.3b. Requirements for uniformity of SCC**

|                                                       |     |
|-------------------------------------------------------|-----|
| Slump flow, in. (between samples in one batch) of SCC | 1.5 |
|-------------------------------------------------------|-----|

### 4.6.6.4 Mixing Time - Stationary Mixers

Unless otherwise recommended by the mixer manufacturer, the minimum mixing time for stationary mixers shall be 1 min for batches of 1 yd<sup>3</sup> (0.76 m<sup>3</sup>) or less. This mixing time shall be increased by at least 15 sec for each cubic yard,

### C4.6.6.4 Mixing Time - Stationary Mixers

Mixing time less than that specified by the manufacturer may be permitted, provided performance tests indicate that the time is sufficient to produce uniform concrete.

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or fraction thereof, in excess of 1 yd<sup>3</sup>. The mixing time shall be increased when necessary to ensure the required uniformity (particularly for pigmented concrete) and consistency of the concrete. Both undermixing and overmixing shall be avoided.

Mixing time in stationary mixers used in the production of SCC shall be established during mixture qualification testing.

### **4.6.6.5 Mixing Time - Shrink Mixing**

When a stationary mixer is used for partial mixing of the concrete during shrink mixing operations, the time may be reduced to a minimum of 30 sec, followed by not less than 50 revolutions nor more than 100 revolutions in the truck mixer, which shall be at an agitating speed in accordance with the mixer manufacturer's recommendations.

Mixing time in stationary mixers and subsequent minimum and maximum mixer truck revolution count requirements when using the shrink mixing method in the production of SCC shall be established during mixture qualification testing.

### **4.6.6.6 Mixing Time - Truck Mixing**

For mixing in a truck mixer loaded to its maximum rated mixing capacity, the number of revolutions of the drum or blades at mixing speed shall be not less than 70 nor more than 100, unless special conditions necessitate additional mixing time. If the batch is at least 1/2 yd<sup>3</sup> (0.4 m<sup>3</sup>) less than the maximum mixer capacity, the number of revolutions at mixing speed may be reduced to 50. All revolutions in excess of 100 shall be at agitating speed per the mixer manufacturer's recommendations.

Minimum and maximum mixer truck revolution count requirements for SCC mixes shall be established during mixture qualification testing.

A minimum of 100 revolutions at a speed of at least 15 revolutions per minute shall be used for

For stationary mixers, mixing time should not exceed the manufacturer's recommended optimum mixing time by more than three times. In the event a batch has to be held in the mixer for a longer period, the speed of the drum blade should be reduced to agitating speed, or the mixer should be stopped in intervals to prevent overmixing.

### **C4.6.6.5 Mixing Time - Shrink Mixing**

### **C4.6.6.6 Mixing Time - Truck Mixing**

When truck mixing is used, depending on the circumstances involved, it may be necessary to develop a focused quality control effort to ensure that the truck drivers perform only authorized actions in terms of mixing speed, mixing time, and the addition of water.

ASTM C94/C94M requires that truck-mixed concrete be discharged before 1.5 hours or 300 revolutions, whichever comes first, from the time mixing water is added. However, if the limit is exceeded, verify that the air content of air entrained concrete and the slump and temperature of the concrete are as specified.

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mixing concrete containing silica fume or metakaolin. When using dry, densified silica fume, these requirements shall be increased to 120 revolutions at a minimum speed of 15 revolutions per minute. Additionally, the load size shall be limited to not more than 75% of the rated mixing capacity.

### **4.6.6.7 Special Batching and Mixing Requirements for Lightweight Aggregates**

Lightweight aggregate concrete shall be batched and mixed as recommended by the producer of the aggregate. Batch weights of lightweight aggregates shall be based on oven-dry weights corrected for absorbed moisture and surface moisture. In some instances, the accurate control of concrete with lightweight aggregate is more feasible measuring by bulk volume rather than by weight. In such cases, batching shall be in accordance with ASTM C685/C685M.

Lightweight aggregate may require dampening prior to batching. Aggregate shall be tested for water absorption at the minimum moisture content likely to occur during production. For aggregates having less than 10% total absorption by weight or shown to absorb less than 2% water by weight during the first hour after immersion in water, dampening prior to mixing is not required. If the lightweight aggregate absorbs more than the amounts shown above, it shall be predampened and a mixing procedure shall be developed that is shown to produce concrete of uniform quality.

### **4.6.6.8 Cold Weather Mixing**

Concrete temperatures at the mixer shall be maintained above a minimum of 50 °F (10 °C). Materials shall be free from ice, snow, and frozen lumps before entering the mixer.

### **C4.6.6.7 Special Batching and Mixing Requirements for Lightweight Aggregates**

ACI 211.2, *Standard Practice for Selecting Proportions for Structural Lightweight Concrete*, provides additional information on the use of lightweight aggregates.

When a lightweight concrete mixture is used for the first time, the mixing and handling procedures should be checked to ensure that they are adequate to produce uniform concrete of the quality specified. In such a case, the aggregate producer's recommendations may be particularly helpful.

Knowledge of the aggregate water absorption characteristics simplifies the process of batching lightweight mixtures. This also helps to optimize mixing time. If the lightweight aggregate unit weight is variable, then batching by volume rather than by weight is necessary.

Dampening of the aggregates may be carried out by submerging the lightweight aggregate or by use of a sprinkling system.

### **C4.6.6.8 Cold Weather Mixing**

When concrete temperatures are less than 50 °F (10 °C), the time required for the concrete to gain strength is greatly extended or strength gain may actually stop.

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When exposure to cold weather is severe, either due to low air temperature or because the concrete sections are thin, the temperature of the fresh concrete shall be increased by heating to ensure that the concrete temperature does not fall below 50 °F (10 °C). When it is necessary to heat the concrete component materials, the aggregates shall not be heated above 150 °F (65 °C), water shall not be heated above 180 °F (82 °C), and the concrete mixture temperature shall be between 50 °F (10 °C) and 95 °F (35 °C).

To avoid the possibility of loss of workability or flash set of the cement when either the water or aggregates are heated to a temperature over 100 °F (38 °C), the water and aggregate shall come together first in the mixer. This is to ensure that the temperature of the combination is reduced to a temperature that is below 100 °F before the cement is added.

Liquids or slurries shall be protected from freezing. Powdered materials shall be protected from moisture that may freeze. Materials that have been damaged by frost, deteriorated, or contaminated shall not be used in the production of concrete.

### **4.6.6.9 Hot Weather Mixing**

The concrete temperature at the mixer shall be maintained below a maximum of 95 °F (35 °C).

## **Commentary**

The benefits and associated cost of heating the components of the fresh concrete should be balanced against the benefits and costs of heating the concrete after placement and during curing.

To help provide for products of uniform color, concrete temperatures should be as uniform as practicable from batch to batch.

Where hot water is used for maintaining a minimum concrete temperature, provisions should be made for the operator to read the temperature of the water before it enters the mixer and after possible blending with cold water.

### **C4.6.6.9 Hot Weather Mixing**

Care should be taken in hot climates to protect batch material storage bins and water lines from direct sun. The temperature of the mixing water and aggregate play a more important role in determining the concrete temperature than does the temperature of the cement at time of batching. To avoid mixing and uniformity problems, it is not advisable to substitute ice for all of the mixing water when admixtures are used in the concrete mixture.

As the concrete temperature increases above 80 °F (27 °C), the setting rate also increases. Because higher temperatures generally reduce the time period for optimal workability, proper scheduling of the concrete placement is critical.

High temperatures in face mixtures at time of placing can create unacceptable finishes and variations in color. See Section C4.7.7 for procedures used to reduce concrete temperatures when placing concrete in hot or windy conditions.

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If high temperatures are encountered, the mixture ingredients shall be cooled before or during mixing.

The temperature of the cementitious materials shall be less than 150 °F (65 °C) immediately prior to batching.

### 4.7 Requirements for Transporting and Placing of Concrete

#### 4.7.1 General

Proven and effective procedures for placing concrete are described in detail in the following publications of the American Concrete Institute:

1. *Guide for Measuring, Mixing, Transporting, and Placing Concrete* (ACI 304R)
2. *Hot Weather Concreting* (ACI 305R)
3. *Cold Weather Concreting* (ACI 306R)

These publications shall be available in the precast concrete plant, and supervisory personnel shall be familiar with the contents.

Sufficient mixing and placing capacity shall be provided so that concrete can be provided on a continuous basis, allowing the precast products produced to be free from unintentional cold joints. If delays occur that result in the concrete attaining initial set or loss of plasticity, and a corrective measure such as a bonding agent cannot be used, partially completed products shall be washed out of the forms/molds or rejected.

Placing methods shall preserve the quality of the concrete in terms of water-cementitious ratio, slump, uniformity, air content, and homogeneity.

If false set occurs, the mixture should sit for 1 min to 3 min and then the mixer should be restarted for an additional 30 sec. The remixing of false set will mechanically break the false set and provide a usable mixture.

Coarse aggregates may be cooled by sprinkling or fogging stockpiles with water, by shading, or with liquid nitrogen.

Flake ice or well-crushed ice of a size that will completely melt during mixing may be substituted for a portion of the mixing water.

### C4.7 Requirements for Transporting and Placing of Concrete

#### C4.7.1 General

In arranging equipment to minimize separation or segregation, it is important to deposit the concrete vertically into the center of transport containers or during final placement. The importance of this increases with an increase in slump, an increase in maximum size and amount of coarse aggregate, or a reduction in cement content. The height of free fall of concrete need not be limited unless a separation of coarse particles (segregation) occurs or uniformity of appearance is affected, in which case a limit of 3 ft to 5 ft (0.9 m to 1.5 m) may be used. However, to protect spacers, embedded features, and mold surfaces and to prevent displacement of reinforcement, concrete fall height should be limited to 2 ft to 3 ft by means of a suitable drop chute or other devices.

As concrete is placed in layers to produce a monolithic and visually acceptable finished product it is important that each layer of concrete be shallow enough that it may be placed while the previous layer is still fresh. This will allow for proper consolidation between layers. The concrete consistency and desired surface appearance will also affect the placement method employed. For example, the lower the slump or water-cementitious ratio, the shallower the lift that should be used.

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### **4.7.2 Transporting and Placing Concrete**

Concrete shall be transported from the mixer to the molds in the shortest practical time and in such a manner as to prevent segregation or loss of mortar.

The transport and placement method shall be part of the mixture qualification. Once determined for a particular element type, the transportation and placement procedure shall be observed for all concrete placements.

Transportation and placing equipment shall be clean.

Free water or excess grout shall not be permitted to drip from transport equipment onto a retarder film or previously finished concrete during the placing operation.

For uniformity testing in mixture qualification, tests using two samples shall be taken. The first sample shall be obtained after placement of approximately 15% of the batch and the second after 85% of the batch.

Retempering by adding water and remixing concrete that has started to stiffen shall not be permitted.

Some SCC has a thixotropic nature. This tendency to gel when the material has been at rest for a short period shall be considered in the transportation and handling techniques used for the material.

### **C4.7.2 Transporting and Placing Concrete**

The effects of transporting the concrete to the placing site should be evaluated and procedures should be maintained to avoid undesirable changes to the concrete characteristics. The need to agitate the concrete during transportation will depend on the length of time between completion of mixing and placement. Any method of transport for SCC can be employed as long as segregation (as determined by the VSI test) is kept to acceptable levels.

The use of nonagitating trucks to transport concrete containing silica fume or metakaolin is not recommended.

Regardless of the manner of transportation, concrete should be placed into the forms/molds while in its original mixed or fresh state.

As concrete is placed into the molds, the paste coating of strand or mild steel should be of no concern up to the top of the section of the precast element. However, cement paste should be kept from or cleaned from all reinforcement or embedments that will extend out of the concrete section.

Mixer trucks have proven to be the best method of delivery of mixed SCC when transporting over rough yard terrain or long distances.

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### **4.7.3 Preventing Aggregate Segregation**

Procedures and arrangements of equipment shall be used that result in placing concrete in a uniform condition without segregation or cold joints and seams.

Placement guidelines shall be qualified by each producer for each SCC mixture. The producer shall observe appropriate placement guidelines to minimize the possibility of segregation and/or visible flow lines.

Determination of maximum free-falling distances through reinforcement shall be qualified through the use of production mock-ups or by other means to ensure acceptable uniformity in the production element.

### **C4.7.3 Preventing Aggregate Segregation**

Obvious clusters and pockets of coarse aggregate are objectionable and should be scattered prior to covering with subsequent lifts of concrete to ensure against rock pockets and honeycombing in the completed unit. Procedures should be evaluated to determine the cause of this condition. Scattered individual pieces of separated coarse aggregate are not objectionable if they are readily enclosed and consolidated into the concrete and do not affect structural or aesthetic properties.

Concrete should not be deposited in the form/mold and then leveled or moved horizontally into final position using vibration. Such practices result in segregation, as the mortar tends to flow ahead of coarser material. This can result in visible flow lines on exposed surfaces. Placing concrete as near to its final location as possible minimizes segregation, the potential for increased entrapped air, and other aesthetic variations. When concrete segregates due to improper handling, the segregation cannot be corrected by subsequent placing and consolidation operations.

SCC can be allowed to free fall a greater distance than normal concrete. Free falling through reinforcement in a form/mold, however, is a very severe test that may tend to cause segregation. Properly designed and qualified SCC mixtures can, in some instances, free fall heights in excess of 10 ft (3 m) without segregation.

Most products can be cast with SCC by starting at one end of the form/mold with the discharge as close to the form/mold surfaces as possible. The SCC mixture is then placed onto prior concrete placement (maintaining head pressure) keeping the mixture flowing toward the opposite end.

Another method is to start placing in the center of the form/mold so that the mixture flows outward from the center in both directions. Whenever possible, avoid opposing flows that may not completely combine. Avoid placement methods that may cause excessive accumulation of form/mold oils that may create a visible pour line. Placing concrete on concrete already in the form/mold minimizes loose aggregate rollout and swirl patterns during consolidation, and it minimizes additional entrapped air between the deposits at the form/mold face.

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### **4.7.4 Preparation of the Form/Mold**

Prior to concrete placement, the molds shall be cleaned. If required, a form/mold release agent or retarder shall be applied uniformly prior to placement of the steel.

### **4.7.5 Placing Concrete Under Severe Weather Conditions**

Freshly deposited concrete shall be protected from freezing, excessively high or differential temperatures, premature drying, and moisture loss during the curing period.

Concrete shall be placed at a uniform temperature between 50 °F (10 °C) and 95 °F (35 °C) unless placement at a higher temperature is confirmed to be acceptable in accordance with ACI 305R, *Hot Weather Concreting*. Measures shall be taken during severe weather conditions to ensure that the concrete remains plastic during placement and finishing operations and that favorable curing conditions are provided thereafter.

### **4.7.6 Placing Concrete in Wet and Rainy Conditions**

The plant shall have adequate weather protection provisions on hand at all times for outside production activities. It shall be possible to deploy the weather protection provisions without compromising the quality of the product.

### **4.7.7 Placing Concrete in Hot or Windy Conditions**

The requirements of ACI 305R, *Hot Weather Concreting*, shall be observed when hot or drying weather conditions are present.

### **C4.7.4 Preparation of the Form/Mold**

Preparation of the forms/molds also involves setting form/mold surfaces, bulkheads, and features to within specified dimensional tolerances.

Loose and other unwanted materials, such as tie wire clippings, should be removed by acceptable methods.

Avoid any dripping or puddling of form/mold release agents or retarders. Retarders should be allowed to dry prior to concrete placement.

### **C4.7.5 Placing Concrete Under Severe Weather Conditions**

Using weather data for the production area, temperature extremes and durations can be identified. A plan of procedures for severe weather conditions should be developed for use whenever weather conditions dictate.

### **C4.7.6 Placing Concrete in Wet and Rainy Conditions**

Excessive free water in the forms should be removed prior to placing concrete.

### **C4.7.7 Placing Concrete in Hot or Windy Conditions**

Wind or direct sunlight can have significant and rapid drying and shrinkage effects on fresh concrete. These along with low humidity are conditions that should be considered and accounted for during placement of concrete. When the ambient temperature is above 80 °F (27 °C), steps should be taken to protect the concrete from the effects of hot or drying weather conditions.

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For concrete placed in hot weather conditions, the concrete temperature shall not be above 95 °F (35 °C) unless placement at a higher temperature is confirmed to be acceptable in accordance with ACI 305R. Adequate moisture shall be retained in the concrete during the curing period to prevent surface drying. The temperature of the concrete at placement shall not be so high as to cause difficulty from loss of slump, flash set, or cold joints.

## Commentary

The primary concerns relating to hot-weather concreting include increased water demand, premature stiffening, loss of workability, increased rate of setting, loss of entrained air, plastic shrinkage cracking, decreased later-age strength, excessive hydration temperatures, and excessive thermal gradients leading to cracking.

The upper limit of 95 °F (35 °C) for concrete placement temperature is a guideline that may need to be lowered to satisfy specific conditions or requirements. If problems are encountered using 95 °F as an upper limit, the maximum temperature should be reduced until problems are eliminated.

If hot or drying weather conditions occur, any of the following procedures or combination of procedures may be used to prevent plastic shrinkage cracking or loss of strength of the concrete:

1. Shaded storage for aggregates.
2. Sprinkling, fog spraying, or chilling aggregates with liquid nitrogen.
3. Burying, insulating, and/or shading water-supply facilities.
4. Use of cold water in batching.
5. Use of shaved or crushed ice for a portion of the mixing water. Only as much ice should be used as will be entirely melted at the completion of the mixing period.
6. Maintaining concrete surfaces in a cool and moist condition by use of wet coverings such as burlap, sprinkling, or ponding as soon as the water sheen disappears. This is especially important for exposed locations in hot and windy conditions.
7. Shading of the product surface during and after casting to avoid heat buildup in direct sunlight.
8. Use of cement with temperatures under 150 °F (65 °C), unless special measures to control concrete temperature as outlined in ACI 305R, *Hot Weather Concreting*, are used and verified to produce concrete of acceptable performance.
9. White-pigmented membranes may be used but are not recommended in very hot weather until after the first 24 hr, as such membranes do not cool the concrete as well as wet curing methods.
10. Set-retarding admixtures, which can delay the concrete setting time and provide a longer

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### 4.7.8 Placing Concrete in Cold Weather Conditions

Special precautions shall be taken to protect concrete placements in cold weather that is below 40 °F (5 °C) to ensure that the concrete gains strength under favorable curing conditions. The requirements of ACI 306R, *Cold Weather Concreting*, shall be observed.

Concrete temperatures during curing shall be maintained above 50 °F (10 °C).

### 4.7.9 Placing Facing Concrete

When placing the concrete face mixture, care shall be taken to avoid coating the reinforcement with cement paste, which may affect proper bonding of subsequent placements of concrete. When this cannot be prevented, subsequent placement of concrete shall be done prior to the hardening of the coating, or the coating shall be cleaned off.

period for placing and finishing.

11. When the temperature of steel is greater than 120 °F (50 °C), steel molds and reinforcement should be sprayed with water just prior to placing the concrete. The surface of the mold should be free of visible water droplets prior to placing the concrete to avoid potential surface finish problems.
12. Use of evaporation reducer.
13. Shading or cooling of forms in hot weather prior to placing concrete.
14. Casting at night or early morning in cooler times of the day.

### C4.7.8 Placing Concrete in Cold Weather Conditions

The primary concerns relating to cold weather are slow setting and slow strength gain, permanent damage to the concrete due to early freezing, and excessive thermal gradients that may lead to cracking.

Concrete can be placed successfully when ambient temperature falls below 40 °F (5 °C). This is done by heating the molds to maintain a minimum concrete temperature of 50 °F (10 °C) to allow for cement hydration. The existence of windy and cold conditions may dictate added protection to maintain temperature of the mold and the concrete after placement.

The mold temperature should be about the same as the concrete temperature. An optimum of 75 °F to 80 °F (21 °C to 27 °C) is desirable. It is important that the temperatures remain relatively constant from unit to unit throughout a project rather than whether they are near the upper or lower level of a temperature range.

### C4.7.9 Placing Facing Concrete

Paste coating of strand or mild steel reinforcement during placement should be of no concern if the paste is not permitted to dry. Reinforcement that extends from the unit should be cleaned of paste.

In lieu of cleaning the coating from reinforcement, the placement of the reinforcement should follow the consolidation of the face mixture.

When mixtures of dry or stiff consistencies are required, the placement rate should be slow enough to

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Facing concrete shall be carefully placed and worked into all sections of the form/mold. This is particularly important in external and internal corners to create true and sharp casting lines. Concrete shall be placed so that flow is away from corners and ends rather than toward them. Each batch of concrete shall be carefully placed into previously placed concrete, as close as possible to its final position. The placed concrete shall then be consolidated by vibration with as little shifting as possible.

Concrete shall be spread, if necessary, with a short-handled, square-end shovel; come-along; hoe; or similar solid-faced tools. If toothed rakes are used to spread concrete, care shall be taken to prevent concrete segregation.

permit proper vibration. This will help to prevent bugholes and honeycombing. However, placing concrete too slowly can produce pour lines or cold joints due to improper consolidation. The rate of placement and vibration (intensity and spacing) should be selected to minimize entrapped air in the concrete. Thin, even layers of 6 in. (150 mm) or less can generally be consolidated with minimum occurrence of air voids, while thicker layers of 12 in. (300 mm) will increase the possibility of trapping more and larger air voids. For this reason, the use of a face mixture or a specially placed mixture of only 1 in. to 2 in. (25 mm to 50 mm) thickness may be advisable.

The use of separate face and backup mixtures or the use of a uniform concrete mixture throughout the unit depends on economics, the type of finish required, the configuration of the unit, window setback, and the practice of the particular precasting plant. Members with intricate shapes and deep, narrow sections generally require one uniform concrete mixture throughout.

Where an aggregate or finished face material changes within a panel, a definite feature (demarcation strip) should be incorporated to facilitate casting and to achieve an acceptable demarcation joint between finishes. Multiple face mixtures with different colored matrices should not be used within one unit unless an acceptable technique is used to prevent contamination of the mixtures. For example, a two-stage (sequential) casting method has been successfully used where one part of a unit is cast first with one mixture and, after curing, is cast into the total unit.

Units with large or steep returns (such as channel column covers and some spandrels) may be cast in separate pieces in order to achieve matching high-quality finishes on all exposed faces and then joined with dry joints. Although the dry joint may not show with certain mixtures and textures, a groove or quirk will help to mask the joint. Where desired, this joint can be recessed deeply enough to allow installation of a small backer rod and placement of a 1/4 in. (6 mm)

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Concrete shall not be subjected to any procedure that will cause segregation or flow lines. When a retarder is used, the concrete shall not be moved over the mold in such a manner that it may disturb the retarder. Concrete placement on a slope shall begin at the lower end of the slope and progress upward, thereby increasing compaction of the concrete.

The thickness of a face mixture after consolidation shall be a minimum of 1-1/2 times the maximum size of the coarse aggregate.

### **4.7.10 Placing Backup Concrete**

In placing backup concrete, care shall be taken to break the fall into the mold so that it will not displace the face mixture.

The bond between the face mixture and backup mixture shall be ensured.

## **4.8 Consolidation of Concrete**

### **4.8.1 General**

Concrete used in architectural precast concrete units shall be uniformly consolidated by internal or external vibration (with or without vibrating table), surface vibrators, spading, impact, or a combination of these methods.

bead of joint sealant. Sometimes precautions may be necessary to ensure watertightness of the dry joints. Care should be taken to ensure that the return is jigged and held securely at the proper angle during production of the base panel.

### **C4.7.10 Placing Backup Concrete**

The allowable time interval between placing the face mixture and the backup depends on the concrete mixture characteristics, the temperatures of the mixture and the ambient air, and the drying conditions near the mold.

The time between placing face mixture and backup mixture should be short enough to ensure proper plastic bonding between the layers and should occur prior to the face mixture attaining its initial set.

When using SCC, unexpected production stops can result in consistency variations or cold joints. Although SCC normally bonds well with previously placed concrete, the likelihood of damage resulting from a cold joint may not be able to be mitigated by vibration, as with normal concrete.

## **C4.8 Consolidation of Concrete**

### **C4.8.1 General**

Vibration should be distributed so the concrete is thoroughly consolidated, producing a dense, uniform mass with surfaces free of imperfections or blemishes. The optimum time of vibration depends on the type of vibrator, the mixture characteristics, and the configurations of mold and reinforcement. Reducing the vibration time on the last lift in returns will result in increased bugholes.

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Consolidation of concrete mixtures shall accomplish full coating of the coarse aggregate and reinforcement with cement paste.

SCC generally does not require mechanical consolidation.

After the proper vibrating equipment has been selected, it shall be operated by trained operators who will consistently maintain the proper vibrator spacing and vibration times, and who have been trained to judge when the concrete is adequately consolidated.

Air pockets around reinforcement should be avoided by the selected consolidation methods.

The effectiveness of vibration shall be judged by the surface condition of the finished concrete, unless circumstances indicate that a more in-depth evaluation is needed. If surface defects such as honeycombing, aggregate or mortar pockets, and excessive air bubbles are noted, the vibration procedure, number and depth of lifts, or other procedures shall be revised as necessary to produce acceptable surfaces.

The selection of the most appropriate vibrator or vibration method involves factors such as:

1. Size, shape, type, and stiffness of molds.
2. Concrete mixture and consistency.
3. Plant preference based on experience.

Vibration procedures shall be evaluated at the beginning of a project to determine the vibration time for each type of vibrator for each mixture, mold type, and configuration. Each member and concrete layer shall be vibrated for the same duration, consistent with the slump of the concrete as delivered to the mold.

Unless there is a gross violation of recommended mixture proportioning and vibration procedures, it is difficult to harm concrete by excessive vibration, provided that the forms/molds are designed to withstand the longer durations of high-frequency vibration.

### **4.8.2 Consolidation of Lightweight Concrete**

### **C4.8.2 Consolidation of Lightweight Concrete**

In consolidation of lightweight concrete, precautions shall be taken to avoid aggregate flotation caused by vibration. Corrective action shall be taken for aggregate flotation.

In consolidation of lightweight concrete, care should be taken not to overvibrate. Since the coarse aggregate particles are the lightest solid ingredients in the mixture, vibration can cause the particles to rise. This may lead to finishing problems and cause the strength to be nonuniform through the depth of the member. The use of slumps of less than 4 in. (100 mm) helps to prevent segregation during handling, consolidation, and finishing. Aggregate flotation may be an indication of segregation or of unacceptable aggregate water content.

### **4.8.3 Consolidation of Face and Backup Mixtures**

### **C4.8.3 Consolidation of Face and Backup Mixtures**

Special attention is required for consolidation of face mixtures, especially if the aggregates are to be exposed later by removing the paste from the surface.

During vibration each individual coarse aggregate particle moves in all directions through the mortar. At the same time, each particle is turning about its shorter axis and striving to occupy a position so that it can penetrate the cement mortar most easily. As the

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Layers of the face-mixture concrete shall be placed as level as possible so that the vibrator does not need to move the concrete laterally, since this will cause segregation (see Section 4.7.9). Face mixtures shall be uniformly distributed within a mold before vibration is applied to that panel. Where there are mounds or high spots in the surface of the concrete as placed, a vibrator shall not be stuck into the center of the mound to knock it down, but instead leveling shall be by hand or mechanical screed.

### **4.8.4 Use of Internal Vibrators**

Workers shall be trained in the proper use of internal vibrators to avoid either under- or overvibration. Care shall be taken to ensure proper vibration with minimal penetration of the backup mixture into the face mixture.

Vibrators shall not be allowed to contact molds where surfaces are to be exposed. Internal vibrators shall not be inserted closer than 2 in. to 3 in. (50 mm to 75 mm) from the mold. Care shall be taken to minimize vibrating the reinforcement, displacing cast-in hardware, or disturbing the face mixture.

aggregate penetrates and thoroughly mixes with the mortar, any water or air bubbles that are trapped beneath it become released and start to move upward. The process can occur only if there is sufficient mortar present.

Experienced and competent vibrator operators working with regularly maintained vibrators and sufficient standby units are essential to a satisfactory consolidation program. There is a tendency for inexperienced vibrator operators to merely flatten the batch. Proper consolidation is ensured only when the other items evidencing adequate vibration are sought and attained.

### **C4.8.4 Use of Internal Vibrators**

The distance between vibrator insertions should generally be about one to one and a half times the radius of action, or such that the area visibly affected by the vibrator overlaps the adjacent just-vibrated area by a few inches. Vibrators in concrete should be moving at all times. Avoid vibration after entrapped air has been removed and concrete is consolidated. Employing internal vibrators in this manner will minimize entrapped air between the concrete and the mold and blend the two layers.

The vibration frequencies that affect the coarse aggregates and fines of a concrete mixture range from 1,200 cycles per minute to 14,000 cycles per minute. The lower frequencies activate the large diameter particles, and the higher frequencies affect the fines and cement in the mixture. High-frequency vibration better ensures complete coverage of larger particles with a film of mortar. The movement of the aggregate particles caused by vibration allows trapped water and air bubbles to move upward. This aspect of consolidation is greatly facilitated by a sufficient quantity of mortar.

Vibrators contacting molds where surfaces are to be exposed may mar and disfigure the concrete surface. Internal vibrators inserted close to the mold may cause the coarse aggregate to be driven away from the mold face, producing local pockets of fine material (stinger marks) on the surface. Vibration of reinforcement may cause reinforcing-steel reflection features (shadow lines) visible in the surface of the finished product.

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When internal vibrators are used to consolidate concrete around coated steel reinforcing bars, the vibrators shall be equipped with rubber or nonmetallic vibrator heads to avoid damaging the coating.

### **4.8.5 Use of External Form/Mold Vibrators**

External vibrators shall be securely fixed to the molds to obtain the maximum vibration effect and to avoid damage to vibrators and molds. During the casting operation, a check shall be made to verify that the vibrators are in operation and firmly in place.

The size and spacing of form/mold vibrators shall be such that the proper intensity of vibration is distributed evenly over the desired area of mold and no mold damage occurs.

### **4.8.6 Use of Surface Vibrators**

Surface vibrators shall be of a type and shape, and shall be applied in such a manner, that will prevent separation of the mixture as a result of suction between the concrete and vibrator

**Consolidating Flowing Concrete.** When casting units with constricted dimensions or limitations on the amount of consolidation effort that may be applied, a high-slump, flowing concrete may be used. When consolidating this concrete, use large-amplitude (that is, large-diameter) internal vibrators inserted at a close spacing and withdrawn slowly. While consolidating in this manner, the surface should be examined for evidence of excess water or paste; if this does appear, the amount of consolidation effort used should be reduced. The high-slump, self-leveling characteristics of the flowing concrete may appear not to require any consolidation. However, as a minimum, nominal vibration should be provided to eliminate large air voids.

### **C4.8.5 Use of External Form/Mold Vibrators**

Proper spacing of external form/mold vibrators is a function of the type, stiffness, and shape of the mold; depth and thickness of the concrete; force output per vibrator; workability of the mixture; and vibrating time.

On large projects, trial production of typical pieces may be appropriate as present knowledge is inadequate to predict an exact solution to the complex problem of vibrator spacing.

Molds should be placed on neoprene isolation pads or other resilient base material to prevent transmission and loss of vibration energy to the supporting foundation.

### **C4.8.6 Use of Surface Vibrators**

Surface vibrators are used to consolidate thin layers of concrete, such as facing mixtures. Typical types of surface vibrators include vibrating screeds, a small plate or grid vibratory tamper (usually 2 ft to 3 ft

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surface. Surface vibrators shall be moved at a rate sufficient to embed the coarse aggregate and bring a sufficient quantity of paste to the surface for finishing. The vibration and rate of movement shall be sufficient to compact the full depth of the concrete layer. Solid plate and bull float vibrators shall be operated at a slight angle from the plane of the concrete surface for best results.

If grate tampers are used, the concrete slump shall not be over 2 in. (50 mm). Vibrating grate tampers shall not be used for structural lightweight aggregate concrete.

### **4.8.7 Use of Vibrating Tables**

Care shall be taken to ensure the proper distribution of vibration when vibrating tables are used. The number and location of external vibrators to be used on a vibrating table shall be determined on the basis of adequate amplitudes of vibration and uniform distribution over the entire concrete surface. The frequency and amplitude shall be checked at several points on the table using a vibrograph, vibrating reed tachometer, or other suitable method. The vibrators shall be positioned to ensure that dead spots are eliminated and the most uniform vibration is attained.

## **4.9 Requirements for Curing Concrete**

### **4.9.1 General**

Freshly deposited and consolidated concrete shall be protected from premature drying and temperature extremes. Concrete shall be cured with a minimal moisture loss, and at a relatively constant temperature, for the period of time necessary to ensure proper hydration of the cement and hardening of the concrete. Curing shall be started immediately following initial set of the concrete. Curing procedures shall be well established and properly controlled to develop the required concrete quality and stripping or transfer strength. Curing procedures shall be designed to minimize plastic shrinkage cracking.

## **Commentary**

[0.6 m to 0.9 m] square in area) powered by an external air vibrator, hand jitterbug, and bull floats with vibrators mounted along the rib section of the floats. Vibrators on the bull floats should be mounted so that the shafts of each vibrator rotate in opposite directions.

When using surface vibrators, care should be exercised to prevent a smooth face mixture back surface, which may result in poor bond to the backup concrete.

### **C4.8.7 Use of Vibrating Tables**

Vibrating tables or casting decks are best used for flat or low-profile units, and provide an easy and effective method for application of external vibration.

The frequency and amplitude of vibrating molds and vibrating tables equipped with external vibrators should be determined at sufficient points to establish the level of uniformity. Inadequate amplitudes cause poor consolidation, while excessive local amplitudes cause the concrete to roll and tumble so that it does not consolidate properly.

## **C4.9 Requirements for Curing Concrete**

### **C4.9.1 General**

Determining the proper type of curing is dependent on variables such as the mass of the member, type and properties of cement, air temperature, humidity, and many others. The curing period of concrete is of significant interest in the production of precast concrete elements. It should begin during the early stages of strength development (at initial set) and continue until the concrete has reached a specified strength for stripping or stressing the member.

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To produce concrete of uniform appearance, consistent and uniform curing conditions shall be provided. Surface misting or other antievaporation measures shall be used to prevent and minimize plastic shrinkage cracking.

Protection of concrete surfaces against moisture loss to prevent shrinkage cracking of SCC or concrete that contains silica fume, metakaolin, or other pozzolans shall begin immediately after finishing.

### 4.9.2 Curing Temperature Requirements

The concrete in the form/mold shall be maintained at a temperature of no less than 50 °F (10 °C) during the initial curing period (prior to reaching stripping strength). The time period between placing of concrete and the start of curing shall be minimized in hot or windy weather to prevent loss of moisture.

During the initial curing period, positive action shall be taken to provide heat if necessary to maintain minimum temperatures and prevent loss of moisture from the element. Curing materials or methods shall not allow one portion of an element to cure differently from other portions of the element.

The maximum curing temperature shall not exceed the recommendations of Section 4.9.5.1.

The maximum initial curing temperature provisions of this section and Section 4.9.5 apply whether or not supplemental heating is used in the curing process.

## Commentary

Proper curing involves maintaining a satisfactory moisture content and temperature in the concrete. Rapid moisture loss may result in reduced strength development and an increased potential for plastic shrinkage cracking. Accordingly, concrete surfaces should be protected to prevent rapid loss of moisture while the concrete is plastic.

ACI 308R, *Guide to Curing Concrete*, describes various curing procedures in detail. High dosages of silica fume or metakaolin produce concrete with significantly reduced bleeding. Therefore, there is no need to wait for the bleeding to conclude before initiating protection of the surface.

### C4.9.2 Curing Temperature Requirements

Except for special locations or climates with prolonged temperatures below 50° F (10° C), continued curing in storage yards should enable the units to reach final design strength. Rapid drying may result in plastic shrinkage cracking.

Retention of the heat released by the hydration of the cement can be used to provide much of the heat for curing.

Insulated tarpaulins are effectively used for a combination of moisture and heat retention. Differential curing of an element may produce color variations in the finished products and differential shrinkage of the concrete, which can lead to warping of the element.

Maximum curing temperature requirements apply to products that attain high curing temperatures from accelerated curing procedures and/or a combination of heat of hydration, solar radiation heating, and high ambient air temperature conditions.

Heat generated during cement hydration raises the temperature of concrete to a greater or lesser extent depending on the size of the concrete placement, its surrounding environment, and the amount of cement in the concrete. As a general rule a 5 °F to 15 °F (2 °C to 9 °C) temperature rise per 100 lb (45 kg) of portland cement can be expected from the heat of hydration. There may be instances in hot-weather-concrete work and massive concrete (36 in. or 1 m

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### **4.9.3 Curing to Attain Specified Stripping or Transfer Strength**

Curing shall be performed until the stripping or transfer strength as indicated on the production drawings has been achieved. The stripping or transfer strength shall be specified by the precast engineer, based on the characteristics of the product.

The stripping, transfer, or handling strength of the product shall be determined by test specimens cured under the same curing conditions as the product.

### **4.9.4 Monitoring of Concrete Curing Temperatures**

Concrete elements cured using the application of heat (or solar radiation) to accelerate curing shall be monitored to ensure that the minimum and maximum concrete temperatures, rate of heating, and rate of cooling specified herein are not exceeded.

Maximum and minimum temperature or rate of temperature change shall be recorded at appropriate monitoring locations.

thick) placements when measures should be taken to cope with the generation of heat from cement hydration.

### **C4.9.3 Curing to Attain Specified Stripping or Transfer Strength**

Stripping or prestress transfer strengths are typically specified at a minimum of 2,000 psi (13.8 MPa) for non-prestressed units and 3,000 psi (20.7 MPa) or greater for prestressed units. Specified release strengths higher than this may require special mixture design, special curing provisions, or longer curing cycles. Allowing products to dry or cool before transfer of prestress (while still in a restrained condition) may cause unwanted cracking.

Documented and correlated methods using concrete maturity (time and temperature relationships) have proven to be beneficial in refining curing procedures and more accurately predicting when the required stripping strength has been achieved.

Due to the difference in mass between standard test specimens and the actual product, curing “under the same conditions” usually requires that the test specimens be protected from moisture loss and rapid temperature variations. Accordingly, the temperature of the specimens should be closely monitored.

In addition to the standard test cylinders cured in accordance with ASTM requirements, additional test cylinders should be made and cured similarly to the units for estimating critical shipping or erection strengths.

### **C4.9.4 Monitoring of Concrete Curing Temperatures**

Careful monitoring of concrete curing temperatures, and correlation with respect to stripping or release strengths, can be effectively used to optimize the curing cycle.

Temperature monitoring locations should be based on the location of heating or cooling sources, the configuration and design of the form/mold and insulating enclosure, and the cross-sectional dimensions and configuration of the product.

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### 4.9.5 Initial Curing Of Concrete

### C4.9.5 Initial Curing Of Concrete

#### 4.9.5.1 General

#### C4.9.5.1 General

Initial curing procedures shall be developed to optimize the concrete strength development while ensuring the long-term durability of the concrete.

Initial curing is an important aspect of many precast concrete operations, which rely on a daily production cycle for ensuring economical production.

Equipment shall be available to control and/or record the time and temperature relationship for the initial curing cycle. The number of thermometers or thermocouples shall be sufficient to establish that uniform heat is supplied to each unit.

For new concrete mixture designs or initial curing procedures, a comparison should be made between test specimens that are subject to the same initial curing conditions as the product followed by final curing per ASTM C31/C31M, and specimens that receive standard curing in accordance with ASTM C31/C31M. The 28-day strength of the specimens representing the product receiving accelerated curing should not be less than 90% of the strength of the standard cured specimens at the same age.

Proper precautions should be taken with initial curing of units using surface retarders to make certain that the proper retarder is selected and that retardation is uniform and effective at the time of stripping and treating the surface. One temperature measuring device should be used for each set of units cast: (1) within 1 hr of each other; (2) with a similar mixture, and (3) cured under the same methods/controls.

Temperature guidelines for initial curing are as follows:

Temperature measuring devices should be located near the concrete test units if they are cured with the product, or at a location farthest from the heat source if a master-slave control is used.

1. The controlling temperatures shall be those actually achieved within the concrete elements, not ambient temperatures of the curing area.
2. Initial curing shall be started after the concrete has attained initial set, determined in accordance with ASTM C403/C403M, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*, except as noted herein. A strength gain of 500 psi (3.4 MPa) indicates that the concrete has attained initial set.

1. Curing procedures should be confirmed on an experimental basis. This is to ensure that the heat application rate limitations or the maximum temperature allowances given herein are not exceeded. The appropriate application of heat is fundamental to keeping the total curing time within a daily production period.
2. After placing, consolidation, and finishing, the concrete should be allowed to attain initial set before heat is applied that will raise the concrete temperature above 104 °F (40 °C); otherwise, the elevated temperature may have a detrimental effect on the long-term strength and durability of the concrete.

The time to initial set (preset period) is typically

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3. During the preset period, the concrete temperature shall not be increased at a rate in excess of 10 °F (5.6 °C) per hour. The total permissible temperature gain in the concrete during the preset period shall not exceed the placement temperature by 40 °F (22 °C) or a maximum of 104 °F (40 °C).

When the concrete temperature is increased by more than 10°F over the placement temperature by applying heat during the preset period, a comparison shall be made between test specimens that are subject to the same initial curing conditions as the product followed by the final curing per ASTM C31/C31M and specimens that receive standard curing in accordance with ASTM C31/C31M. The 28-day strength of the specimens representing the product receiving preset curing shall not be less than 90% of the strength of the standard cured specimens at the same age.

in the range of 3 hr to 8 hr after batching. The length of the preset period is dependent on factors such as the type of cement, use of admixture, water-cementitious ratio, temperature, and other mixture characteristics. Because of the wide possible variation of initial set times, determination of the actual initial set time per ASTM C403/403M is very important.

For a given concrete mixture design, the preset period may be established from test data at various initial concrete temperatures. A minimum of three ASTM C403/C403M time-of-setting test results should be plotted on a temperature-time graph. It is preferable to use test data obtained at 10 °F (6 °C) intervals. The extreme data points should cover the anticipated range of concrete placement temperatures. The best-fitting smooth curve is then drawn through the data points. To determine an appropriate preset time, plot the actual concrete placement temperature on the best-fit curve and find the associated time of initial set. The preset period determined from the graph should be rounded up to the next 1/2 hr.

Any changes in the concrete mixture components or ambient conditions that are likely to affect the preset time should be considered cause for performing new ASTM C403/C403M tests.

3. These temperature restrictions apply when heat is supplied to the curing enclosure prior to initial set. Temperatures in excess of 104 °F (40 °C) are possible due to natural cement hydration without supplemental heating and are not prohibited.

If it is desired to raise the temperature of the concrete during the preset period, a better approach is to heat the concrete constituents, thus raising the temperature of the fresh concrete prior to placement. The maximum concrete temperature of 95 °F (35 °C) at time of placement should be observed as well as the 104 °F maximum allowed prior to initial set.

Increasing the concrete temperature by more than 10 °F (5.6 °C) prior to initial set can result in a reduction of concrete strength and long-term durability. This provision requires that control test specimens be made to determine the effect on

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4. For initial curing, heat shall be applied at a controlled rate following the preset period in combination with an effective method of supplying or retaining moisture.

A heat gain not to exceed 36 °F (20 °C) per hour, measured in the concrete, is acceptable provided the concrete has attained initial set in accordance with ASTM C403/C403M.

5. The maximum concrete temperature during initial curing for products exposed to the different types of service listed below shall not exceed the values given for that type of service. This temperature shall be measured inside the unit, in the portion of the unit that is likely to experience the highest concrete temperature during curing.

concrete properties.

Standard curing requires that test specimens be stored for up to 48 hr at a temperature range of 60 °F to 80 °F (16 °C to 27 °C) for concrete strength below 6,000 psi (41.4 MPa). For concrete strength 6,000 psi and above, use a temperature range of 68 °F to 78 °F (20 °C to 26 °C), followed by moist curing at a temperature of  $73 \pm 3$  °F ( $23 \pm 2$  °C) until tested. The companion specimens should be monitored to ensure the same accelerated curing conditions as the product they represent. When the product is removed from the form, these specimens should be placed in the same final curing environment as the control specimens until they are tested.

4. The limitations on concrete temperature gain rate and the maximum permissible temperature above placement temperature during the preset period should be observed.

The rate of heat gain should not be greater than that necessary to attain the minimum stripping and transfer strength in the required amount of time.

5. The maximum concrete temperature should not be greater than necessary to attain the minimum stripping and transfer strength in the required amount of time. This is because high internal concrete temperatures have been shown to increase the potential for alkali-silica reaction (ASR) and delayed ettringite formation (DEF), which are potential matrix deterioration mechanisms.

Special mixture design measures may also be required to avoid premature concrete deterioration in concretes that employ aggregates that are susceptible to ASR, which is sometimes associated with DEF. If testing indicates potentially reactive aggregates, additional proven mixture design measures should be used to mitigate the possibility for ASR.

The intention of these requirements is not to exceed the maximum allowable concrete temperature.

Note that while a maximum curing temperature without mitigating measures of 158 °F (70.0 °C) is allowed, as ACI and several major DOTs

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- a. In damp or continuously wet environmental conditions, limit curing temperature to 158 °F (70.0 °C).

specify. Mitigation procedures, as outlined here, have been found to be a possible deterrent of DEF with curing temperatures up to 170 °F (76.7 °C).

a. “Damp” or “continuously wet” should apply to concrete elements that will be subjected to a moist environment during service. Examples of this service category include:

- (1) External elements of buildings or structures that are exposed to precipitation, surface water, high humidity, or groundwater.
- (2) Internal building elements subject to high humidity or moist conditions.
- (3) Elements, parts of which may frequently drop below the dew point of the surrounding air resulting in frequent exposure to condensation.
- (4) Massive elements (greater than approximately 3 ft [1 m] in cross section) such that the internal moisture content of the concrete remains high.

Increases in cement fineness,  $\text{SO}_3$ ,  $\text{SO}_3/\text{Al}_2\text{O}_3$  ratio, and total equivalent alkali content above typical historic values appear to be additional risk factors for such reactions.

- b. When exposed to damp or continuously wet conditions, limit curing temperature to 170 °F (76.7 °C) if a mitigation concrete mixture design measure is employed.

- b. If it is not practically possible to stay below 158 °F (65.6 °C), mitigation concrete mixture design measures should be employed.

The following are possible mitigation concrete mixture design measures. Note that only one of the listed measures should be employed, not all of the measures.

- (1) Cement: use Type IP (where P is minimum 20% Class F fly ash), IS (where S is minimum 35% GGBFS), or Type II, IV, or V with a fineness  $< 400 \text{ m}^2/\text{kg}$ . Up to 10% of Type IP or IS cement may be replaced with Class F fly ash, GGBFS or silica fume.

There is some evidence that using fly ash for cement replacement at

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percentages less than 20% has little protective effect against DEF.

- (2) Or use cement with one-day mortar strength (ASTM C109/C109M) < 20 MPa (2,900 psi).
- (3) Or replace percentage of cement by weight with  $\geq 25\%$  fly ash meeting ASTM C618 Class F.

There is evidence that ASTM C618 Class C fly ash used at cement replacement percentages  $\geq 35\%$  may provide protection equivalent to Class F fly ash.

Note that fly ash in these quantities may reduce the modulus of elasticity of the concrete and the tensile strength of the concrete. For applications where these parameters are important, they should be directly determined by test as part of the concrete mixture qualification process.

- (4) Or replace percentage of cement by weight with 35% to 50% GGBFS meeting ASTM C989.
- (5) Or replace percentage of cement by weight with 35% to 50% of a combination of Class F fly ash (maximum 35%), GGBFS, or silica fume (maximum 10%).

Note that fly ash in these quantities may reduce the modulus of elasticity of the concrete and the tensile strength of the concrete. For applications where these parameters are important, they should be directly determined by test as part of the concrete mixture qualification process.

- (6) Or replace percentage of cement by weight with 35% to 50% of cement with a combination of Class C fly ash and at least 6% silica fume, UFFA (ultra-fine fly ash), or metakaolin. However, no more than 35% may be fly ash and no more than 10% may be silica fume.

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- (7) Or replace percentage of cement with 10% metakaolin, ASTM C618.
- c. When exposed to infrequent wetting, continuously dry limit curing temperature to 180 °F (82 °C).
- c. For units not exposed to a damp, continuously wet environment, or for structures subject to only infrequent local wetting, local protective measures to limit exposure to continuous wetting have been shown effective in ensuring long-term durability.
- This applies to dry interior usage situations and to selected exterior applications in desert environments.
- Testing to determine the absence of potential for ASR or DEF should consider the fact that these mechanisms may not be observable in concrete structures in some cases until years after the facility has been put into service.
- For this reason, curing to this temperature level should be associated with a record of successful long-term product performance in similar conditions.
6. The maximum cooling rate from the sustained accelerated curing temperature shall be 50 °F per 24 hours and 5 °F per hour (27.8 °C per 24 hours and 2.8 °C per hour). In order to prevent surface crazing or other thermal- related damage, the cooling at this rate shall continue until the concrete temperature is 40 °F (22 °C) or less above the ambient temperature.
6. Units should be allowed to cool gradually to prevent thermal shock, which may cause surface crazing or cracking. When the concrete is warmer than the ambient conditions, there is tendency for soluble salts (efflorescence) to migrate to the surface immediately after stripping. Cool water should not be used to accomplish aggregate exposure until the unit has cooled to ambient temperature.
- Concrete should also be protected from temperature drops that could cause thermal shrinkage cracks, especially within 24 hr of casting. Thermal shrinkage cracking may occur when the cooling rate is greater than 5 °F (3 °C) per hour, or greater than 50 °F (28 °C) in 24 hr, in concrete members with a least dimension of 12 in. (300 mm) or less.
7. Temperature recording devices shall be used to record the time-temperature relationship for the entire curing period or until stripping or transfer strength is achieved. A temperature recording device shall be placed for each concrete strength test.
7. To aid personnel who control the temperature during curing, it is recommended that the desired curing time-temperature relations should be placed on the chart of the recording thermometer. With this information available, the desired temperature can be more easily maintained. Temperature monitoring should be performed at the coolest and hottest positions in the unit.

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Curing temperatures have increasingly detrimental effects on the concrete as the boiling point of water (212 °F [100 °C]) is approached. In addition to possible detrimental chemical changes in the concrete, the expansion of moist air or vapor in the pore spaces of the cement paste can cause damage that results in a loss of strength and durability.

### **4.9.5.2 Curing with Live Steam**

Steam curing shall be performed under an enclosure to minimize moisture and heat loss. The curing enclosure shall allow free circulation of the steam. Steam jets shall be positioned to provide a uniform distribution of heat without discharging directly on the concrete, forms/molds, or test cylinders.

### **C4.9.5.2 Curing with Live Steam**

Monitoring techniques will require temperature checks at various points to effectively control curing temperatures.

### **4.9.5.3 Curing with Radiant Heat and Moisture**

During the cycle of radiant heat curing, effective means shall be provided to prevent rapid loss of moisture in any part of the member.

### **C4.9.5.3 Curing with Radiant Heat and Moisture**

Radiant heat may be applied by circulating steam or hot liquids through pipes, electric blankets, heating elements, or circulation of warm air.

Moisture may be supplied by a cover of moist burlap, cotton mats, or other effective means. Moisture may be retained by covering the member with an impermeable sheet in combination with an insulating cover, or by applying a liquid seal coat or membrane-curing compound.

Due to the slow rise of ambient temperatures with radiant heat, application of the heat cycle may be accelerated to meet climatic conditions. In all cases, the curing procedure to be used should be well established and carefully controlled to meet the requirements outlined in Section 4.9.

### **4.9.6 Curing by Moisture Retention Without Supplemental Heat**

#### **4.9.6.1 General**

For curing of the concrete without supplemental heat, the surface of the concrete shall be kept covered or moist until such time as the compressive strength of the concrete reaches the specified stripping or transfer strength.

### **C4.9.6 Curing by Moisture Retention Without Supplemental Heat**

#### **C4.9.6.1 General**

An acceptable method is to leave the element in the form/mold, keeping the exposed surfaces continuously moist by fogging, spraying, or covering with wet mats, or by covering the exposed surface with an impermeable cover or membrane curing compound.

Relative humidity of the air at the concrete surface

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### **4.9.6.2 Moisture Retention Enclosures**

Enclosures used for the purpose of retaining moisture during the curing period shall ensure that free water is not lost from any concrete surface during the curing cycle. Moisture retention enclosures shall remain in place until the completion of the curing cycle as described above.

### **4.9.6.3 Curing with Membrane Curing Compound**

The use of membrane curing compound to retain moisture within the concrete during curing shall be as follows:

1. The coating of membrane curing compound conforming to ASTM C309 or ASTM C1315 shall cover the entire exposed surface with a uniform film. The coating shall remain in place without gaps or omissions until the full curing cycle is complete. Positive means shall be taken to detect and recoat areas of incomplete coating.
2. The membrane curing compound shall be applied to the exposed concrete surface in accordance with the manufacturer's recommendations.
3. The membrane curing compound shall be compatible with coatings or other materials to be applied to the product in later construction stages.

should be above 80% during the initial curing period.

### **C4.9.6.2 Moisture Retention Enclosures**

Moisture retention enclosures should be resistant to tearing and should be positively fastened in place to avoid displacement by wind or other means during the curing cycle.

### **C4.9.6.3 Curing with Membrane Curing Compound**

Curing compounds should only be used on surfaces where discoloration or staining will not result in an unsatisfactory product. Some curing compounds function as bond breakers and may interfere with adhesion of repairs or surface coverings such as paint, fabric, insulation materials, or other types of protective coatings. Curing compounds with bond-breaking characteristics should only be used if a definite bond break is required.

Some project specifications require curing compound approval prior to use.

Membrane curing compounds should not be used in areas where joint sealants or other required adhesive materials are to be applied, unless entirely removed at the end of the curing period. Removal should be performed by sandblasting or with an approved solvent, unless conclusive test results demonstrate that the residue of the membrane does not reduce bond.

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## **Commentary**

### **5.1 Fabrication and Placement of Reinforcing Steel**

### **C5.1 Fabrication and Placement of Reinforcing Steel**

#### **5.1.1 General**

Procedures for fabrication and placement of reinforcing steel shall be developed, implemented, and understood by appropriate personnel. Procedures and practices shall be reviewed to ensure conformance.

#### **C5.1.1 General**

Procedures developed for epoxy-coated or galvanized reinforcement should be based on industry and/or manufacturer's recommended practice as a supplement to the provisions of this document.

#### **5.1.2 Storage of Reinforcing Steel**

Reinforcing-steel deliveries shall be identified with a heat number that can be tied to a mill certificate. Reinforcing steel shall be kept free of contamination and stored separately in a neat and orderly fashion. It shall be identified so that different types, grades, sizes, and preheat requirements can be identified and recognized through the entire reinforcement preparation process. Bundles of reinforcing materials shall be kept straight and free of kinks until cut and bent to final shape to facilitate dimensional control within established placing tolerances. All reinforcing steel shall be stored off the ground on blocks, racks, or sills. Special attention shall be given to prevent loose rust from forming or the steel from becoming contaminated with grease, oil, or other materials that would adversely affect the bond.

#### **C5.1.2 Storage of Reinforcing Steel**

Reinforcing steel should be divided into categories of preheat unless a uniform high preheat is chosen for all welded assemblies. To designate different preheat requirements, it is recommended that either a tagging or a coloring system be used to designate preheat requirements when the bars are received.

Good bond between reinforcement and concrete is essential if the steel is to perform its functions of resisting tension and keeping crack widths small. Therefore, the reinforcement should be free of materials injurious to bond, including loose rust. Mill scale that withstands hard wire brushing or a coating of tight rust is not detrimental to bond.

Coated reinforcing typically includes epoxy and galvanized coatings.

Epoxy-coated reinforcing bars shall be handled in a manner so that the protective coating is not damaged beyond what is permitted by ASTM A775/A775M or A934/A934M.

If it is necessary to store epoxy-coated bars outdoors for an extended period of time—usually more than two months—the bars should be protected from the weather and direct sunlight.

Equipment for handling coated welded wire or reinforcing bars shall have protected contact areas. Nylon slings or padded wire rope slings shall be used. Bundles of coated welded wire or reinforcing bars shall be lifted at multiple pick-up points to minimize abrasion from sags in the bundles. Hoisting with a spreader beam or similar device shall be used to prevent bar-to-bar abrasion from sags in the bundles. Coated reinforcement shall not be dropped or dragged. Coated reinforcement shall be stored on timbers or other suitable protective cribbing with the dunnage spaced close enough to prevent sags in the bundles.

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Each bundle of welded-wire reinforcement shall have a suitable tag that bears the name of the manufacturer, style designation, width, length, and any other information specified by the purchase agreement. Steel strapping used to bundle the welded-wire sheets shall not be used to lift the bundles.

### **5.1.3 Fabrication of Reinforcing Steel**

The fabrication equipment shall be of a type, capacity, and accuracy capable of fabricating reinforcing cages to the required quality, including tolerances. Fabrication tolerances shall be in accordance with ACI 117 unless stated otherwise in the project specifications.

Review of fabrication shall be performed by quality control personnel to check that reinforcement has been cut and bent to correct shapes and dimensions, and is of correct size and grade.

Reinforcing bars shall be bent cold, unless otherwise permitted by the precast engineer, and shall not be bent or straightened in a manner that will injure the material. Bars with kinks or improper bends shall not be used. The diameter of bend measured on the inside of the bar shall be in accordance with ACI 318. Bars to be galvanized shall be bent in accordance with ASTM A767/A767M.

When zinc-coated (galvanized) reinforcement is damaged, the area to be repaired shall be coated with a zinc-rich paint (92% to 95% metallic zinc in the dry film) conforming to ASTM A767/A767M in accordance with ASTM A780/A780M.

Small spots of epoxy coating damage that may occur during handling and fabrication shall be repaired with patching material when the limits stated in the project specifications are exceeded. The maximum amount of repaired coating damage at the precast plant shall not exceed 2% of the total surface area per lineal foot (0.3 m) of the coated bar. This means that a careful inspection and evaluation is needed prior to the approval of touch-up or recoating.

Damaged epoxy coating shall be repaired with patching material conforming to ASTM

### **C5.1.3 Fabrication of Reinforcing Steel**

It is recommended that reinforcing bars be bent after galvanizing when possible. If not possible, galvanizing may be performed after bending, but a larger bend diameter may be required to prevent strain-age embrittlement. When galvanizing is performed before bending, some cracking and flaking of the galvanized coating at the bend is to be expected and is not a cause for rejection. The tendency for cracking of the galvanized coating increases with bar diameter, severity of bending, and rate of bending.

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A775/A775M and in accordance with the patching material manufacturer's recommendations.

When galvanized or epoxy-coated reinforcing bars are welded or cut during fabrication, the weld area and the ends of the bar shall be coated with the same material used for repair of coating damage.

The starting and ending points of welded wire reinforcement bends with an inside diameter less than eight wire diameters shall be located at least four wire diameters from the nearest welded cross wire. For wires larger than W6 or D6, the diameter of the mandrel about which the bend is made shall be a minimum of four wire diameters. A minimum of two wire diameters shall be used for W6 or D6 and smaller wires.

If reinforcing steel is fabricated by an outside supplier, that supplier shall furnish the representative mill certificates and records of compliance to the specification requirements.

Cage assemblies, whether made for the entire casting or consisting of several subassemblies, shall be constructed to fit in the molds without being forced. Cages shall have sufficient three-dimensional stability that they can be lifted from the jig and placed into the mold without permanent distortion. Also, the reinforcing cages shall be sufficiently rigid to prevent dislocation during concrete consolidation in order to maintain the placement and tolerance requirements.

Reinforcing bars shall be tied using black annealed wire or welded in accordance with AWS D1.4/D1.4M with the approval of the precast engineer. Zinc-coated or epoxy-coated reinforcement shall be tied with plastic or epoxy-coated tie wire or other acceptable material. All tie wires shall be bent back away from formed surfaces to provide maximum concrete cover.

Where cages are tied, ends of ties shall not encroach on the concrete cover of the reinforcement. When cages are welded, care shall be taken to ensure that tack welding does not undercut reinforcing bars and thus diminish the area and strength.

For assembling ASTM A706/A706M bars into cages, if the holding wires conform to ASTM A82/A82M or A496/A496M, electric resistance welds from a fusion process may be used.

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All splicing of welded wire reinforcement or reinforcing bars, whether by lapping, mechanical connections, or welding, shall be shown on the approved shop drawings. The concrete cover and bar spacings, as a result of splicing, shall conform to ACI 318. Mechanical connections or splices shall be installed in accordance with the splice device manufacturer's recommendations. After installation of mechanical connections on zinc- or epoxy-coated reinforcing bars, coating damage shall be repaired appropriately. All parts of mechanical connections used on coated bars, including steel splice sleeves, bolts, and nuts, shall be coated with the same material used for repair of coating damage.

### **5.1.4 Installation of Reinforcing Steel**

The size, shape, and spacing of all reinforcement shall be checked against the approved shop drawings. Variations in spacing of reinforcement exceeding allowable tolerances shall be corrected.

All reinforcement, at the time concrete is placed, shall be free of grease, form/mold oil, wax, dirt, paint, loose rust or mill scale, or other contaminants that may reduce bond between steel and concrete or stain the surface of the concrete.

When placing concrete through more than one mat of reinforcement, bars shall be vertically aligned above each other in all horizontal directions to minimize interference with placing and consolidating concrete.

Reinforcement shall be accurately located in the mold as indicated on the approved shop drawings. It shall be securely anchored to maintain its designed location within allowable tolerances while concrete is placed and consolidated. If spacers are used, the spacers shall be of a type and material that will not cause spalling of the concrete, rust marking, or other deleterious effect. Metal chairs, with or without coating, shall not be used in a finished face. For smooth cast facing, chairs shall be plastic tipped or all plastic to ensure the absence of surface rust staining. If possible, reinforcement cages shall be securely suspended from the back of the molds. Uncoated reinforcement shall be

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Inspection and plant personnel should be familiar with the manufacturer's recommendations for installation of mechanical connection systems. Mechanical devices that are intended to be coupled with reinforcement cast in adjoining work should receive close inspection for accuracy of placement.

Mechanical connection devices are generally required and designed to develop a minimum of 125% of the specified yield strength of the bar being spliced. Quality control documentation should include manufacturer's certification to substantiate the capacity of the device.

### **C5.1.4 Installation of Reinforcing Steel**

Reinforcement should be placed symmetrically as possible about the panel's cross-sectional centroid to minimize bowing and distortion of panels. Asymmetrical placement may cause panel warpage due to restraint of drying shrinkage or temperature movements.

Spacers (bar supports) or chairs may mar the finished surface of an element that will eventually be exposed to weathering.

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supported on reinforcement supports made of plastic.

Zinc-coated (galvanized) reinforcement supported from the mold shall rest on bar supports made of plastic or other acceptable dielectric material or other acceptable materials. Galvanized reinforcement shall not be directly coupled to large areas of uncoated steel reinforcement unless plastic tie wire is used and local insulation is provided with dielectric materials, such as polyethylene or similar tape.

Epoxy-coated reinforcing bars supported from the mold shall rest on bar supports made of plastic or other acceptable dielectric material. Reinforcing bars used as support bars for epoxy-coated material shall be coated with epoxy as well. Proprietary combination bar clips and spreaders used with epoxy-coated reinforcing bars shall be made of corrosion-resistant material or coated with nonconductive material.

Supports shall be sufficient in number and strength to support the reinforcement and prevent displacement before and during concreting operations. Spacing shall be such that sagging between supports will not intrude on the specified concrete cover or placement tolerances.

Concrete cover to the nearest reinforcement shall be checked by measurement. Care shall be taken to maintain the critical dimensions determining the cover over reinforcement. The reinforcement type, sizes, and spacing shall also be checked against the approved shop drawings. Variations in spacing of the reinforcement exceeding allowable tolerances shall be corrected. The horizontal clear distance between reinforcement and mold shall be equal to the specified concrete cover or 1.5 times the maximum aggregate size, whichever is larger.

When mechanical splice devices are used, the required cover shall be measured to the nearest surface of the device. Attention shall also be given to scoring, false joints or rustication, and drips, with the required minimum cover measured from the thinnest location to the reinforcement.

The bimetallic couple established by direct contact between galvanized steel and uncoated steel should not exhibit corrosive reactions as long as the depth to zinc/steel contact is not less than the cover required to protect uncoated steel alone under the same conditions or the galvanized mass is larger than the uncoated steel mass.

Protection of reinforcing steel from corrosion and the resultant possibility of surface staining is obtained by providing adequate cover. A protective iron oxide film forms on the surface of the bar as a result of the high alkalinity of the cement paste. As long as this alkalinity is maintained, the film is effective in preventing corrosion. The protective high alkalinity of the cement paste is usually lost only by leaching or carbonation. Accordingly, concrete of sufficiently low permeability and with the required cover over the steel should provide adequate protection. Low permeability is characteristic of well-consolidated concrete with a low water-cementitious ratio. This composition is typical of architectural precast concrete.

Prestressing strand should be protected by a minimum concrete cover of 3/4 in. (19 mm). Reinforcing steel should be protected by concrete cover equal to the nominal diameter of bars, but not less than 3/4 in.

Minimum cover requirements over reinforcement should be 1-1/2 in. (38 mm) for ungalvanized

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Reinforcement shall be placed within the allowable tolerances, but the concrete cover shall be set so that the resulting concrete cover is never less than the specified cover.

Care shall be observed in placing of bars that extend out of the member and are intended to provide structural connection to adjoining cast-in-place or sequential castings. The extensions shall be within the governing tolerances specified or  $\pm 1/2$  in. (12 mm) of plan dimensions. Exposed reinforcing bars shall be protected from corrosion with a cold zinc coat or cement slurry to prevent excessive corrosion and staining of the exposed surfaces during storage. Paste adhering to extended steel shall be removed prior to subsequent castings to ensure proper bond.

Reinforcement shall not be bent after being embedded in hardened concrete without approval of the precast engineer.

If reinforcing steel or hardware anchors cannot be located as shown on the drawings, all changes shall be reviewed and approved by the precast engineer. The drawings shall also be corrected to show the as-cast position. Under no circumstances shall main reinforcement or

reinforcement or  $3/4$  in. (19 mm) for galvanized or epoxy-coated reinforcement when the precast concrete elements are acid treated or exposed to a corrosive environment or to severe exposure conditions. However, the  $3/4$  in. cover is not a realistic option unless the maximum aggregate size does not exceed  $1/2$  in. (12 mm) and the reinforcing cage is not complex.

Reinforcing bar sizes No. 3 through No. 5 may be cold bent the first time, provided the reinforcing bar temperature is above  $32^{\circ}\text{F}$  ( $0^{\circ}\text{C}$ ). For bar sizes larger than No. 5, the bars should be preheated before bending. Heat may be applied by any method that does not harm the reinforcing bar material or cause damage to the concrete. A length of reinforcing bar equal to at least five bar diameters should be preheated; however, preheating should not extend below the surface of the concrete. The temperature of the reinforcing bar at the concrete interface should not exceed  $500^{\circ}\text{F}$  ( $260^{\circ}\text{C}$ ). The preheat temperature of the reinforcing bar should be between  $1,100^{\circ}\text{F}$  and  $1,200^{\circ}\text{F}$  ( $593^{\circ}\text{C}$  to  $649^{\circ}\text{C}$ ). The preheat temperature should be maintained until bending or straightening is complete. The preheat temperature should be measured by temperature measurement devices, contact pyrometers, or other acceptable methods. The heated bars should not be artificially cooled (with water or forced air) until the temperature has cooled to at least  $600^{\circ}\text{F}$  ( $316^{\circ}\text{C}$ ).

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prestressing steel be eliminated to accommodate hardware.

### **5.2 Prestressing**

### **C5.2 Prestressing**

#### **5.2.1 General Tensioning Requirements**

#### **C5.2.1 General Tensioning Requirements**

Tensioning of tendons shall be accomplished within stated tolerances, as the force is critical for both performance and structural safety of the member and the structure of which it forms a part. Because the prestress force is critical for both performance and structural safety and it cannot be checked accurately later in the production process, the stressing operation is important and shall be subject to careful production and quality controls.

The ultimate capacity of a prestressed concrete member is not likely to be significantly affected by small variations in the tensioning of individual tendons. However, such variations can result in differential camber, inaccurate concrete stresses, lateral bowing of members, and reduction of the cracking load, all of which can contribute to the manufacture of unsatisfactory members.

#### **5.2.2 Tensioning of Tendons**

#### **C5.2.2 Tensioning of Tendons**

For all methods of tensioning, force in the tendons shall be determined by monitoring either applied force or elongation and independently checked by the other. At the completion of tensioning operations, the two control measurements, force and elongation, shall agree within 5% of the computed theoretical values. If discrepancies are in excess of 5%, the tensioning operation shall be suspended and the source of error determined and evaluated by qualified personnel before proceeding. Additionally, the control measurements of force and elongation shall have an algebraic difference of 5% or less. If the measurements do not agree with each other within 5%, a load cell may be added at the dead end and if force measurements agree within 5% between the gauge at the live end and the load cell at the dead end, the elongation agreement can be waived.

In tensioning of tendons, the gauging system indicates that the proper force has been applied. Applied force may be monitored by direct measurement using a pressure gauge piped into the hydraulic pump and jack system, dynamometer, load cell, or other accurate devices. A check of elongation indicates that the correct size of tendon has been used and operation losses are within tolerance limits, and provides a check on the gauging system. Elongation also aids in confirming the physical properties and characteristics of the strand. For information on elongation corrections, refer to Section 5.3.11, and for information on force corrections, refer to Section 5.3.12.

If the method of jacking to elongation and checking by gauge pressure is used, it is extremely important to monitor the gauge at all times to prevent overstressing of the strand. If excessive friction in the tensioning setup exists, a partial length of the tendon will be overstressed to achieve the theoretical elongation. Gauge pressure should not exceed design pressure by 5%.

The tolerances in this manual are not intended to allow the practice of routinely falling short on the control measurement. Other governing specifications may require no less than 100% of the design jacking force to be applied.

In all methods of tensioning, an initial force necessary to eliminate slack in the system shall first be applied. After an initial force has been

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applied to the tendon, reference points for measuring elongation due to additional tensioning forces shall be established. For single-strand tensioning, the reference mark shall be on the strand.

Calculations for elongation and gauge readings shall include appropriate allowances for chuck seating, bed shortening under load, abutment rotation, thermal effects, gauge correction based on calibration data, friction, and any other compensation for the setup.

Known recoverable friction losses (temporary in nature) may be compensated for based on past experience. After seating and adjustments to setup, the force versus elongation must be within the 5% tolerance based on liftoff or load cell readings.

### **5.2.3 Methods of Force Measurement**

Methods of measurement of the tensioning force shall consist of one or more of the following:

1. Digital or analog gauges to measure the pressure or force applied by a hydraulic jack.
2. Dynamometers connected in tension into the tensioning system.
3. Load cells connected into the tensioning system so the action of the tensioning operation imparts a compressive force to the sensing equipment.

In a parallel strand setup that provides minimal strand support during tensioning, the strand weight will produce a drop in stress once the strand is lifted into the proper position. In such cases, the strand weight may be compensated for.

### **C5.2.3 Methods of Force Measurement**

1. Pressure gauges or transducers should have dials or digital readout calibrated to show jacking force by means of an approved and calibrated load cell. The gauges can show hydraulic pressure, which, through correlation with the area of the ram in use, determines the actual force used for the tensioning process.

Rams and gauges should be calibrated together as a system. However, in multistrand tensioning systems, gauges may be calibrated against a master gauge of known accuracy, provided the rams are calibrated against the same master gauge.

2. Dynamometers can be used for initial tensioning operations due to the reduced level of forces involved in initial tensioning.
3. Properly calibrated load cells will provide the most accurate measure of tendon force at the point of application. Jacking systems are available with a load cell in the jack head or pressure transducer and a digital readout instead of a gauge.

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4. Force computed from the actual elongation of the strands shall be based on its physical properties and compensation adjustments.

### **5.2.4 Gauging Systems**

Hydraulic gauges, dynamometers, load cells, or other devices for measuring the tensioning force shall be graduated to read within a resolution of  $\pm 2\%$  of anticipated loads. Gauges, jacks, pumps, hoses, and connections shall be calibrated as a system in the same manner as used in tensioning operations. Calibrations shall be performed by an approved testing laboratory or calibration service, under the supervision of a registered professional engineer on the staff of a production plant, or as a consultant, in accordance with the equipment manufacturer's recommendations. A certified calibration curve shall accompany each tensioning system. Pressure readings can be used directly if the calibration determines that readings are within a  $\pm 2\%$  tolerance of actual force. Calibrations shall be performed at any time a tensioning system indicates erratic results, and at intervals no greater than 12 months.

Pressure gauges, pressure transducers for hydraulic systems, or other measuring devices, such as digital readout, shall have a full range of measurement of 1-1/2 to 2 times their normal working pressure, whether for initial or final force. If the same unit is used for both initial and final tensioning, the jacking system shall have separate gauges or separate scales to ensure accurate measurements of both the initial and final force. Gauge/transducer readings based on system pressure shall not be made below 10% or above 90% of the full-scale capacity of the gauge transducer, unless the gauge/transducer is calibrated in that range with a verified 2% accuracy.

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4. To determine the tensioning force (P) from elongation ( $\Delta$ ) use the equation

$$P = \Delta \frac{A E}{L}$$

where A is the cross-sectional area of the strand, E is the modulus of elasticity of the strand, and L is the tensioned length of the strand, dead-end chuck to point of measurement.

Sample calculations for tensioning setups are shown in Appendix H.

### **C5.2.4 Gauging Systems**

Gauges or digital readouts for single-strand jacks may be calibrated by means of an approved and calibrated load cell. Gauges for large multiple-strand jacks acting singly or in multiple should be calibrated by proving rings or by load cells placed on either side of the moveable stressing abutment.

In multiple-strand tensioning, use of a master gauge system to monitor accuracy of hydraulic gauges is acceptable as an ongoing calibration method, since the cycles of tensioning are only a fraction of the cycles in a single-strand system.

Gauges should have indicating dials at least 6 in. (150 mm) in diameter. Gauges should also be mounted at or near working eye level and within 6 ft (1.8 m) of the operator, positioned so that readings may be obtained without parallax.

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Tensioning methods employing hydraulic gauges shall have appropriate bypass valve snubbers and fittings so that the gauge pointer will not fluctuate but will remain steady until the jack load is released.

### **5.2.5 Control of Jacking Force**

Pressure bypass valves may be used for stopping the jack at the required force or for manually stopping the application of force with the valve. The accuracy of setting of automatic cutoff valves shall be verified by running to the desired cutoff force. This shall be performed when there is reason to suspect improper results, and as a minimum, at the beginning of every operational day.

### **5.2.6 Wire Failure in Strand or Tendons**

Failure of individual wires in a pretensioning strand or post-tensioning tendon is acceptable, provided the 5% allowable variation in prestress force for all strands in the entire element is not exceeded, the total area of broken wires is not more than 2% of the total area of tendons in a member, and the breakage is not symptomatic of a more extensive distress condition. The entire strand shall be considered ineffective if a wire breaks in a three-wire strand.

Welding shall not be performed near any prestressing strand. The prestressing strand shall not be exposed to spatter, direct heat, or short-circuited current flow.

### **5.2.7 Calibration Records for Jacking Equipment**

Calibration records shall show the following data:

1. Date of calibration.
2. Agency, laboratory, or registered

### **C5.2.5 Control of Jacking Force**

When manual cutoffs are used for control of jacking force, the rate of force application should be slow enough to permit the operator to stop the jack within the limits of the specified force tolerances.

### **C5.2.6 Wire Failure in Strand or Tendons**

The 2% limit of the total area of tendons in a member represents a relatively limited number of broken wires that can be accepted in a setup. When the 2% tolerance is exceeded, an adjustment is required that may sometimes necessitate detensioning and replacing the affected strands.

In any event, the setup with broken wires should be examined to determine the reason for the break, and engineering should be alerted for an evaluation. Strands that have welds within the coils sometimes break at the weld points of individual wires. Other problem areas include incorrectly aligned strand chucks, which create a bind at the front of the chuck during seating, or improperly maintained chucks. In single-strand tensioning operations, improper alignment of the jack surface interface with the chuck may also cause the strand to bind in the chuck.

Weld spatter can cause stress concentrations, and the temperature rise due to the direct effect of welding heat or the indirect effect of current flow through the high-tensile prestressing steel can cause damage or breakage in part or all of the strand.

### **C5.2.7 Calibration Records for Jacking Equipment**

Tensioning systems must be calibrated on a regular basis or whenever erratic results are encountered to provide effective control of tensioning. Tensioning calculations should be done with correct and current

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- engineer supervising the calibration.
3. Method of calibration (proving ring, load cell, testing machine, etc.) and its calibration reference.
  4. The full range of calibration with gauge readings indicated against actual load (force).

Calibration records for all tensioning systems in use shall be on hand for use in preparing theoretical tensioning values and shall be maintained until the next calibration. Personnel involved in preparing tensioning calculations shall have a copy of the calibration records for reference.

### **5.3 Pretensioning**

#### **5.3.1 Storage of Prestressing Steel**

Prestressing steel reels and coiled tendons shall be stored with identifying tags listing the heat number to relate the reel or tendon to a mill certificate. It is recommended that the reel or coil numbers shall be identified on the tensioning sheets. Care shall be taken in storage to avoid confusion between different types (low-relaxation or stress-relieved [normal-relaxation] strand) or diameters. Material handling of prestressing steel in the plant shall be done carefully to avoid abrading, nicking, or kinking the strands, bars, or wire as they are moved through the plant or set up for stressing. Special attention shall be given to protecting sheathing when unloading and storing coiled, sheathed tendons. Prestressing steel shall be stored off the ground.

Care shall be taken in the storage of prestressing steel to prevent corrosion due to humidity, galvanic, or electrochemical reaction due to contact with dissimilar metals.

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calibration data. Accordingly, such data should be distributed to personnel preparing tensioning calculations.

Tensioning system calculations may be performed by properly supervised plant personnel.

### **C5.3 Pretensioning**

#### **C5.3.1 Storage of Prestressing Steel**

The minimum yield of low-relaxation and stress-relieved (normal-relaxation) strand are different, so the strands need to be identified to avoid overstressing the stress-relieved strand by applying low-relaxation strand loads.

High-strength steel is much more susceptible to corrosion than steel of lower strengths. Where prestressing steel is exposed to wet weather or excessively humid conditions in storage, corrosion damage may occur within a few weeks. Storage under cover is preferred as a means of minimizing corrosion. Corrosion that deeply etches or pits the surfaces cannot be tolerated on prestressing steels; however, a light coating of tight surface rust is acceptable.

Strand properties are altered by concentrated heat or arcing electrical current. This alteration can result in lowered ultimate strength, which could result in strand failure under load.

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Bands on strand packs shall not be cut by a torch. Cutting or welding around strands in storage or prior to casting shall not be allowed.

### **5.3.2 General**

In all methods of pretensioning, the force shall be applied in two increments. An initial force shall be applied to the individual strands to straighten, eliminate slack, and provide a starting or reference point for measuring final elongation. The final force shall then be applied with elongation measured from the reference points.

Each plant shall develop written tensioning procedures providing step-by-step instruction to personnel performing the tensioning operation. Personnel shall be well trained and authorized to perform and/or record the tensioning process. These personnel shall be identified in the written procedures.

Tensioning procedures shall include instructions for:

1. Operation and control of jacking equipment.
2. Operation and control of gauging system.
3. Tensioning to an initial force and marking strand in preparation for measuring elongation.
4. Tensioning to a given force, measuring, and recording the corresponding elongation.
5. Checking for strand anchor seating.
6. Procedures in case of out-of-tolerance results.
7. Procedures in case of wire failure.
8. Alternative tensioning methods of measurement.
9. Detensioning and stripping.

### **C5.3.2 General**

Two methods of pretensioning are in general use: single-strand tensioning, which consists of tensioning each strand individually, and multiple-strand tensioning, which consists of tensioning several strands simultaneously. Either method may be used subject to proper allowances and controls. Both methods should utilize initial tension, then a final tension increment.

Prestressing in architectural units, after all losses, is typically in the range of 150 psi (1 MPa) to 800 psi (5.5 MPa) across the product section.

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### **5.3.3 Strand Surfaces**

Special care shall be exercised to prevent contamination of strands from form/mold release agent, mud, grease, or other contaminants that would reduce the bond between the steel and the concrete. Form/mold release agent shall be applied to the mold in a manner that does not contaminate the strand.

### **5.3.4 Stringing of Strands**

To avoid possible entanglement of strands and minimize unbalanced loads on the forms/molds during tensioning, a planned sequence of stringing and tensioning shall be followed.

Strands shall be pulled from the correct side of the pack, as identified by the manufacturer. Each length of strand shall be cut between the strand chuck and the coil or reel. Portions of strand that have been previously gripped with chucks shall not be incorporated in lengths of strand to be tensioned.

After stringing and tensioning, the strand shall be inspected for contamination by form/mold release

### **C5.3.3 Strand Surfaces**

Prior to stringing of strands, bottom forms should be inspected for cleanliness and accuracy of alignment, as it is difficult to make corrections after the strands have been tensioned. The entire force of a strand is transferred into the concrete through bonding of the hardened concrete to the strand. Therefore, it is extremely important that the strands be cleaned prior to concrete placement to ensure that bonding takes place. Since it is extremely difficult to effectively clean strands that have been contaminated, it is desirable to plan a program for prevention of contamination, rather than depending upon cleaning after contamination occurs.

Release agents, which do not dry, but remain as an oil, should be evenly applied to ensure release without excess or puddles that may contaminate strand placed in the mold. Excessive release agent should be removed from the form/mold surface.

See Section C6.2.2 (4) for more information regarding strand surface condition.

### **C5.3.4 Stringing of Strands**

An orderly procedure of stringing and tensioning strands facilitates the keeping of records, and is essential when data from a force recording device are to be identified with a particular strand.

Strand may be furnished either in coils, in reel-less packs, or on reels. Strands may be strung individually or in multiples. Strand pulled out from a coil or reel-less pack will rotate each time a revolution is pulled from the coil. Provision should be made to relieve these rotations.

Strands may be threaded through bulkheads or cages of reinforcing steel. In this case, care should be taken so the strand passes through freely and binding does not occur during the tensioning operations.

The practice of continuous stranding is not allowed due to the potential of placing nicked strand within a member. All strand chucks notch or nick the wires of the strand. The nicks result in local stress concentrations that may result in failure of the strand during tensioning. Such damage may also lower the ultimate strength of the strand through fatigue.

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agent or other surface coatings and, if contaminated, shall be cleaned using an approved method

### **5.3.5 Strand Chucks and Splice Chucks**

Strand chucks and splice chucks shall be capable of securely anchoring maximum tensioning forces. Chucks shall be used as complete units. Strand chucks designed with spring-equipped caps shall be used with caps. Strand chuck components shall be cleaned and inspected between each use and lubricated as necessary. Barrels, wedges, or caps that become visibly worn, cracked, or distorted, or allow slippage, shall be discarded. Strand chucks shall be assembled with compatible components from the same manufacturer to avoid improper fit and seating on strands. Inspection and maintenance of strand chucks in use shall include matching of chuck barrels and wedges by strand size and manufacturer. During inspection and reassembly, care shall be taken to avoid assembling improper chucks, such as 1/2 in. (13 mm) barrels with 7/16 in. (11 mm) wedges.

### **5.3.6 Strand Splices**

Strand lengths spliced together shall have the same lay of wire to avoid unraveling. The ends of the strand to be spliced shall be cut by shears, abrasive saws, or grinders.

The location of strand splices shall not fall within a member unless the splice is designed to develop the full ultimate strength of the strand.

For single-strand tensioning, the number of strands per bed that may be spliced is not restricted, provided all seating losses of the individual splices are verified and accounted for in the elongation calculations.

### **5.3.7 Strand Position**

Strands shall be positioned in accordance with the detailed dimensions shown in the production drawings. Strands shall be supported as required to maintain the vertical and horizontal position within the tolerances as specified in Division 7.

### **C5.3.5 Strand Chucks and Splice Chucks**

Strand chucks generally consist of a barrel, grooved wedges that are held together with an O-ring, and a spring-equipped cap.

Proper care of strand chucks cannot be overemphasized. In Appendix D, guidelines are given for inspection of strand chucks. Any cracks observed in wedges and barrels are evidence that the elements should be taken from service immediately to avoid a potential failure.

Strand chucks that are not equipped with spring caps have a tendency to seat the wedges unevenly, producing stress risers on sides of the strand at the forward contact point. When these chucks are used, proper attention should be given to ensure even seating of the sections.

### **C5.3.6 Strand Splices**

When strand sections are spliced together with opposing lay (twist), the splice will rotate, resulting in considerable stress loss in the strand.

The structural properties of the strand in the immediate vicinity of torch cutting are significantly affected by heat. Strand ends to be spliced should not be cut with a torch.

If strand is reused in the tensioning system, fresh cuts shall be made to the ends of the strand where chucks are resealed.

### **C5.3.7 Strand Position**

The importance of the correct quantity and position of prestressing strand cannot be overemphasized. These factors are critical to the product performing as designed. At the very least, strand position should be checked initially at the ends of the members and at all

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### 5.3.8 Spacing of Strands

At ends of members, the minimum center-to-center spacing of strands shall be as shown in Table 5.3.8, unless otherwise specified.

**Table 5.3.8 Minimum spacing of strand**

| Strand size, in. (mm) | Spacing, in. (mm) |
|-----------------------|-------------------|
| 3/8 (9.5)             | 1-1/2 (38.1)      |
| 7/16 (11.1)           | 1-5/8 (41.3)      |
| 1/2 (12.7)            | 1-3/4 (44.5)      |
| 9/16 (14.3)           | 1-7/8 (47.6)      |
| 0.6 (15.2)            | 2 (50.8)          |

### 5.3.9 Initial Tensioning

Care shall be taken to ensure that a valid starting point is established for elongation measurement by initial tension. After strands have been positioned, an initial force in the range of 5% and 25% of the final force shall be applied to each strand. Regardless of the method used, initial force shall be measured within a tolerance of  $\pm 100$  lb ( $\pm 45.4$  kg) per strand if the initial force is

intermediate bulkheads along the form. Member behavior is relatively insensitive to horizontal location of tendons in typical flat panels or members that are significantly wider than they are thick.

Check beds and equipment (headers, etc.) initially to ensure desired strand position. It is particularly important to check strand position requirements when incidental reinforcing steel is supported partially or entirely by the strands, as the weight of the incidental steel will tend to pull the strand out of position.

In long-line products or heavily reinforced cage sections, strand should be chaired to ensure proper position. The position of prestressing steel in relatively shallow members, such as panels, is especially critical and should be closely controlled and monitored. The sequence of placement and location of reinforcing steel, inserts, and blockouts should be carefully planned to avoid interference with the designed vertical position of the prestressing steel.

### C5.3.8 Spacing of Strands

Half-inch and 0.6 inch "special" are larger than normal 1/2 in. and 0.6 in. strand, respectively. Similar spacing should be used. A 0.02 in. larger spacing is not necessary. Half-inch "special" strand is at the upper limit of the ASTM requirement for 1/2 in. nominal strand.

### C5.3.9 Initial Tensioning

Initial tensioning establishes an important reference point for final tensioning operations. For that reason, the initial tension should be enough to remove the slack from the strand so that a consistent point of reference can be established for final and accurate elongation measurements. A sufficient initial force should be applied to produce the majority of strand seating into the dead-end chuck. If a final tensioning

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equal to or less than 10% of final force, or  $\pm 200$  lb ( $\pm 90.7$  kg) per strand if the initial force is greater than 10% of the final force. Elongation measurements as a measure of initial force are impractical and shall not be used. In self-stressing forms/molds, care shall be taken to tension strand symmetrically to prevent warping of the form/mold due to eccentric loading.

### **5.3.10 Measurement of Elongation**

At the completion of initial tensioning, reference marks shall be established from which elongation by final tensioning forces can be measured. Elongations are then accurately measured from these reference points. Elongations shall be measured as required in Sections 5.2.2 and 5.3.13.

### **5.3.11 Elongation Calculation and Corrections**

The elongation measurement shall account for all operation losses and compensations in the tensioning system. For computation of the elongation, the modulus of elasticity and steel area of the tendon shall be determined from mill certificates provided by the manufacturer of the strand. An average area and modulus may be used, provided the force indicated falls within the tolerance limit specified herein. Corrections to the basic computed elongation for a bed setup vary between casting beds and shall be evaluated and compensated for in computing elongation. Principal operating variables are:

#### **1. Chuck seating.**

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force of less than  $0.40f_{pu}$  is used, special procedures are required to prevent strand slippage in the chuck. Consult the strand supplier for appropriate procedures.

### **C5.3.10 Measurement of Elongation**

For single-strand tensioning, elongation measurements should be made by marking the strand to allow measurement of that strand. Reference marks should be made with a marker and the strand should not be nicked or dented.

Measurements of elongation must be the actual measurements rather than estimates to verify the accuracy of correction values and the overall tensioning process. The degree of accuracy necessary in measuring elongation depends on the magnitude of elongation, which is a function of the length of the bed. Accuracy of measurement closer than the nearest 1/4 in. (6 mm), corresponding to a maximum error of 1/8 in. (3 mm), is considered impractical. For forces used normally with 1/2-in.-diameter (13 mm) high-tensile-strength strand and wire, accuracy of 1/4 in. corresponds to force variations of approximately 3% in a 50 ft (15 m) length of bed, and 1% for a 150 ft (45 m) bed. Accuracy of this order can and should be maintained.

### **C5.3.11 Elongation Calculation and Corrections**

Sample calculations for tensioning setups are shown in Appendix H.

The computation of elongation is based on force applied to the strand, which is a percentage of the ultimate capacity of the strand. Forms/molds should be surveyed and monitored to establish appropriate elongation corrections. Any alterations of the form/mold will require reevaluation of corrections and many new setups will require variation of assumptions. The following are the most common corrections for consideration:

- 1. Chuck seating.** To add additional elongation to offset seating losses requires additional force to elongate the strand. The extra force must be

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|                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                            | added to the desired theoretical force. This is often referred to as live-end seating overpull.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>a) Dead-end seating.</b> Seating at the dead end from initial load to final load, which will typically occur and show up as elongation at the live end. | <b>a) Dead-end seating.</b> The process of placing an initial force on the strand to seat the strand in the dead-end chuck; however, from that initial tension force to the final tension force, additional seating will typically occur. This additional seating will show up as added elongation in the measured elongation.                                                                                                                                                                                                                                                                                                                                 |
| <b>b) Live-end seating.</b>                                                                                                                                | <b>b) Live-end seating.</b> As a strand is seated into the live-end chuck, seating loss occurs. In multiple-strand tensioning, this is a relatively nominal amount, similar to dead-end seating loss. However, in single-strand tensioning, force is transferred from the jack to the chuck after the final load is reached. If the chucks are in good condition with properly functioning spring caps, this seating loss is not too great, but it must be anticipated and will vary from 3/8 in. to 3/4 in. (10 mm to 19 mm). This should be monitored by plant personnel to determine an appropriate value for the tensioning system in use at the plant.    |
| <b>c) Splice chuck seating.</b>                                                                                                                            | <b>c) Splice chuck seating.</b> Similar to dead-end seating loss, the strands are predominantly seated in the splice chuck by the initial tension loads. A small amount of seating loss will still take place from the initial force to the final force. Strands should be marked on each side of the splice to confirm the assumed seating loss. This should be done often enough to confirm assumptions of seating used in calculations.                                                                                                                                                                                                                     |
| <b>2. Friction in the jacking system.</b>                                                                                                                  | <b>2. Friction in the jacking system.</b> Elongation corrections are not required for friction compensation. Refer to Section C5.3.12, Force Corrections, for applicable force corrections.<br><br>When friction is excessive for multiple-strand systems, rendering the gauge pressure ineffective for a control, load cells should be used as a third method for verification of the tensioning force.<br><br>Internal friction in gauges, jacks, pumps, hoses, and connections is accounted for when the entire system is calibrated as a unit.<br><br>Certain bed setups cause friction to occur as the strands are jacked. Where this is determined to be |

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- the source of error for exceeding tolerances, the friction force may be measured by use of load cells or other means and compensated for in the calculations. Where it is not self-evident that the friction force dissipates during the setup process, strand liftoff to check gauge pressure may be necessary.
- 3. Form/mold shortening (self-stressing forms/molds).**
- 3. Form/mold shortening (self-stressing forms/molds).** In single-strand tensioning of self-stressing beds, the bed shortens as each strand is tensioned. The amount of shortening should be monitored to identify the proper adjustment. When an adjustment is performed, it is done by overstressing the strand to offset the losses. Adjustments can be made for half of the total loss expected on each strand if the final tensioning is within the 5% tolerance.
- 4. Abutment rotation or movement of anchorages.**
- 4. Abutment rotation or movement of anchorages.** In multiple-strand tensioning, the abutment deflection should be anticipated and added to the expected elongation. No added force is needed.
- In single-strand tensioning to abutments, the subsequent movement of the abutment, as later strands are stressed, results in a reduced force in the first strands. When this effect results in loss of stress outside the 5% tolerance, adjustments, as described for form/mold shortening, are necessary.
- 5. Thermal effects.**
- 5. Thermal effects.** This item is important for abutment beds as the abutments are not affected by the temperature rise of the strand from the temperature at the time of tensioning on a cold morning to the concrete temperature at the time of placement in the forms/molds as mid-day or afternoon. The actions would be reversed for strand tensioned at elevated temperatures with cooler concrete cast around it. Self-stressing beds are not affected by this phenomenon because the bed itself undergoes a similar change. As the strand is warmed and expands, the bed does as well. Since the strand is anchored to the bed, the force in the strand is relative to the bed length. As the strand is expanding and trying to relax, the bed is expanding and holding the strand at its desired value.
- Since tensioned strands are held at a fixed length, variation between ambient temperature at the time of tensioning and concrete temperature at

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the time of placing results in changes of stress. Lowering of strand temperature increases force, while a temperature rise results in force loss. For strands tensioned to approximately 70% to 75% of the strand ultimate tensile strength, a temperature variation in the strand of 10 °F (5 °C) will result in a variation of 1%. Allowance shall be made in the tensioning for temperature variation of 25 °F (15 °C) or more by understressing or overstressing at the rate of 1% for 10 °F of anticipated temperature variation, depending respectively on whether a reduction or rise of temperature is anticipated. This adjustment is typically not required for self-stressing beds

### **5.3.12 Force or Gauge Corrections**

Operational conditions resulting in variations of force as indicated by jacking pressure consist of:

- 1. Chuck seating.** Release of strands from single-strand jacks results in a force loss as the strand seats into the live-end chuck. To compensate for this loss, strands shall be tensioned and elongated additionally to offset the seating. The extra force shall be added to the desired theoretical force.
- 2. Friction in jacking system.**
  - a. Rams used in jacks for single-strand tensioning are typically small; therefore, friction losses in the jacking system can usually be ignored, provided gauges and systems are calibrated in accordance with Section 5.2.7. The anchorages are not part of the jacking system.
  - b. Losses in the tensioning system shall be compensated for in accordance with Section 5.3.11.
  - c. Friction due to strands passing through bulkheads, bundling, and dragging along beds or over points of deflection may be compensated for if proven to dissipate during the bed setup operation. Load cells or other means shall be used to verify that the strand in the product is tensioned within stated tolerances to the

### **C5.3.12 Force or Gauge Corrections**

- 1. Chuck seating.** To add additional elongation to offset seating losses requires additional force to elongate the strand. The extra force must be added to the desired theoretical force. This is often referred to as live-end seating overpull.
- 2. Friction in jacking system.**
  - b. Internal friction in gauges, jacks, pumps, hoses, and connections is accounted for when the entire system is calibrated as a unit.
  - c. Certain bed setups cause friction to occur as the strands are jacked. Where this is determined to be the source of error for exceeding tolerances, the friction force may be measured by use of load cells or other means and compensated for in the calculations. Where it is not self-evident that the friction force dissipates during the setup

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specified load.

3. **Form shortening.** When tensioning strand in a self-stressing bed, the bed carries the load of the tensioned strand, which causes the bed to shorten. If this shortening produces a loss in the strand tension, which combined with other factors results in a variation outside of the 5% tolerance, then an adjustment is required.
4. **Abutment rotation or movement of anchorages.** When strands are anchored to abutments, the abutment deflects under the load. If this deflection produces a loss in strand tension, which combined with other factors results in a variation of the 5% tolerance, then an adjustment is required.
5. **Thermal effects.** For abutment anchorage setups where strands are anchored to abutments that are independent from the form, thermal adjustments are required if the temperature of the steel at the time of tensioning differs by more than 25 °F (15 °C) from the time concrete begins to set, and if the net force differential is greater than 2.5%. Consideration shall be given to partial bed length usage and adjustments made when the net effect on the length of bed used exceeds the allowable. The thermal coefficient of expansion of steel shall be taken as  $6.5 \times 10^{-6}$  °F ( $12 \times 10^{-6}$  °C).

process, strand liftoff to check gauge pressure may be necessary.

3. **Form shortening.** In single-strand tensioning of self-stressing beds, the bed shortens as each strand is tensioned. The amount of shortening should be monitored to identify the proper adjustment. When an adjustment is performed, it is done by overstressing the strand to offset the losses. Adjustments can be made for half of the total loss expected on each strand if the final tensioning is within the 5% tolerance.

4. **Abutment rotation or movement of anchorages.** In multiple-strand tensioning, the abutment deflection should be anticipated and added to the expected elongation. No added force is needed.

In single-strand tensioning to abutments, the subsequent movement of the abutment, as later strands are stressed, results in a reduced force in the first strands. When this effect results in loss of stress outside the 5% tolerance, adjustments, as described for form/mold shortening, are necessary.

5. **Thermal effects.** This item is important for abutment beds as the abutments are not affected by the temperature rise of the strand from the temperature at the time of tensioning on a cold morning to the concrete temperature at the time of placement in the forms/molds at mid-day or afternoon. The actions would be reversed for strand tensioned at elevated temperatures with cooler concrete cast around it. Self-stressing beds are not affected by this phenomenon because the bed itself undergoes a similar change. As the strand is warmed and expands, the bed does as well. Since the strand is anchored to the bed, the force in the strand is relative to the bed length. As the strand is expanding and trying to relax, the bed is expanding and holding the strand at its desired value.

Since tensioned strands are held at a fixed length, variation between ambient temperature at the time of tensioning and concrete temperature at the time of placing results in changes of stress. Lowering of strand temperature increases force while a temperature rise results in force loss. For strands tensioned to approximately 70% to 75% of the strand ultimate tensile strength, a temperature

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### **6. Gauge corrections based on calibration data.**

#### **5.3.13 Final Tensioning of Straight Strands**

For single-strand tensioning, after application of the initial force and establishment of reference marks for measuring elongation, the full strand force shall be applied. Strand force shall be determined in accordance with Section 5.2.2 for every strand. An exception is the case of a completely open bed with no bulkheads or other possible sources of friction. In such instances, strand force shall be checked on the first and last strands tensioned and at least 10% of the remaining strands.

The final force on the strand shall not exceed 80% of the specified tensile strength of the strand after seating.

#### **5.3.14 Final Tensioning of Harped Strands**

Not applicable.

#### **5.3.15 Equal Distribution of Force in Harped Strands**

Not applicable.

#### **5.3.16 Strand Debonding**

Methods used to debond strands shall eliminate bond over the entire specified length of debonding. Substances that permanently alter the physical and/or chemical properties of the

variation in the strand of 10 °F (5 °C) will result in a variation of 1%. Allowance shall be made in the tensioning for temperature variation of 25 °F (15 °C) or more by understressing or overstressing at the rate of 1% for each 10 °F of anticipated temperature variation, depending respectively on whether a reduction or rise of temperature is anticipated. This adjustment is typically not required for self-stressing beds.

### **6. Gauge corrections based on calibration data.** Calibration of tensioning systems indicates the pressure reading necessary to achieve design load. The appropriate pressure should be selected to achieve the desired design load.

#### **C5.3.13 Final Tensioning of Straight Strands**

Straight strands are the most straightforward tensioning setup. Care is required to be sure that a valid starting point is established by pulling to initial force for elongation measurement and that all appropriate corrections are made in the setup calculations.

Since elongation is measured by travel of the anchorage, a reference mark is usually made at the face of the anchorage on each side of the bed.

#### **C5.3.14 Final Tensioning of Harped Strands**

This section is not applicable to products covered in MNL-117. See PCI MNL-116.

#### **C5.3.15 Equal Distribution of Force in Harped Strands**

This section is not applicable to products covered in MNL-117. See PCI MNL-116.

#### **C5.3.16 Strand Debonding**

Pretensioned members may be manufactured by including effective bond breakers on strand to reduce or modify concrete stresses at critical points of the member. Leakage of paste into sleeving must be

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surrounding concrete beyond the debonding interface shall not be used.

### **5.3.17 Detensioning**

Force shall not be transferred to pretensioned members until concrete strength, as indicated by test cylinders or other properly calibrated nondestructive test techniques, is in accordance with the specified transfer strength.

If concrete has been heat cured, detensioning shall be performed immediately following the curing period while the concrete is still warm and moist.

In single-strand detensioning, both ends of the bed shall be released simultaneously and symmetrically to minimize sliding of members. Forms/molds, ties, inserts, or other devices that restrict longitudinal movement of the members along the bed shall be removed or loosened. Alternatively, detensioning shall be performed in such a manner and sequence that longitudinal movement is precluded.

General procedures for detensioning shall be developed, documented, and implemented by appropriate personnel for the tensioning system used by the plant and the typical product line. Specific procedures for unusual product shapes and prestressing strand configuration shall be detailed on production documents. The sequence used for detensioning strands shall be according to a pattern and schedule that keeps the stresses nearly symmetrical about the vertical axis of the members. Maximum eccentricity about the vertical axis of the member in the casting bed

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prevented. The most commonly used element for debonding is plastic sheathing. Other elements may be used, such as retarder if lightly applied. Items such as animal fat or reactive greases should not be used as they affect the concrete beyond the debonding interface. PVC pipe with free chloride ions, which would migrate into the concrete, should also not be used.

### **C5.3.17 Detensioning**

Tests have shown that the bond transfer length for wet mixed concrete is not appreciably affected by concrete strengths in the range of 2,500 psi to 4,000 psi (17.2 MPa to 27.6 MPa) at release. Concrete strength does influence camber and dimensional changes due to strains in the concrete. A minimum concrete strength of 3,000 psi (20.7 MPa) at time of detensioning is recommended.

If concrete is allowed to dry and cool after steam curing and prior to detensioning, dimensional changes may cause contracting or undesirable stresses in the concrete. Strands should be detensioned immediately after removal of the curing enclosure and all external restraints have been removed from the product, or a way should be developed to partially or fully detension strands before removal of the curing enclosure. The use of self-stressing forms reduces the effect of dimensional changes.

For tension to be released gradually, strands should not be cut quickly but should be heated until the metal gradually loses its strength. This becomes much more significant as the ratio of prestressing force to area of member increases.

Grinders or other similar cutting devices may also be acceptable provided that wires that make up a strand are cut individually.

Cracking of the concrete in the end region of the product may be the result of the detensioning method and sequence used. Implementation of a well-designed strand-cutting procedure and sequence has been shown to reduce or eliminate cracking.

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shall be limited to one strand or 10% of the strand group.

### **5.3.18 Detensioning of Harped Strand**

Not applicable.

### **5.3.19 Detensioning of Dry-Mix, Machine-Cast Products**

Not applicable.

### **5.3.20 Protection of Strand Ends and Anchorages**

Special attention shall be directed toward finishing the ends of the members in the area of strand ends and anchorages, as specified on the shop drawings. Unless such areas are maintained in a permanently dry condition after erection, strand ends and anchorages shall be protected against moisture penetration.

## **5.4 Post-tensioning of Plant-Produced Products**

### **5.4.1 General**

The tensioning of post-tensioned members is governed by many of the considerations applicable to pretensioned concrete

### **C5.3.18 Detensioning of Harped Strand**

This section is not applicable to products covered in MNL-117. See PCI MNL-116.

### **C5.3.19 Detensioning of Dry-Mix, Machine-Cast Products**

This section is not applicable to products covered in MNL-117. See PCI MNL-116.

### **C5.3.20 Protection of Strand Ends and Anchorages**

Lack of proper protection of end anchorages allows an access point for moisture, which may lead to corrosion. This is especially true in environments where chlorides or other deleterious substances may be present in the water. Under such circumstances, adequate protection may be mandatory.

When exposed to view, anchorages (stressing pockets) should be recessed and packed with a minimum of 1 in. (25 mm) thickness of nonmetallic, nonshrink mortar and receive a sack finish. Prior to installing the pocket mortar, the inside concrete surfaces of the pocket should be cleaned out and coated or sprayed with a bonding agent. This mortar seal should be adequately covered for curing as shrinkage or contraction cracks will permit moisture penetration. When not exposed to view, strand ends should be coated with a rust inhibitor, such as bitumastic, zinc-rich, or epoxy paint, to avoid corrosion and possible rust spots.

## **C5.4 Post-tensioning of Plant-Produced Products**

### **C5.4.1 General**

Many architectural panels that do not lend themselves to being pretensioned because of difficulties with long-line casting, such as jacking bulkhead or self-stressing form requirements, can be easily post-tensioned. The process of post-tensioning incorporates the installation of bonded or unbonded tendons in preformed voids or ducts throughout the length of the member, or through a section of the member. After curing the member, strands are tensioned and

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Force in the tendons shall always be measured by gauge readings and verified by elongation. Due to frictional losses typical in post-tensioned members and generally due to their relatively short length (as compared with most pretensioning beds), the predetermination of jacking forces and elongations, ensuring accuracy and reconciliation in measurement, is particularly important. The elastic shortening of the concrete member during tensioning shall be given due consideration in computing apparent elongations.

Records shall be maintained for plant post-tensioning operations in a similar fashion to other plant operations.

Post-tensioning systems shall be installed in accordance with the manufacturers' directions and proven procedures. Manufacturers' recommendations shall be observed regarding end block details and special reinforcement in anchorage zones applicable to the particular systems.

Plastic-coated unbonded tendons with a low coefficient of angular friction looped within the panel and anchorages installed at one end only, or at both ends, may be used. Curvature in the tendon profile shall preferably not be closer than 3 ft (0.9 m) from the tensioning anchorage. Tendons shall be firmly supported at intervals not exceeding 4 ft (1.2 m) to prevent displacement during concrete placement.

anchored against the hardened concrete.

Bonded tendons are installed in preformed voids or ducts and are made monolithic with the member and protected from corrosion by grouting after the tensioning operation is completed. Unbonded tendons are protected against corrosion by a properly applied coating of galvanizing, epoxy, grease, wax, plastic, bituminous, or other approved material, and are carefully cast in concrete in a sheathing of heavy plastic. Unbonded tendons are connected to the member only through the anchorage hardware, which should be sized and designed in accordance with ACI 318.

The strand (tendon) most frequently used in architectural precast post-tensioned concrete is called the monostrand. Although monostrands can be fabricated to be grouted, they are usually coated with grease and covered with paper or plastic. Thus, they are typically used in the unbonded condition. If friction is exceptionally high due to length or curvature of the tendon, a strand coated with teflon and encased in a plastic tube is available. These monostrands have a low coefficient of angular friction ( $\mu = 0.03$  to  $0.05$ ). Anchorages and pocket formers should be rigidly attached to the forms/molds to prevent intrusion of cement paste into the anchorage cavity. Ties between the sheathed tendon and support steel should not be so tight as to cause visible

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### **5.4.2 Details and Positions for Ducts**

Ducts for post-tensioning tendons shall be constructed of flexible or semi-rigid metal or corrugated HDPE or polypropylene tubing installed within the member. Tendons that are not to be bonded by grouting may be installed in ducts of plastic or other material. Metal ducts shall be of a ferrous metal and may be galvanized. Aluminum or PVC shall not be used for ducts.

The alignment and position of ducts within the member shall be controlled. The trajectory of ducts shall not depart from the curved or straight lines shown on the design drawings by more than 1/2 in. (13 mm) in any 10 ft (3 m) length. For curved members, the tendons, and consequently the ducts, shall be placed on or symmetrically about the axis of the member that is parallel to the direction of the curvature. The position of ducts with respect to the thickness (depth) of the member, especially at critical locations, shall be maintained within a dimensional tolerance consistent with the size and usage of the members. A maximum variation from the specified position of  $\pm 1/4$  in. ( $\pm 6$  mm) or 1/8 in. per 1 ft of depth, whichever is smaller, shall be used.

The alignment of ducts shall be such that tendons are free to move within them and, if grouting is to be used, the area shall be sufficient to permit free passage of grout. The inside diameter shall be at least 1/4 in. (6 mm) larger than the nominal diameter of single wire, bar, or strand tendons. For multiple wire or strand tendons, the inside cross-sectional area of the duct shall be at least twice the net area of the prestressing steel.

Ducts installed in members prior to casting the concrete shall be tightly sealed. Ducts or duct

deformations (indentations) in the sheathing.

### **C5.4.2 Details and Positions for Ducts**

Materials commonly used for formed ducts are 22-gauge to 28-gauge galvanized, bright spirally wound, or longitudinally seamed with flexible or semi-rigid seams.

Although most ducts are formed using metal tubing, occasionally collapsible or inflated rubber tubes that can be removed after the concrete has hardened are used to form a void in the member. This would not be a preferred method if grouting is to be utilized, due to the difficulty of establishing composite action between the member concrete and the grout placed in the void. For grouted tendons, a corrugated HDPE or polypropylene duct with a minimum thickness of 0.08 in. (2 mm) may be used if the materials meet the appropriate Post-Tensioning Institute recommendations.

Short kinks or wobbles in alignment will result in appreciable increases in friction during tensioning.

Tendons may be installed in the ducts either prior to or subsequent to placing concrete. In general, it is

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forms shall be sufficiently supported and fastened to ensure that proper positioning is maintained during casting and consolidation of concrete.

Joints between duct sections shall be adequately coupled and taped to maintain geometry and prevent concrete paste intrusion during casting. After duct placement, reinforcement, and forming are complete, an inspection shall be made to locate possible duct damage. All holes, openings, or excessive dents shall be repaired prior to placing concrete.

All ducts shall have grout openings at both ends. Grout openings and vents shall be securely anchored to the duct and either to the forms or to reinforcing steel to prevent displacement during concrete placing operations.

### **5.4.3 Friction in Ducts**

The tensioning (jacking) force necessary to provide the required stress and to overcome the frictional force shall be indicated in the post-tensioning details. Production documents shall also show the techniques to be observed in jacking, which may consist of overjacking, jacking from both ends, and overelongation followed by a reduction of load for seating the anchorages.

Maximum jacking force shall not exceed the applicable limits in ACI 318.

### **5.4.4 Tensioning**

A schedule indicating the minimum concrete strength at jacking and a sequence of tensioning tendons to keep concrete stresses within predetermined limits of symmetry about the axis of the member shall be established and shown on the production drawings. The concrete compressive strength shall be determined from test cylinders.

A minimum initial force of 10% of the jacking force shall be applied to the tendon to take up slack and to provide a starting point for elongation measurement. The jacking force shall then be applied, including any overload and release that may be called for in the procedure. The rate of application of the force shall be in accordance with the post-tensioning

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preferable to place the tendons subsequent to the concreting operation so that water and grout can be blown or cleaned from the duct to avoid blockage of the duct.

### **C5.4.3 Friction in Ducts**

Friction on the post-tensioning tendon is due to length and curvature of the ducts. The length effect is the amount of friction that would be expected in a straight tendon due to minor misalignment (wobble of the duct). The curvature effect results from friction due to the prescribed curvature of the duct. Both components of this friction are proportional to the respective coefficients of friction between the tendon and the inside surface of the duct. Coefficients and constants to be used for computing frictional effect have been established by research for all duct and tendon combinations in common usage.

### **C5.4.4 Tensioning**

Post-tensioning in plant-produced members is generally in short lengths, so elongation is usually a small value, which places added emphasis on carefully obtaining accurate readings.

For post-tensioned tendons shorter than 25 ft (7.6 m), special tensioning methods and elongation measurement methods are required.

An accurate gauge is a necessity for unbonded tendons, as tensioning the strands to a calculated elongation is difficult due to various possible strand configurations (multitude of tendon curvatures) and frictional losses.

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manufacturers' recommended procedure.

The final force applied to the tendon and the actual measured elongation shall agree with the theoretical values and each other within 7%. If tensioning is not achieved within this tolerance, then procedures shall be altered until tolerance limits are observed. For post-tensioned tendons, the force at the end anchorages immediately after tendon anchorage lock-off shall not exceed  $0.70f_{pu}$ .

### **5.4.5 Anchorages**

Anchorage devices for all post-tensioning systems shall be aligned with the direction of the axis of the tendon at the point of attachment. Concrete surfaces against which the anchorage devices bear shall be perpendicular to the tendon axis. Anchorage losses due to seating loss or other causes shall be measured accurately and compared with the assumed losses shown in the post-tensioning schedule and shall be adjusted or corrected in the operation when necessary.

The connections attaching the anchorages to the form shall be sufficiently rigid to avoid accidental loosening during concrete placement. The anchorage area shall be sealed after the tendons or strands are post-tensioned. Minimum concrete cover for the anchorage shall not be less than the minimum cover to the reinforcement at other locations.

### **5.4.6 Grouting**

Ducts shall be blown free of water after curing of the concrete and provision shall be made to keep water out of the ducts prior to grouting. To provide maximum protection to the tendons, grouting shall be performed soon after completion of the tensioning operation within a time suitable for the environmental conditions unless otherwise specified.

Grout shall always be applied by pumping toward open vents. Grout shall be applied continuously under moderate pressure at one point in the duct until all entrapped air is forced out the open vent or vents. Vents shall not be closed until they discharge a steady stream of grout. Once all

The actual elongation of the unbonded strand should be checked against the theoretical elongation to ensure that the strand is entirely tensioned. The strand may become bound or kinked, or the anchor may not be working properly and prevent the strand from being fully tensioned.

Sample calculations for tensioning setups are shown in Appendix H.

### **C5.4.5 Anchorages**

For unbonded systems, the anchorage provides the only force transfer point from tendon to member; therefore, it is critical that the anchorages be capable of developing 95% of the ultimate strength of the tendon.

Alignment of anchorages is critical for seating of tendons. Misalignment during casting can reduce effectiveness of anchorages.

Plastic pocket formers used as a void form at tensioning anchorages should prevent intrusion of concrete or cement paste into the wedge cavity during concrete placement. Pocket formers should be coated with grease prior to insertion to help prevent concrete leakage into the anchorage and to aid in removal during form/mold stripping

### **C5.4.6 Grouting**

Post-tensioning members that are to carry heavy fluctuating or dynamic loads or that are subject to frequent wetting or drying or severe climatic exposure should have the ducts pressure grouted following the completion of tensioning. Grouting is an important operation, serving to protect the tendons, relieve the anchorage of stress fluctuation, and increase the efficiency of the tendon in resisting ultimate moments.

If a delay is expected in grouting, a rust inhibitor can be applied to the tendon before placement in the duct.

Refer to the current edition of Post Tensioning Institute's Specification for Grouting of Post-Tensioned Structures.

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## **Standard**

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vents are closed, pumping shall continue until a steady pressure of 100 psi is maintained for 10 sec.

Thixotropic grouts shall be mixed with a shear-type mixer rather than a paddle mixer.

### **5.4.7 Sealing of Anchorages**

Tendon anchorages shall receive a concrete or grout seal to provide the minimum cover required. This seal shall be adequately covered for curing to prevent shrinkage or contraction cracks that will permit moisture penetration. Anchorage pockets shall be sealed with low-shrinkage nonmetallic grout.

If a concrete or grout seal cannot be provided, then the anchorage and tendon end shall be completely coated with a corrosion-resistant paint or other effective sealer. The anchorage and tendon end shall then receive a cover that will provide fire resistance at least equal to that required for the structure.

### **C5.4.7 Sealing of Anchorages**

Care should be exercised to protect end anchorages of tendons. Even with grouted tendons, the end anchorage is an integral part of the post-tensioned system.

Lack of proper protection of end anchorages allows an access point for moisture, which may lead to corrosion. This is especially true in environments where chlorides or other deleterious substances may be present in the water. Under such circumstances, adequate protection may be mandatory.

# ***DIVISION 6 – QUALITY CONTROL***

## **Standard**

## **Commentary**

### **6.1 Inspection**

### **C6.1 Inspection**

#### **6.1.1 Necessity for Inspection**

#### **C6.1.1 Necessity for Inspection**

To ensure that proper methods for all phases of production are being followed and the finished product complies with specified requirements, inspection personnel and a regular program of inspecting all aspects of production shall be provided in all plants. Inspectors shall be responsible for the monitoring of quality only and shall not be responsible for or primarily concerned with production.

Prepour, postpour, and final finish inspections are necessary for managing quality. Recurring defects require decisive correction by management.

Every effort toward cooperation shall be observed between production and quality control personnel. Production personnel are responsible for quantity and quality. Inspection personnel are responsible for observing, monitoring, and measuring quality.

Plant management should give the quality control department sufficient time and resources to do an adequate job. Inspection operations should be managed so that production is not delayed as long as specified procedures are being followed. Many items must be checked during the prepour inspection, and each type of element (different mark numbers) may have a different set of requirements. A plant's training program should be written and include a definitive outline of items to be inspected.

Plant management may delegate inspection tasks to non-quality-control personnel as defined in the plant's Quality Systems Manual (QSM). Along with delegation should come accountability.

#### **6.1.2 Scope of Inspection**

#### **C6.1.2 Scope of Inspection**

To establish evidence of proper manufacture and quality of precast concrete products, a system of records shall be utilized in each plant. The system of records shall provide full information regarding testing of materials, tensioning, concrete proportioning, placing, curing, inspection of finished products, camber, member dimensions, and concrete strength. The inspection process shall be as identified in the approved QSM.

To document the prepour inspection, quality control records should be identified with the job number, mark number, pour date, and other information used to identify the specific product after inspection.

In general, the scope of the quality control prepour, postpour, final finish, and shipping inspections to be performed in precast plants shall include, but not necessarily be limited to, the following:

The postpour inspection is the time to confirm that products were made in conformance with the shop drawings. The most important aspect of the postpour inspection is timeliness. Postpour inspections should be made as soon as practical after products are stripped from their forms/molds. If a defect is evident or a mistake has been made and that defect or mistake is detected during the postpour inspection, similar defects and/or mistakes in products yet to be cast can

1. All required plant testing and inspection of materials and embeds.

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2. Review of mixture designs.
3. Inspection of forms/molds and new setup changes prior to placement of concrete. The plant shall prepare its own list of items to be checked as a part of the prepour inspection, and emphasis shall be on items that cannot readily be checked after concrete placement.
4. Checking of blockout position, sealing of forms/molds, rustification strips, cast-in items, coverage, position, amount and size of reinforcement, and any other critical tolerance items. This also includes verifying that these items are properly secured during placement of concrete.
5. Check forms/molds, jigs, fixtures, and other accessory objects for adequate maintenance by verification of tightness, dimensions, and overall general quality.
6. General observation of batching, mixing, conveying, placing, consolidating, curing, stripping, and finishing of concrete.
7. Daily inspection of stripped product.
8. General observation of plant equipment, weather, and other items affecting production.
9. Preparing of concrete specimens for testing and performing all appropriate fresh concrete tests.
10. Inspection of final finish to make sure that the product matches the standard established by the approved project mockup, range samples, or first production unit for color, texture, and uniformity. Finish defects, cracking, and other problems shall be reported and a decision made as to acceptance, repairs, or manufacturing change. Units that are damaged are to be recorded and identified.
11. Check finished product against approved shop drawings and approved samples to

be prevented. The final finish inspection may be the last opportunity to confirm the proper color and texture on each face prior to erection. Corrections at the jobsite are more difficult and costly.

The number of persons required to perform inspecting services will vary with the size and scope of operations within the plant. It is important that a sufficient number of inspection personnel are available to carry out all prescribed tasks to maintain the thoroughness of inspections and tests. Assignments and responsibilities for all inspecting functions should be clearly defined in a written process and planned in production scheduling.

Information gained through quality control inspection should be reviewed on a daily basis with production personnel. This review should be useful in identifying areas that may need production procedures reinforced or modified, or equipment that needs to be repaired or replaced.

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## **Commentary**

ensure that proper finishes are on all required areas, product dimensions are correct, cast-in items are correctly located, product is properly identified and marked, and all measurements are within allowable tolerances.

12. Inspect product for proper blocking (dunnage), methods for prevention of chipping, warping, cracking, contamination, and blocking stains, or any other items that may adversely affect the quality of the product.
13. Reinspection of products following any repair.
14. Confirm segregation and/or disposal of nonconforming materials.

For elements cast using SCC, the producer shall develop a program of verifying the uniformity between representative finished elements.

This inspection may include the use of full or partial mock-ups of new element shapes or sizes cast using SCC.

### **6.2 Testing**

### **C6.2 Testing**

#### **6.2.1 General**

#### **C6.2.1 General**

Testing shall be an integral part of the total quality control program. Testing for quality control of precast concrete units shall follow plant standards as well as the specifications for a particular project.

Testing is necessary for internal plant quality control as well as quality control of the individual precast concrete units. Testing should be directed towards maintaining a uniform level of plant standards. Testing operations should be incorporated into plant operations to avoid unnecessary delays in production and provide adequate product and process review.

If the plant has contracted for any quality control functions to be performed by an outside independent laboratory, the laboratory shall be accredited by the Cement and Concrete Reference Laboratory of the National Institute of Standards and Technology (National Voluntary Laboratory Accreditation Program). The laboratory shall conform to the requirements of ASTM E329 and the plant or independent laboratory shall meet the concrete inspection and testing section requirements of ASTM C1077.

Precast plants shall be equipped with adequate testing equipment.

At least one individual involved in the testing of fresh concrete or directing such tests shall

# ***DIVISION 6 – QUALITY CONTROL***

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## **Commentary**

maintain a current ACI Field Testing Technician, Grade 1, certification or approved equivalent certification.

Specified properties of all materials in Divisions 3 and 4 shall be verified by appropriate ASTM standard tests performed by the material supplier or the precaster.

In order to establish evidence of proper manufacture and conformance with plant standards and project specifications, a system of records shall be maintained to provide approved mixture designs, documentation of satisfactory raw material and concrete tests, and any other pertinent documentation.

### **6.2.2 Acceptance Testing of Materials**

Suppliers of materials shall be required to furnish certified test reports for all materials used in the precast products, such as cement, aggregates, admixtures, curing materials, reinforcing and prestressing steel, connection materials, and hardware materials, indicating that these materials comply with the applicable ASTM standards, project specifications, and plant standards.

#### **1. Cement**

Mill certificates are required with each shipment of cement. Mill certificates shall contain appropriate chemical and physical properties, as well as test data. Mill certificates shall contain the alkali content in percent expressed as  $\text{Na}_2\text{O}$  equivalent. Mill certificates or test report of cement shall be kept on file in the plant for at least five years after use.

### **C6.2.2 Acceptance of Testing of Materials**

In some instances, materials may not conform to nationally recognized standards but may have a long history of satisfactory performance. Such materials are permitted when acceptable evidence of satisfactory performance is provided and approved by the architect/engineer.

#### **1. Cement**

Mill test reports should be reviewed for changes from previous reports. Lower concrete strength should be expected from lower cube strength, lower  $\text{C}_3\text{S}$ , lower fineness, higher percent retained on No. 325 sieve (45  $\mu\text{m}$ ), and higher loss on ignition. Increase in total alkali may reduce concrete strength gain after seven days and impair the strength-producing efficiency of water-reducing admixtures. Variation in the color of gray cement may in part be traced to a variable  $\text{Fe}_2\text{O}_3$  content (a 2% variation in  $\text{Fe}_2\text{O}_3$  being significant).

An additional report available from cement producers allows the concrete producer to evaluate cement strength uniformity (ASTM C917). The data will show 7- and 28-day cube strengths with a 5-day moving average and standard deviation. It is suggested that precasters routinely obtain these reports for the previous 6 to 12 months to monitor consistency of cube strengths.

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If the tricalcium silicate ( $C_3S$ ) content varies by more than 4%, the ignition loss by more than 0.5%, or the fineness by more than  $375\text{ cm}^2/\text{g}$ , Blaine (ASTM C204) from mean values used in mixture design, then problems in maintaining a uniform high strength may result. Sulfate ( $SO_3$ ) variations should be limited to  $\pm 0.20\%$ .

Until project acceptance, it is good practice to keep a 10 lb to 15 lb sample of each cement shipment (composite from two or three subsamples) in an airtight and moisture-proof container with a minimum air space over the sample to check color and strength development, if necessary.

If problems have occurred with cement color variations, a visual check in sunlight of a cement sample for color conformity for each project should be made before allowing the cement to be loaded into the silo. A visual check of cement color should be made and compared with previous samples by placing the sample between two pieces of plate glass and taping the edges to hold the cement. This is helpful in verifying that cement is from the same mill source. Unannounced changes in mill sources may result in variable concrete properties, such as air content, strength, setting, and color.

### **2. Aggregates**

Fine and coarse aggregates shall be regarded as separate ingredients. Aggregates shall conform to ASTM C33/C33M or C330/C330M as required to meet design specifications. The grading requirements of ASTM C33/C33M or C330/C330M shall be waived or modified to meet the required design specifications. Sieve analysis, in accordance with ASTM C136, shall be conducted on samples taken from the initial shipment received at the plant. Sampling for aggregates from stockpiles or from conveyor belts shall be in accordance with ASTM D75/D75M. Once a sample has been taken, the sample shall be mixed and then quartered in accordance with ASTM C702. Specific gravity, absorption, and petrographic analysis performed within the past five years shall be obtained from the supplier prior to the time of first usage, when a new lift or horizon in a quarry is utilized, or when there appears to be a change in the quality of the aggregate.

### **2. Aggregates**

Sieve analysis tests are required to ensure uniformity of materials received and to check consistency of gradation with the aggregate supplier's reported sieve analysis, taking into account expected changes in gradation that may be caused by rough handling in shipment.

Specific gravity and absorption for normalweight coarse aggregate should be determined according to ASTM C127 and for fine aggregate according to ASTM C128.

The specific gravity and absorption of an aggregate are used in certain computations for mixture proportioning and control, such as the absolute volume occupied by the aggregate. These values are not generally used as a measure of aggregate quality, though some porous aggregates that exhibit accelerated freeze-thaw deterioration do have low specific gravities.

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ASTM C88 soundness test is not recommended, unless specified. Also, the L.A. abrasion test, ASTM C131, is not required if during the concrete production process the increase in fines does not affect compressive strength nor the approved surface finish.

The specific gravity of lightweight aggregate shall be determined in ACI 211-2, Appendix A – Pycnometer Method. The oven dry loose unit weight (ASTM C29/C29M) of the lightweight aggregate shall be determined. A maximum 10% change in unit weight of successive shipments from a sample submitted for acceptance tests is allowed.

Evaluation of aggregates for potential alkali-silica or alkali-carbonate reactions (excessive expansion, cracking, or popouts in concrete) shall be based on at least 15 years of exposure to moist conditions of structures made with the aggregate in question, if available, or petrographic examination (ASTM C295) to characterize and determine the presence of potentially reactive components. If an aggregate is found to be susceptible to alkali-silica reaction using ASTM C295, it shall be evaluated further using ASTM C1260 and C1293. Aggregates that exhibit ASTM C1260 mortar bar expansion at 14 days greater than 0.10% shall be considered potentially reactive. Aggregates further evaluated by ASTM C1293 that exhibit mean concrete prism expansion greater than 0.04% at one year shall be considered potentially reactive. Aggregate sources exhibiting expansions no more than 0.04% and demonstrating no prior

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Petrographic analysis should be made in accordance with ASTM C295 to ensure that selected aggregates are durable, inert, and free from iron sulfide (pyrite) or other deleterious materials. Favorable results of petrographic examination may eliminate the need for alkali reactivity tests. The frequency of testing will vary depending on the nature of the source of the aggregate.

For some relatively smooth-surface, lightweight coarse aggregates, regular specific gravity and absorption procedures by ASTM C127 can be used; a lid is needed on the basket used in the test to confine floating pieces.

Lightweight aggregates should be ordered with specification restrictions. Uniformity of specific gravity and dry loose unit weight is an important concern for lightweight concrete. However, some sources do not consistently provide this material within a reasonable set of limits; therefore, adjustments in mixture proportions may be required as properties change. Suppliers should forward gradation analysis and specific weight tests of the material with all initial shipments. The specific volume should be performed on each shipment so adjustments in batching can be made as the material changes in specific gravity from that assumed in the mixture design.

When possible, aggregates should be evaluated for past performance in concrete, taking into account the alkali content of the cements used, whether the aggregate was used alone or in combination with another aggregate, and the exposure conditions and age of the concrete.

Mitigation measures for alkali reactivity include the use of pozzolans and/or slag cement, either as a component of blended cement or as a separate addition at the concrete production facility. In some cases, the quantity of supplementary cementitious material in blended hydraulic cement is not sufficient to control expansions due to alkali-silica reaction. Additional supplementary cementitious material, either of the same or different kind, may be added to the blended hydraulic cement if necessary. As a guideline, Class F fly ash may require a minimum of 15% to 25% by mass of total cementitious materials to meet the expansion criterion, while slag cement may

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evidence of reactivity in the field shall be considered non-reactive. Reliance shall not be placed on results of only one kind of test in any evaluation.

If an aggregate is judged to be susceptible to alkali-carbonate reaction using ASTM C295, it shall be evaluated further for alkali-carbonate reaction in accordance with ASTM C586 or ASTM C1105 using the proposed cement-aggregate combination. Cement-aggregate combinations exhibiting mean expansion values greater than 0.015% at 3 months, or 0.025% at 6 months, or 0.030% at 1 year shall be considered potentially reactive.

ASTM D4791 shall be used to determine the percentage of flat or elongated particles in crushed coarse aggregate. Flat and elongated aggregate particles (slivers) shall be limited to a maximum of 15% by weight of the total aggregate. If aggregate is to be exposed in panel returns, the percentage shall be limited to 10%. ASTM C1252 (Method A) shall be used to evaluate angularity of fine aggregate. These requirements may be waived if performance testing demonstrates satisfactory results.

Tests for deleterious substances and organic impurities shall be done at the start of a new aggregate supply and annually thereafter, unless problems are encountered requiring more frequent testing. Deleterious substances in aggregates shall be limited to the allowances given in ASTM C33/C33M for exposed architectural concrete located in severe weathering regions with the following exceptions: (1) fine aggregate shall not exhibit a color darker than Organic Plate 1 when tested for organic impurities in accordance with ASTM C40; and (2) clay lumps and friable (readily crumbled) particles in fine aggregate shall be limited to a maximum of 1% percent and in coarse aggregate to a maximum of 0.25% percent.

Coarse aggregates may occasionally contain particles with an iron sulfide content that results in unsightly stains. Since this aggregate could meet the staining requirements of ASTM C330/C330M, the stain index shall be tightened. If ASTM C295 indicates the presence of iron sulfides, then aggregates tested by ASTM C641

require 40% to 50% and calcined clay approximately 15% to 20%. Class C fly ash is not recommended for this purpose, as it may actually increase expansion at dosages less than 15%. Silica fume is also not the preferred material for this purpose. Ternary combinations (using two supplementary materials) can also be very effective.

The tests for aggregate reactivity may be performed in any order. In general, ASTM C1260 is considered conservative in that it may identify seemingly innocuous aggregates as reactive. ASTM C1293 is considered more definitive, but takes a full year to identify aggregates as reactive and two years to verify the effectiveness of mitigation measures.

One generally accepted definition of a flat particle is one in which the width or length exceed the thickness by some ratio, usually 3:1. An elongated particle is one where the length exceeds the width by some ratio, usually 3:1. Flat pieces and elongated pieces (slivers) will produce irregular and nonuniform finishes when exposed and do not hold well in the concrete matrix during high-pressure washing. Rough-textured, angular, elongated particles require more water to produce workable concrete than do smooth, rounded, compact aggregates. Hence, aggregate particles that are angular require more cement to maintain the same water-cementitious ratio. In addition, the long, slivery aggregate pieces produce concrete difficult to adequately consolidate because of aggregate interlock.

Many times friable (readily crumbled) particles or clay balls in aggregate, which are detected by ASTM C142, are weakened on wetting and may degrade on repeated wetting and drying.

Precast concrete units, although not normally exposed to salting or intense freezing and thawing, may be exposed to strong wet-dry cycles. Coarse aggregates sensitive to wet-dry cycles may crumble and such crumbling may be noticeable even if the aggregates are used in small quantities.

Staining due to iron sulfides generally becomes noticeable at a later date due to moisture and oxidation from exposure to the atmosphere.

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shall show a stain index less than 20.

Unless all aggregate is stockpiled at the beginning of a project, a sample of the approved aggregate for exposed surfaces shall be maintained until the architect accepts all units. As shipments of aggregates are received, a visual inspection shall be made such that the general appearance of the material can be compared with the approved aggregate sample.

### **3. Water**

Water shall be potable, or chemically analyzed when a private well or nonpotable water is used in the concrete mixture. Except for water from a municipal supply, an analysis of the water shall be on file at the plant, updated annually, and clearly related to the water in use. Seawater or other sources of water that contain concentrations of substances known to be deleterious to concrete shall not be used. Recycled mixture water shall be in compliance with ASTM C1602/C1602M.

Mortar cubes made in accordance with ASTM C109/C109M using nonpotable or questionable mixing water shall have a 7-day strength equal to at least 90% of the strength of companion specimens made with potable or distilled water. Time of set (ASTM C191) for mortar made with questionable water may vary from 1 hr earlier to 1-1/2 hrs later than the control sample made with potable or distilled water. Water resulting in greater variations shall not be used.

### **4. Reinforcing steel and prestressing materials**

Plant testing of reinforcing steel, welded-wire reinforcements, or prestressing materials shall not be required if mill certificates and coating reports are supplied. Mill certificates for reinforcing steel, welded-wire reinforcements, and prestressing materials in stock or in use shall be required and indicate that the materials meet the requirements of applicable ASTM specifications and ACI 318.

### **4. Reinforcing steel and prestressing materials**

It should be a standard practice to review mill certificates from suppliers of reinforcing bars for conformance to the purchasing requirements and shop drawings. As reinforcing shipments are reviewed, bar size and grade should be confirmed. Based on the chemical analysis and if the reinforcing steel is to be welded, the welding criteria should be established and the reinforcing steel marked accordingly. If the reinforcing steel is weldable according to AWS D1.1 and D1.4, the required preheat will vary depending on the chemical analysis of the steel.

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Certificates shall be obtained for each size, heat, and shipment and for each grade of reinforcing materials. Mill certificates for all reinforcing materials shall be kept on file at the plant for at least five years after use. Incoming steel, wire, and strand shall be examined for damage, excessive scaling, or pitting.

The stress-strain curve of the prestressing steel shall be for material tested from heats used to produce reel packs and shall be referenced to those reel packs. Average, typical, or generic curves are not acceptable.

When it is required to restrict the range in the chemical composition of steel to provide satisfactory weldability, the supplier shall certify conformance with these supplemental requirements in writing.

The in-plant review and monitoring of welded-wire reinforcement shall include a periodic inspection as the material is received to confirm that the styles conform to the required size and spacing specified. Spacing of the wires shall be within 1/4 in. (6 mm) of the desired spacing, and the resistance welds at intersections of wires shall not have more than 1% broken welds. Additionally, if specific finish requirements are specified, such as galvanizing or epoxy coating, this shall be confirmed at the point of delivery.

In lieu of mill certificates, reinforcing steel shall be tested for its physical and chemical properties in accordance with ASTM A370 to verify conformance with the applicable ASTM specifications.

### **5. Admixtures**

The manufacturer of the admixture shall certify that individual lots meet the appropriate ASTM requirements. All relevant admixture information

Upon receipt of a shipment, bars should be reviewed for their general condition. Bars are acceptable with nominal mill scale, as well as some rusting. Bars should not have excessive pitting or loss of section caused by rusting. If the rust is easily removed either by finger pressure or a pencil eraser and no significant pitting is observed, the bars are in conformance with acceptable standards.

Upon receipt of prestressing steel, the mill certificates from the supplier should be reviewed for conformance with the purchase requirements. The prestressing steel should be physically inspected for confirmation of the material size and proper tagging of reels or shipments. The prestressing steel should be identified with a mill certificate indicating that it is low-relaxation or stress-relieved strand. These materials should be inspected for excessive rust, nicks, and kinks that can cause problems in tensioning of the materials. Rusting is generally acceptable if the rust is light and the pitting has not begun (refer to PCI JR379, "Evaluation of Degree of Rusting on Prestressed Concrete Strand"). If rust can be removed by finger pressure or by the use of a nonmetallic pad, it is generally not cause for rejection. Suppliers and plant personnel need to be aware of any special requirements when ordering, shipping, and storing strand. Kinks or nicks in strands provide an area where stresses may be concentrated, and breakage can occur. Material that is received with kinks or nicks should not be accepted.

### **5. Admixtures**

The proprietary name and net quantity in pounds (kilograms) or gallons (liters) should be plainly indicated on the package or container in which the

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with respect to performance, dosages, application methods, and limitations shall be on file at the plant. Air-entraining admixtures shall conform to the requirements of ASTM C260. Other admixtures shall conform to the requirements of ASTM C494/C494M, Types A, B, D, F, and G, or ASTM C1017/C1017M, Level 1 Testing. The supplier shall certify these admixtures do not contain calcium chloride. Fly ash or other pozzolans used as admixtures (supplementary cementitious materials) shall conform to ASTM C618. Metakaolin shall conform to ASTM C618 Class N requirements and silica fume to ASTM C1240.

Laboratory test reports submitted by the supplier of chemical admixtures shall include information on the chloride ion content and alkali content expressed as Na<sub>2</sub>O equivalent. Test reports are not required for air-entraining admixtures used at dosages less than 2 fl oz per 100 lb (130 mL per 100 kg) of cement or nonchloride ion and total alkali content of the admixture are to be expressed in percent by mass of cement for a stated or typical dosage of the admixture, generally in fluid ounces per 100 lb of cement (milliliters per 100 kg).

### **6. Pigments and pigmented admixtures**

The supplier shall certify that pigments or other coloring agents comply with the requirements of ASTM C979.

### **7. Hardware and inserts**

Plant tests shall not be required for hardware, but certification shall be obtained for all steel materials and each different grade of steel to verify compliance with specifications. Inserts need not be plant tested if used only as recommended by the suppliers and within their stated (certified) capacities and application qualifications. Records shall be on file establishing working capacity for each kind and size of insert used for handling and/or connection corresponding to the actual concrete strengths when inserts are used. This is unless the manufacturer's load table indicates adequate

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admixture is delivered. The admixture should meet ASTM requirements on allowable variability within each lot, between lots, and between shipments.

It is desirable to determine that an admixture is the same as that previously tested or that successive lots or shipments are the same. Tests that can be used to identify admixtures include solids content, specific gravity using hydrometer, infrared spectrophotometry for organic materials, chloride content using silver nitrate solution, pH, and others. Admixture manufacturers can recommend which tests are most suitable for their admixtures and the results that should be expected. Guidelines for determining uniformity of chemical admixtures are given in ASTM C494/C494M, C233, and C1017/C1017M, Level 1.

Normal setting admixtures that contribute less than 0.1% chloride by weight (mass) of cement are most common. Their use should be evaluated based on application, the final use of the precast unit, and whether the unit is prestressed. If chloride ions in the admixture are less than 0.01% by weight (mass) of cementitious material, such contribution represents an insignificant amount and may be considered innocuous.

### **6. Pigments and pigmented admixtures**

Synthetic mineral oxide pigments may react chemically with other products used on the surface, such as surface retarders or muriatic acid, and should be tested for these reactions prior to use.

### **7. Hardware and inserts**

If suppliers' load tables indicate adequate capacity at a concrete strength lower than the design concrete strength, the insert capacity is satisfactory.

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capacity at a concrete strength lower than the maximum strength at time of use. No extrapolation of suppliers' test data is permitted. In lieu of certification for hardware, six specimens of each size and material heat number of a steel item shall be tested in accordance with ASTM A370 to verify conformance with the applicable ASTM specification. For other hardware items, information shall be on file at the plant describing the material qualities, applications, and limitations.

### **8. Vendor-supplied assemblies**

When assemblies are produced outside the precast plant, the vendor producing the assemblies shall test assemblies in accordance with the testing procedures in Sections 6.2.3(8) and 6.2.3(9). The procedures shall be provided to the vendor and written into the sales agreement to require conformance. Vendor personnel shall maintain records of the stud weld testing on an hourly basis, and these records shall be provided to the precast plant. In addition, random sampling shall be done for each production lot of assemblies received at the precast plant. Any failure of the visual inspection or the bend test shall require like testing on an additional random 10% sample of the production lot. Any failure within this 10% sample shall require inspection and bend testing of 100% of the production lot, or replacement of the entire lot.

Substitution of reinforcing bars for deformed bar anchors shall not be allowed unless approved by the precast engineer.

Weld size and location shall be checked for welded assemblies at a rate of 1 per 50 assemblies. If discrepancies are found, then all assemblies shall be checked.

Headed stud and deformed bar anchor materials and base metal materials shall be compatible with the stud welding process. Suppliers of both materials shall provide physical and chemical certification on the product supplied. The tests shall correlate to the material supplied. One unit for each 50 assemblies shall be selected and the stud weld(s) visually inspected, with one stud bend tested in accordance with the procedures detailed in Section 6.2.3(9).

### **8. Vendor-supplied assemblies**

The heads of anchor studs are sometimes subject to cracks or "bursts" during manufacturing. These are essentially cracks starting at the edge of the head and progressing toward the center. As long as the cracks do not extend more than half of the distance from the edge to the shank, as determined by a visual inspection, they are not cause for rejection. These interruptions do not adversely affect the structural strength, corrosion resistance, or other requirements of the headed studs.

An assembly failure in service can be inelastic and occur without warning. Two failures in 10% of a production lot are cause for serious concern. In addition to testing the entire lot, the manufacturer should be consulted and their procedures and materials checked for conformance with standards. A production lot is any collection of like assemblies received in a single shipment. Separate shipments of the same assembly type constitute multiple production lots.

Weldable characteristics of reinforcing bars are usually different than deformed bar anchor studs, and strengths may not be the same.

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### **9. Curing compounds, form/mold release agents, surface retarders, weatherproofing agents, and bonding agents**

Instructions for proper use and application shall be obtained from suppliers and kept on file at the plant for all such materials used in the plant. If membrane-curing compounds are used to retain moisture in concrete, such materials shall conform to ASTM C309; if sheet materials are used, they shall conform to ASTM C171.

### **10. Concrete mixtures**

Concrete mixture proportions shall be established under carefully controlled laboratory conditions. For concrete mixtures, representative cylinders shall be cast and cured under plant production conditions to demonstrate the strength and weight of the concrete produced. All concrete mixtures shall be developed using the brand and type of cement, the type and gradation of aggregates, and the type of admixtures proposed for use in production mixtures. If at any time these variables are changed, the mixture shall be reevaluated. This reevaluation may include one or more of the following concrete properties: (1) air content; (2) durability; (3) strength (selected tests at appropriate ages); and (4) color, surface texture, or aggregate exposure.

Records of all concrete mixtures used in a plant and their respective test results shall be on file. Acceptance tests for concrete mixtures shall include:

- a. Compressive strength.** Test specimens (6 in. x 12 in. [150 mm x 300 mm] cylinders, 4 in. x 8 in. [100 mm x 200 mm] cylinders, or 4 in. [100 mm] cubes) shall be made and cured in accordance with ASTM C31/C31 or C192/C192M and tested in accordance with ASTM C39/C39M. Test specimens using 4 in. (100 mm) cubes are permitted provided proper and proven correlation data with 6 in. x 12 in. (150 mm x 300 mm) or 4 in. x 8 in. (100 mm x 200 mm) cylinders is available. Compression tests shall be performed for determination of design, release of tension, and stripping strength. For SCC mixtures, modify ASTM C31/31M or C192/C192M

### **9. Curing compounds, form/mold release agents, surface retarders, weatherproofing agents, and bonding agents**

Any sealer used should be guaranteed by the supplier or applicator not to stain, soil, or discolor the precast concrete finish, or cause joint sealants to stain concrete. Any sealer should be compatible with the previously applied bonding agent. Consult manufacturers of both sealants and sealers for compatibility or pretest before applying the sealer.

### **10. Concrete mixtures**

Casting of a mixture in a critical part of an actual mold is often advisable for checking a mixture under production conditions.

Once performed for a particular SCC mixture, qualification tests need not be repeated. However, if a mixture is not performing as expected, it is recommended to go back to the qualification tests to determine which characteristics of the mixture have changed from the original qualification.

- a. Compressive strength.** Typically, the 28-day design strength established for the concrete mixtures should be not less than 5,000 psi (34.5 MPa).

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procedures to delete rodding or vibrating cylinder or cube molds. A test shall be the average strength of two 6 in. x 12 in. (150 mm x 300 mm) cylinders, two 4 in. (100 mm) cubes or three 4 in. x 8 in. (100 mm x 200 mm) cylinders at a given age.

**b. Workability – slump or slump/flow.**

1. Slump tests shall be performed in accordance with ASTM C143/C143M.
2. Slump/flow spread tests shall be performed in accordance with ASTM C1611/C1611M for SCC mixtures. Tests shall be evaluated for spread, time to reach spread, and Visual Stability Index (VSI).

**c. Density (unit weight).** Density (unit weight) shall be tested in accordance with ASTM C138/C138M or C567, except no tamping or vibrations shall be used for SCC mixtures.

**d. Air content.** Air content shall be measured in accordance with ASTM C173/C173M or C231/C231M as applicable, except no tamping, rodding, or vibration shall be used for SCC mixtures.

**b. Workability – slump or slump/flow.** The standard slump test is inadequate as a measure of the workability of concrete produced by SCC mixtures

**c. Air content.** The volumetric method of checking air entrainment (ASTM C173) may be used on any type of aggregate, whether it is dense, cellular, or lightweight. The pressure method (ASTM C231/C231M) gives excellent results when used with concrete made with relatively dense natural aggregates for which an aggregate correction factor can be determined satisfactorily. It is not recommended for use on concrete made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. It also may not work properly on very harsh or low-slump mixtures.

Since architectural precast concrete units are generally erected in an above-grade vertical position, which is a moderate environment, air contents as low as 3% to 6% in the concrete or 7% air in the mortar fraction appear to provide the required durability. Air-entrainment levels no higher than necessary are preferred, since the compressive strength of concrete is reduced by approximately 5% for each 1% of entrained air (when the water-cement ratio is held constant). Strength reductions tend to be greater in mixtures containing more than 550 lb of cement per 1 yd<sup>3</sup> (326 kg/m<sup>3</sup>). Since most precast concrete mixtures contain a high cement factor, relatively high

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- e. **SCC.** The acceptance of concrete units cast with SCC shall be based on the use of applicable ASTM standard test methods or methods as outlined in PCI Interim Guidelines (TR6).
- f. **Shrinkage verification.** Shrinkage tests shall be made in accordance with ASTM C157/C157M.

- g. **Absorption.** The maximum water absorption for normalweight concrete (150 lb per ft<sup>3</sup> [2,403 kg/m<sup>3</sup>]) face mixtures at 28 days shall not exceed 6% by weight. Alternatively, absorption expressed by volume shall not exceed 14%. The absorption of the face mixture of a continuous production run shall be verified every 6 months, for each new project, and whenever the materials and/or production methods are modified.

Specimens shall be tested after 28 days in accordance with ASTM C642, except procedures described in Sections 5.3 and 5.4 of the ASTM test are not required.

reductions in strength may be anticipated with high levels of air entrainment. Also, as compressive strengths increase and water-cementitious ratios decrease, air-void parameters improve and entrained-air percentages can be set at the moderate exposure limits.

The addition of normal amounts of air-entraining agent to harsh gap-graded facing mixtures will improve the workability and increase resistance to freezing and thawing even though only a small amount of air is usually entrained.

- f. **Shrinkage verification.** Because of the high powder content in SCC mixtures or where mixture designs minimize bleeding, early curing methods should be considered to limit the potential for plastic shrinkage cracking. In applications where the shrinkage characteristics are an important design parameter, this aspect of the concrete mixture should be considered in design and confirmed in the production mixture. Because some SCC mixtures may have a higher potential for shrinkage than normal concrete, increased attention to ensuring that specified shrinkage limits are attained may be required.
- g. **Absorption.** A water absorption test of the proposed face mixtures may provide an early indication of weathering properties of the concrete (rather than durability).

**Samples for testing.** Three 4 in. x 8 in. (100 mm x 200 mm) cylinders or 4 in. (100 mm) cubes should be cast with concrete from three different batches from each of the mixtures being tested. If possible, samples should be cast in containers from the mold material intended for the actual production unit. Test samples should be consolidated, cured, and finished similar to the products they represent. Test samples should be

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clean and free from any parting or form release agent or any sealer.

**Test procedure.** The percentage absorption is the average absorption of the three specimens. This figure may be transformed to volume percentage based on the specific weight of the concrete tested.

A comparison of water quantities absorbed after a given time, for instance 15 min, may be determined from Rilem Test Method II.4, Water Absorption under Low Pressure (Pipe Method). This test procedure can be used to assess the effectiveness of a sealer. However, a correlation to ASTM C642 has not been developed; therefore, acceptance criteria have not been established for the Rilem Test.

### 6.2.3 Production Testing

Production testing shall be directed toward maintaining production and product uniformity by routine testing of materials and concrete to ensure that they are consistent with material suppliers' reported data or established requirements.

#### 1. Aggregates.

A sieve analysis (ASTM C136) and unit weight test (ASTM C29/C29M) shall be consistently conducted in the plant with test samples taken at random points between stockpile and batching hopper for aggregate being used. Such tests shall be carried out for each aggregate type and

### C6.2.3 Production Testing

Quality control charts displaying production test results should be used to uncover unanticipated variations in materials, batching, mixing, curing, and testing concrete. The primary objective of quality control charts is to test whether or not a process is in statistical control. Quality control charts are valuable in visually presenting the data in a manner where variation can be readily seen. These charts can provide information on whether a problem exists in a concreting operation; however, quality control charts may not locate where the variability is occurring. Quality control charts do provide clues on where to look for process variability. Quality control charts provide the benefits of (1) limiting defective batches, (2) fewer rejected batches, and (3) better overall quality.

For further commentary on the use of control charts, refer to *ACI Manual of Concrete Inspection*, SP-2, and Gebler, Steven H., "Interpretation of Quality Control Charts for Concrete Production," *ACI Materials Journal*, July/August 1990, pp. 319–326.

#### 1. Aggregates.

Sampling should preferably be from conveyors or the discharge opening of bins. Stockpiles are most difficult to sample properly and should be avoided as sample sources, if possible. The most representative sample is that from a conveyor belt. For fine aggregate, take scoops from the belt until a

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size at least once every two weeks or for each of the following aggregate volumes, where usage in a two-week period exceeds such volume:

- a. Aggregates used in architectural face mixtures. . . . . 40 yd<sup>3</sup> (31 m<sup>3</sup>)
- b. Fine aggregates used for backup mixtures . . . . . 200 yd<sup>3</sup> (150 m<sup>3</sup>)
- c. Coarse aggregates used for backup mixtures. . . . . 400 yd<sup>3</sup> (310 m<sup>3</sup>)

Each shipment of aggregate shall be visually compared with the approved aggregate sample.

Moisture tests are not required for bagged aggregates stored indoors. Surface moisture in bulk aggregates shall be evaluated and compensated for in all concrete proportioning. Moisture content shall be determined by one of the following:

- a. Drying (ASTM C566)
- b. A meter that measures moisture by the pressure of chemically generated gas
- c. An electric probe that indicates moisture by measuring the resistance between electrodes
- d. Microwave energy absorption

representative sample is obtained from which the test sample can be split or quartered. For coarse aggregate, sample from the belt only if it is practicable to stop the belt while all material on a short length of the belt is removed. If arrangements cannot be made to stop the belt, or if there are not belt conveyors at the plant, other means must be used. The next-best method of sampling is to take the entire momentary discharge of coarse aggregate from a chute or bin gate. Take at least several cubic feet of material and quarter the test sample from this amount. Such samples are most representative when it is possible to quarter them from material taken from the first, middle, and last of the material quantity to be tested.

Close control over gradation of aggregates is essential to minimize variations in surface texture and color in the finished product. Aggregates should be handled and stored in a way that minimizes segregation and degradation and prevents contamination by deleterious substances. Dry rodded unit weight of aggregate is important for mixture design. Variations in dry rodded unit weight may indicate a change in gradation, specific gravity, or particle shape.

It is good practice to maintain a running average on 5 to 10 previous gradation tests by dropping the oldest results and adding the most recent to the total on which the average is calculated. These averages can then be used to make necessary adjustments to mixture proportions.

For coarse aggregate, determine the loose density and then calculate void content based on the specific gravity of the aggregate. If the void content changes from the initial supply, have the aggregate supplier investigate the variation.

Compensation for surface moisture is particularly important for face mixtures where the amount of fine aggregates batched by weight varies enough to seriously affect the color and texture of the finished face. The free moisture on aggregates affects net aggregate weight as well as the amount of water added to the batch. This variation may cause over- or underyielding of concrete mixtures. It is recommended that weighing hoppers be equipped with properly maintained moisture meters. The meters should be periodically calibrated to detect changes of at least 1% in the free-moisture content of fine and coarse aggregates so corrections can be made and mixtures adjusted at any time. Readings from

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- e. Other devices calibrated against the ASTM C566 test method

Any method that is used to measure aggregate free-surface moisture shall result in free-moisture values that are representative of the aggregate entering the mixer.

The moisture meter, electric probe, or microwave energy absorption are satisfactory for moisture determination provided they are calibrated against the drying method (ASTM C566).

If continuous moisture determination is not used, the free-surface moisture shall be determined at the beginning of any batching operation and then at 4 hr intervals during batching operations, at any time there is visual change in the mixture consistency or an obvious change in moisture content.

### **2. Concrete strength**

During production, concrete shall be sampled and specimens made in accordance with the following specifications, except as modified herein:

- ASTM C172 – Sampling of Fresh Concrete
- ASTM C31/C31M – Making and Curing Concrete Test Specimens in the Field

Each sample shall be obtained from a different batch of concrete on a random basis, avoiding any selection of the test batch other than by a number selected at random before commencement of concrete placement.

moisture-metering devices, based on conductivity, will vary with the density of the aggregates and are not recommended for lightweight aggregates. Determination of moisture content by drying is time consuming and not necessarily accurate for practical concrete proportioning, as it tests only an isolated sample.

It is necessary to calibrate moisture sensors for each material. It should be checked against and calibrated to oven-dried tests over the entire range of measurements. The total time to complete a calibration depends on the drying time, but most calibrations take less than 3 hours. It is recommended that the sensors or meters should be checked periodically (weekly during regular use) and recalibrated if necessary. Sensors are subject to wear, and if they are out of adjustment, or not positioned correctly in the flow of material, they will not provide an accurate reading.

During production of SCC, tests of aggregate grading and moisture content should be carried out more frequently than normal concrete testing because SCC is more sensitive than normal concrete to variations in these parameters.

The close attention to adjusting batch quantities for measured free-surface moisture demanded by the consistent production of SCC provides an added quality benefit to architecturally exposed precast products. Consistent moisture corrections will lead to more consistent color in the finished product.

### **2. Concrete strength**

Testing of concrete strengths by using specimens is a critical part of the quality control program. In addition, properly correlated rebound hammer or other nondestructive tests performed on the element itself may be used to indicate stripping strength.

Samples for strength tests should be taken on a strictly random basis if they are to measure properly the acceptability of the concrete. A predetermined sampling plan (chance approach) should be set up before the start of production by establishing the

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Test specimens shall be made and cured in accordance with ASTM C31/C31M. Either 6 in. x 12 in. (150 mm x 300 mm) cylinders, 4 in. x 8 in. (100 mm x 200 mm) cylinders are acceptable, Four inch (100 mm) cubes are also acceptable provided that proper correlation with standard 6 in. x 12 in. (150 mm x 300 mm) or 4 in. x 8 in. (100 mm x 200 mm) cylinders is available.

For SCC mixtures with slump flows of 20 in. (500 mm) or greater, test specimens shall be made according to ASTM C1611/C1611M. Flowable mixtures with slump flows less than 20 in. (500 mm) shall be consolidated by rodding according to ASTM C31/C31M.

The maximum size of aggregate in 4 in. x 8 in. (100 mm x 200 mm) cylinders or 4 in. (100 mm) cubes shall not exceed 1 in. (25 mm). If larger aggregate is contained in the concrete, the compressive strength shall be measured using standard 6 in. x 12 in. (150 mm x 300 mm) cylinders. Special cube size may be used when they more adequately represent particular products, if correlation to standard 6 in. x 12 in. (150 mm x 300 mm) cylinders is provided.

A minimum of five 4" x 8" (100mm x 200mm) or four 6" x 12" (150mm x 300mm) compression specimens shall be made daily for each individual concrete mixture (whether facing or backup mixture), or for each 40 yd<sup>3</sup> (31 m<sup>3</sup>) of any one mixture where the daily consumption exceeds this volume.

The required average strength of the concrete shall be selected in accordance with ACI 318, Chapter 5, "Concrete Quality, Mixing, and Placing."

intervals at which samples will be taken. The intervals may be set in terms of either time elapsed or yardage placed. The choice of times of sampling or the batches of concrete to be sampled must be made on the basis of chance along with the period of placement in order to be representative. If batches of concrete to be sampled are selected on the basis of appearance, convenience, or other possibly biased criteria, statistical concepts lose their validity. Obviously, not more than one test should be taken from a single batch, and water should not be added after the sample is taken.

Although 4-in.-diameter (100 mm) cylinders or cubes tend to test slightly higher than 6-in.-diameter (150 mm) cylinders, the difference is usually insignificant.

Preparation and testing of cubes should be nearly as consistent with the appropriate requirements for cylinders as possible, with the exception that the concrete be placed in a single layer of 4 in. (100 mm). Rodding or external vibration methods would then proceed as outlined in the ASTM designations. Internal vibration should not be applied to the consolidation of cubes.

Molds for making specimens should be in accordance with applicable requirements of ASTM C31/C31M and C470/C470M.

The strength of a test specimen can be greatly affected by jostling, changes in temperature, and exposure to drying, particularly within the first 24 hr after casting. Thus, test specimens should be cast in locations where

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Cylinder molds shall be kept clean and free from excessive deformations and shall conform to the requirements of ASTM C470/C470M.

Test specimens shall be made as near as possible to the location where they will be cured and shall not be disturbed in any way from 1/2 hr after casting until they are either ready to be stripped or tested. Specimens shall be protected from rough handling at all ages.

Test specimens shall be cured with and by the same methods as the units they represent up to the time of detensioning or stripping from the form/mold. Cylinders stored next to a product shall have the curing conditions verified as similar to the product. In lieu of actual curing with the member, cylinders may be cured in curing chambers correlated in temperature with the product they represent. In such a case, the correlation shall be constantly verified by use of recording thermometers in the curing chambers and comparison with the temperature records of the product, and by use of the same methods of moisture retention for curing chambers and casting beds.

After stripping of the unit, test specimens shall be removed from their molds and stored in a moist condition at  $73 \pm 3$  °F ( $23 \pm 1$  °C) until time of testing.

Unless specimen ends are cast or ground to within 0.002 in. (0.05 mm) of a plane surface, the specimen shall be capped prior to testing or unbonded caps (elastomeric pads) may be used

subsequent movement is unnecessary and where protection is possible. Cylinders should be protected from rough handling at all ages. Because of the danger of producing cracks and weakened planes, cylinders cast from concrete with slumps less than approximately 1 in. (25 mm) should not be moved even in the first 15 min to 30 min. Concrete in cylinders may be consolidated by rodding or by vibration as specified in ASTM C31/C31M, except for SCC mixtures with slump flows of 20 in. or greater where ASTM C1611/C1611M applies. Any deviations from the requirements of ASTM C31/C31M should be recorded in the test report. If vibrators are used, techniques should be developed to preclude segregation.

Due to the fluidity of SCC, the cylinders should be handled with extreme care and stored on a level, stable surface until the cylinders are to be tested for product stripping.

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in accordance with ASTM C1231/C1231M. Capping procedures shall be as specified in ASTM C617, except that with fast-setting sulfur compounds especially manufactured for capping, compression testing may be performed 1/2 hr after the caps have been in place. The casting temperature of capping compounds shall be controlled per the manufacturer's recommendations. Thermostatically controlled heating pots shall be used.

Testing specimens to determine compressive strength shall be performed in accordance with ASTM C39/C39M. The strength of concrete at any given age shall be determined as the average of two specimens. If either specimen shows definitive evidence (other than low strength) of improper sampling, molding, handling, curing, or testing, it shall be discarded, and the strength of the remaining cylinder shall be considered the test result.

The strength of the concrete shall be considered satisfactory if both the following requirements are met:

- a. The average of all sets of three consecutive strength tests equal or exceed the specified 28-day strength.
- b. For specified strength of 5,000 psi (35 MPa) or less, no individual strength test (average of two cylinders) shall be more than 500 psi (3.5 MPa) below the specified strength For specified strength greater than 5,000 psi, no individual strength test (average of two cylinders) shall be less than 0.90 times the specified strength.

Nondestructive test (NDT) methods shall be acceptable provided the following conditions are met:

Nondestructive testing (NDT) may be useful tools to supplement, but not replace, cylinder tests, except as noted. NDT can serve to give a comparative or qualitative evaluation of concrete strengths. It may serve to determine stripping, transfer, or shipping strengths when cylinders have been damaged or have all been used.

NDT is generally performed on the product rather than a sample and does not destroy the product or area tested. The most common method is the rebound hammer. For all such testing, the most important

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- a. A correlation curve is established for each combination of concrete mixture design, curing procedure, and age of test.
- b. A minimum of 30 tests is used to establish each correlation curve.
- c. Test results fall within the 95% confidence limits of the correlation curve.
- d. Correlation curves shall be established for each test instrument, even of the same type.

Where concrete strengths are to be evaluated by a rebound hammer in accordance with ASTM C805/C805M, at least three sets of readings (test areas) shall be taken along the member. The area to be tested shall have a uniform surface, produced by stone rubbing if necessary. Care shall be taken not to obtain readings on an isolated piece of coarse aggregate at the surface, on any surface imperfection, directly over reinforcing steel, or over other steel near the surface.

The compressive strength for concrete in the area tested shall be taken from the point on the calibration curve corresponding to the average reading, and the strength of the unit shall be taken as the average of the strengths indicated at the three test areas.

If the compressive strength of a unit is questionable (ACI 318), at least three cores shall be taken from each unit considered to be potentially deficient. Test cores shall be obtained, prepared, and tested in accordance with ASTM C42/C42M. If the unit represented by the cores will be dry under service conditions, cores shall

criterion is correlation with actual compressive strength.

- a. Development of a correlation curve allows the use of a new or unapproved testing method after correlating that method to an approved method of testing. Correlation testing should be done annually as a minimum and at the start of a new mixture design.
- c. If values cannot be obtained during testing that are consistently within the 95% confidence limits using NDT, then a valid correlation curve cannot be established. When this occurs, the specific procedure, specimen size, or test method being considered should not be used, since it cannot be related to the standard with the required degree of confidence.

If it is necessary to drill cores, their locations should be determined by the precast engineer to least impair the strength of the structure and the exposed surface finish. Core holes should be adequately patched without damage to the appearance or structural integrity of the element.

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be air dried (at room temperatures with the relative humidity less than 60%) for seven days, and shall be tested dry. Concrete in the unit represented by the core tests shall be considered structurally adequate if both of the following requirements are met:

- a. The average strength of three cores is equal to at least 85% of the specified strength.
- b. No single core is less than 75% of the specified strength

When possible, cores should be drilled so that the test is applied in the same direction as the service load. Horizontally (in relation to casting) drilled cores may be up to 15% weaker than vertically drilled cores. Cores should be drilled with a diamond bit to avoid an irregular cross section and damage from drilling. If possible, cores should be drilled completely through the member to avoid having to break out the core. If the core must be broken free of the element, wooden wedges should be used to minimize the likelihood of damage and an extra 2 in. (50 mm) of length at the broken end should be allowed to permit sawing off ends to plane surfaces prior to testing.

The inclusion of reinforcing steel in the cores may either increase or reduce the test strength. The variation tends to be larger for cores containing two bars rather than one. Therefore, the cores should be trimmed to eliminate the reinforcement provided a length to diameter ratio of 1.00 or greater can be attained.

### 3. Slump, slump flow, and VSI

- a. **Slump.** Slump tests for each concrete mixture design shall be made in accordance with ASTM C143/C143M at the start of operations each day, when making strength test specimens, when the consistency of the concrete appears to vary, and at least once per every three air content tests.

The following tolerances (ACI 117) shall be allowed for individual batches provided the slump variation does not affect appearance or other qualities of the concrete beyond that allowed in the specifications:

Slump specified as "maximum" or "not to exceed" for all values..... +0 in.

Slump specified as 3 in. (75 mm) or less,  
..... +0, -1-1/2 in. (+0, -38 mm)

Slump specified as greater than 3 in. (75 mm),..... +0, -2-1/2 in. (+0, -63 mm)

Slump specified as a single value:

- Slump of 2 in. (50 mm) or less,  
..... ±1/2 in. (±13 mm)
- Slump of 2 in. (50 mm) through 4 in. (100 mm),..... ±1 in. (±25 mm)

### 3. Slump, slump flow, and VSI

- a. **Slump.** The slump test is a measure of concrete consistency. For given proportions of cement and aggregate without admixtures, a higher slump correlates to a wetter mixture. Slump is indicative of workability when assessing similar mixtures. However, it should not be used to compare mixtures of totally different proportions. When used with different batches of the same mixture, a change in slump can indicate a change in consistency, aggregate grading, aggregate moisture content, cement or admixture properties, amount of entrained air, or temperature. Therefore, slump test values are indicative of hour-to-hour or day-to-day variations in the uniformity of a given concrete mixture.

Flowable concrete achieved by the incorporation of high-range water reducer (HRWR or superplasticizer) is difficult to control within tight tolerances at specified slumps of 7 in. (175 mm) or greater. In addition, it is difficult to accurately measure high slumps. Consideration should be given to eliminating a maximum slump requirement when HRWR is used to achieve flowable concrete.

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- Slump that is more than 4 in. (100 mm),  
.....±1-1/2 in. (±38 mm)

Slump specified as a range, no tolerance (outside of the range).

- b. Slump flow and VSI.** The slump flow, the T-50 (also called T-20), and the Visual Stability Index (VSI) test shall be used in production to control the quality of fresh SCC with a slump flow value equal to or greater than 20 in. These tests shall be performed in accordance ASTM C1611/C1611M.

Concurrent with each slump flow test, quality control shall assign a VSI rating to the SCC from which the slump/flow test was performed.

SCC with a VSI rating of 2 or more shall be subjected to a second test. If the retest rating is 2 or more, the mixture is rejected. SCC mixtures that consistently have visual ratings of 2 or more and the cause cannot be determined and corrected shall be subjected to each of the tests used for the original production qualification of the mixture. If necessary, the mixture design shall be adjusted so that all performance criteria of the mixture are met.

The precaster shall determine the frequency of conducting these tests based on the level of experience history available for a particular SCC mixture. The frequency of testing shall not be less than that used for normal high-performance concrete. The tolerance for slump flow shall be established during the qualification testing for the SCC mixture design.

### 4. Air content

If an air-entraining admixture is used, the air content shall be measured in accordance with ASTM C173/C173M or C231/C231M as applicable, except no tamping, rodding, or vibration shall be used for SCC with a slump flow value equal to or greater than 20". Air content shall be tested periodically during the operation

- b. Slump flow and VSI.** The slump/flow test, the T-50 (also called T-20) test, and the VSI rating of stability are primarily tools for measuring and evaluating the consistency of SCC production mixtures between batches on a daily basis. Constant diligence is required on the part of quality control and production personnel while casting with SCC. A decision is required at some responsible level concerning the acceptability of each batch. Visual assessment of the mixture, whether during a slump/flow test or during placement of the SCC in the product, is the first line of defense against continued use of a mixture that is not performing as designed.

The T-50 test should be run and the value recorded on new mixtures to establish a value for this parameter that can be checked in the event of mixture performance problems.

When SCC production is well controlled, it may be unnecessary to perform the T-50 test at the same frequency as the slump/flow and VSI tests.

For new SCC mixtures, each batch should be tested until a high level of consistency is established. If the application has a high level of reinforcement, a slump flow less than 22 in. (559 mm) is not recommended.

For those types of mixtures where the T-50 test is applicable, the T-50 test should be performed a minimum of twice per month or every 2,000 yd<sup>3</sup> of production or whenever a change in SCC viscosity is noted.

### 4. Air content

The volumetric method of measuring air content (ASTM C173/C173M) may be used on any type of aggregate, whether it is dense, cellular, or lightweight. The pressure method (ASTM C231/C231M) gives excellent results when used with concrete made with relatively dense, natural aggregates for which an aggregate correction factor can be determined

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with a minimum of one daily check per mixture design or when making strength test specimens.

Variations from the specified value of air content shall not exceed 1.5 percentage points to avoid adverse effects on compressive strength, workability, or durability.

A check on the air content shall be made when the slump varies more than  $\pm 1$  in. ( $\pm 25$  mm), temperature of the concrete varies more than  $\pm 10$  °F ( $\pm 6$  °C), a change in aggregate grading occurs, or there is a change of concrete yield.

### **5. Density (Unit weight)**

Density (unit weight) tests of concrete in accordance with ASTM C138/C138M shall be conducted at least once per week for each mixture design regularly used, except for lightweight concrete, which shall be tested daily in accordance with ASTM C567 to confirm batching consistency. Unit weight tests of SCC shall be conducted daily. When the nominal fresh density varies from the established value by more than  $\pm 2$  lb per ft<sup>3</sup> ( $\pm 32$  kg/m<sup>3</sup>) for normalweight concrete or  $\pm 2\%$  for structural lightweight concrete, batch adjustments shall be made.

### **6. Temperature of concrete**

The temperature of freshly mixed concrete shall be measured in accordance with ASTM C1064/C1064M and recorded when slump, air content, or compressive strength test specimens are made. This shall apply for every batch in hot or cold weather conditions and at the start of operations each day.

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satisfactorily. It may not give accurate results for very harsh or low-slump mixtures. With such mixtures, the application of pressure to the surface of the concrete may not result in the expected compression of air in the void system. The volumetric method, ASTM C173/C173M, is not subject to this limitations and should produce accurate results on even the driest concrete. Although these tests measure only air volume and not air-void characteristics, which can only be determined microscopically (ASTM C457), it is has been shown by laboratory tests that these methods are generally indicative of the adequacy of the air-void system.

### **5. Density (Unit weight)**

The density (unit weight) is a quick and useful measurement for assessing quality. A change in unit weight generally indicates a change in either air content or aggregate weight. When density measurements (ASTM C138/C138M or C567) indicate a variation of the calculated fresh density from the laboratory mixture design of more than 2 lb per ft<sup>3</sup> (32 kg/m<sup>3</sup>) for normalweight concrete, or  $\pm 2\%$  for structural lightweight concrete, the air content should be checked first to establish whether the correct amount of air has been entrained. If air contents are correct, then a check should be made on the aggregates to ensure that the unit weight, gradation, moisture content, or proportions have not changed. Results of these checks generally will reveal the cause of the variations in unit weight of concrete and indicate what mixture adjustments need to be made. After adjustments are made, the unit weight should again be measured.

The density test results are used to calculate the volume or yield produced from known weights of materials and to calculate the cement content in pounds per cubic yard of concrete.

### **6. Temperature of concrete**

Temperature of fresh concrete affects a number of properties of concrete. Warm concrete sets faster than cool concrete. Warm concrete requires more water per cubic yard than cool concrete to produce the same slump. For mixtures of the same slump without admixtures, unless more cement is used in the warmer concrete, the concrete will have a higher water-cementitious ratio. Warm concrete gains strength faster than cool concrete, but the strength at later ages

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may be lower than that of cool concrete. Knowledge of the temperature of fresh concrete permits the batch plant operator to adjust mixtures. Concrete at higher temperatures requires more air-entraining agent to produce the same air content. Warm concrete tends to dry faster; consequently, curing of warm concrete is even more important than curing of cool concrete. Also important is maintaining a given minimum temperature during cold-weather concrete operations. This is to prevent freezing to ensure appropriate strength gain, both during placement and during the initial cure time.

### **7. Air temperature**

Ambient air temperature shall be recorded at the time of sampling for each strength test.

### **8. Welding**

Quality control shall verify welder's qualification, make certain proper electrodes are used, and ensure that a preheat temperature indicating device is on hand and used appropriately. Welder qualification shall be for the welding process, expected weld types, and position of welds to be performed. As a minimum, the welder shall be qualified for complete joint penetration groove welds and flare-groove welds.

The welder's qualification shall be considered as remaining in effect indefinitely unless: (1) the welder is not engaged in a given process of welding for which the welder is qualified for a period exceeding six months, or (2) there is some specific reason to question a welder's ability.

Personnel responsible for acceptance or rejection of welding workmanship shall be qualified. The following are acceptable qualification criteria:

- a. Current or previous certification as an AWS Certified Welding Inspector (CWI) in accordance with the provisions of AWS QC1.
- b. Current or previous qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2.
- c. An engineer or technician with training or experience in steel fabrication, inspection, and testing.

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The qualification of personnel responsible for acceptance or rejection of welding workmanship shall remain in effect indefinitely, provided such personnel remain active in inspection of welded steel fabrication, unless there is specific reason to question the personnel's ability.

Inspectors shall have passed an eye examination with or without corrective lenses to prove: (1) near-vision acuity of Snellen English, or equivalent, at 12 in. (305 mm), and (2) far-vision acuity of 20/40 or better. Vision examination of all inspection personnel is required every three years or less if necessary to demonstrate adequacy.

Prior to welding, inspection shall include the following:

- a. Review of welding drawings and welding procedure specifications.
- b. Ensuring that welding materials and consumables are in accordance with specifications.
- c. Checking and identifying as-received materials against specifications.
- d. Checking storage of filler materials.
- e. Checking welding equipment.
- f. Checking weld joint preparations.
- g. Checking for base metal discontinuities.
- h. Establishing a plan for the recording of results.

Visual inspection during welding by the weld operator shall include:

- a. Quality of weld root bead.
- b. Joint root preparation, such as slag removal, prior to welding the second side.
- c. Preheat and interpass temperatures.
- d. Sequence of weld passes.
- e. Subsequent layers for apparent weld quality.
- f. Cleaning between passes (use of a wire brush or chipping hammer to remove slag).
- g. Conformance with the applicable procedure; for example, voltage, amperage, heat input, and/or speed.

Visual inspection guidelines are given in AWS B1.11 while radiographic and ultrasonic testing procedures and limits are given in AWS D1.1/D1.1M and D1.4/D1.4M. If required by specifications, radiographic testing (while very costly) is good, and ultrasonic testing is poor in detecting volumetric discontinuities, such as porosity. Ultrasonic testing is good for detecting planar discontinuities, such as incomplete sidewall fusion, while radiographic testing can miss such discontinuities unless oriented parallel or near parallel to the radiation direction.

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The following items shall be inspected on at least 10% of all assemblies after welding to determine the quality of the welds:

- 1) Geometric imperfections. The fillet weld faces shall be slightly convex, concave, or flat, as shown in Figure 6.2.3(a) A and B. Weld profiles exhibited in Figure 6.2.3(a) C are unacceptable. Figure 6.2.3(a) D and E shows similar acceptable and unacceptable profiles for groove type welds.
- 2) The weld metal and heat-affected zone of the base metal shall be free of cracks.
- 3) There shall be thorough fusion between weld metal, base metal, and successive passes in the weld.
- 4) All craters shall be filled to the full cross section of the weld, except for the ends of intermittent fillet welds outside the effective length.
- 5) Welds shall be free from overlap.
- 6) For materials less than 1 in. (25 mm) thick, undercut depth greater than 1/32 in. (1 mm) in the solid section of the reinforcing bar or structural members shall not be allowed except at raised reinforcing bar deformation where 1/16 in. (1.5 mm) is permissible. For steel shapes or plates, refer to AWS D1.1 for the requirements of the specific structure type.
- 2) Visual inspection for cracks in welds and base metal and other discontinuities should be aided by a strong light, magnifier, or other such devices, as may be found to be helpful. Size, length, and contour of welds should be measured with suitable weld-size gauges. Groove welds should be measured for proper reinforcement on both sides of the joint. Quality control should compare the welds with three-dimensional "workmanship samples" available from AWS. These are actual welded samples, or plastic replicas of welded samples that depict actual weld conditions.
- 3) Only incomplete fusion apparent during a visual inspection needs to be considered unless specifications require radiography or ultrasonic examination.
- 5) Overlap is the protrusion of weld metal beyond the weld toe or root weld.

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- 7) For reinforcing bars, the sum of diameters of piping porosity in flare-groove and fillet welds shall not exceed 3/8 in. (10 mm) in any linear inch (25 mm) of weld and shall not exceed 9/16 in. (14 mm) in any 6 in. (150 mm) of weld. For steel shapes or plates, refer to AWS D1.1/D1.1M for the requirements of the specific structure type.
- 8) Incomplete joint penetration.
- 9) Slag inclusions.
- 10) Amount of distortion.

The size, length, location, and type of all welds shall be as shown on approved drawings. No welds shall be omitted or added without approval.

Weldments shall be checked after fabrication for brittleness by striking at least one out of every 50 pieces with a 3 lb (1.3 kg) hammer. Brittle weldments will break under a hammer blow. When such brittle weldments are found, all assemblies made using similar procedures shall be considered suspect and checked for acceptance.

Deficient welds shall be corrected by rewelding or removal in accordance with specified procedures.

### **9. Stud welding**

The stud-welding operator shall be responsible for the following tests and inspections to ensure that the proper setup variables are being used for the weld position, stud diameter, and stud style being welded. Testing is required for the first two studs in each day of production and for changes in the setup such as stud gun, stud-welding equipment, total welding lead length, or changes greater than 5% in current (amperage) and dwell time.

Size, length, and contour of welds should be measured with suitable weld-size gauges. Groove welds should be measured for proper reinforcement on both sides of the joint. Quality control should compare the welds with three-dimensional workmanship samples available from AWS. These are actual welded samples, or plastic replicas of Figure 6.2.3(a), Weld profiles.

### **9. Stud welding**

Testing of sample studs should be part of daily operations. If failures occur in plate stock to which a stud is welded, then the requirements for plates should be reviewed by engineering.

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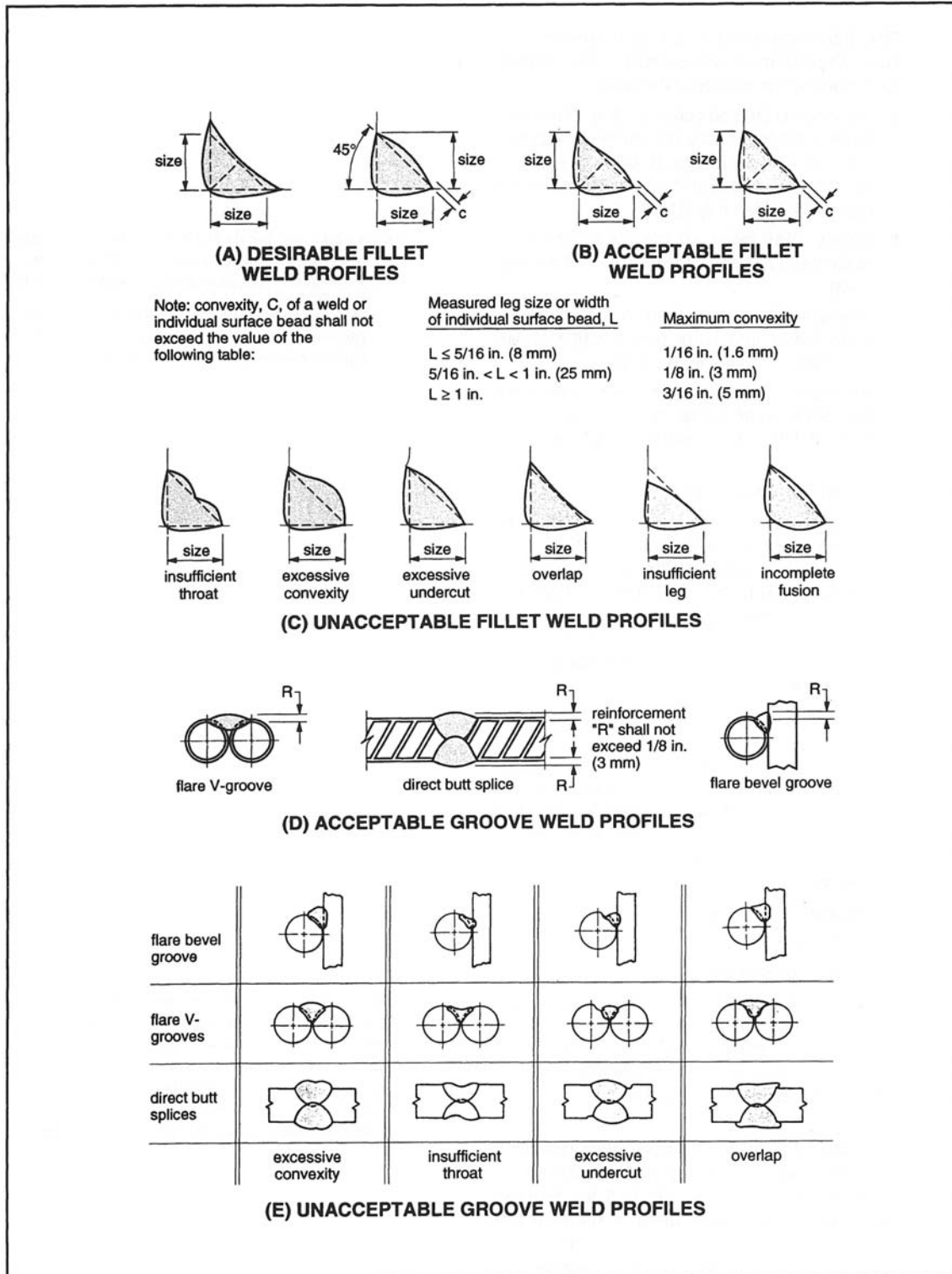


Fig. 6.2.3(a) Weld profiles

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**Down-hand stud welding qualifications.** For studs welded in the down-hand position, at the start of each production period, the operator shall weld two studs of each size and type to a production weld plate or a piece of material similar in material composition and within  $\pm 25\%$  of the production weld plate thickness. The test weld plate and production weld plate pieces shall be clean of dirt, paint, galvanizing, heavy rust, or other coatings that could prevent successful welding or adversely affect weld quality. The studs shall be visually inspected by the operator to ensure that a proper weld fillet has formed. The weld fillet (flash) may be irregular in height or width, but shall completely encompass "wet" the stud circumference without any visual sign of weld undercut. The test studs shall exhibit an after-weld length measurement shorter than the before-weld stud length. After-weld length shall be consistent on both test welds and on all production welds. Typical length reductions for various stud diameters are as follows in Table 6.2.3(a).

**Table 6.2.3(a) Length reductions**

| Stud diameter,<br>in. (mm)           | Length reduction,<br>in. (mm) |
|--------------------------------------|-------------------------------|
| 3/16 through 1/2<br>(5) through (12) | 1/8 (3)                       |
| 5/8 through 7/8<br>(16) through (22) | 3/16 (5)                      |
| 1 (25) and over                      | 3/16 to 1/4 (5 to 6)          |

After the test studs are allowed to cool, the studs shall be bent to an angle approximately 30 deg from their original axis by striking the studs with a hammer or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud. At temperatures below 50 °F (10 °C), the stud shall be bent slowly using the bending device only.

Threaded studs shall be torque tested in accordance with AWS D1.1/D1.1M to a proof load of approximately 90% of the specified yield strength rather than bend tested.

At temperature below 50 °F (10 °C), some stud and base materials may lack adequate toughness to pass a hammer test.

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Completion of the visual and mechanical tests listed above on both test studs without evidence of failure in the weld zone constitutes acceptance of the stud welding procedure and qualifies the process and the operator for production welding in the down-hand position.

If either test stud fails the visual measurement or bend test inspection, the operator shall check the welding variables and make the necessary adjustments. Two additional studs shall be welded by the operator after adjustment and retested per the above procedure.

Failure of either stud in the second set of test specimens shall be cause for the stud welding operation to be stopped and appropriate supervisory personnel notified.

**Non-down-hand stud welding qualifications.** Studs welded to positions other than down-hand and studs welded to the heel of an angle or into the fillet of an angle shall be subject to the same preproduction tests and inspections, except that 10 studs shall be welded and satisfactorily bend tested to 90 deg without failure. This shall be performed prior to proceeding with production welding.

Weld procedure specifications (WPS) and procedure qualification records (PQR) shall be maintained by the appropriate supervisory personnel.

Preproduction test samples shall be identified and set aside for verification and approval by the welding supervisor or for other action in the case of weld failures. Studs on approved test samples, which can be used in production, may have the bent studs straightened. This shall be done with a device placed over the stud and straightened if the precast engineer determines it to be functionally and structurally acceptable.

Production welded studs requiring a bend shall be bent to the required position for embedment in a similar manner with a suitable device. The studs shall be bent with a slow, continuously applied load in such a manner that the bend is not made directly at the stud base. Instead, the bend shall be above the stud base so that a bend radius four to six times the stud diameter is made

Successfully completing 10 stud tests shall be considered as adequate qualification of the process and the operator for production down-hand welding in the out-of-position configuration or for other application details.

Successfully completing 10 stud tests shall be considered as adequate qualification of the process and the operator for production non-down-hand welding in the out-of-position configuration or for other application details.

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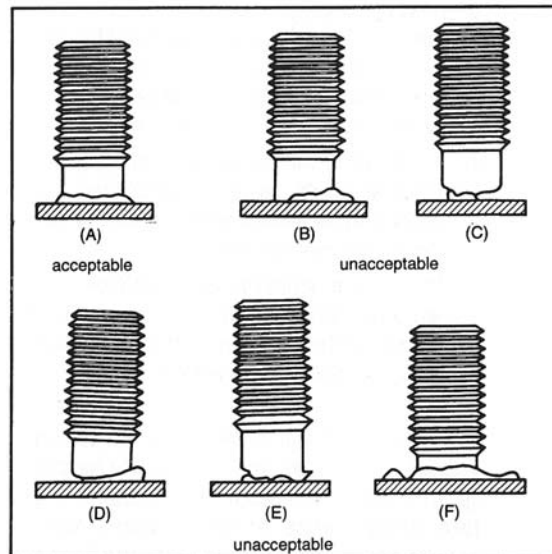
during the bending process. Studs shall not be heated prior to or during bending operations.

**Visual inspection of stud welding.** During stud welding, the operator shall ensure that all studs have the ceramic arc shield removed and are visually inspected at 1 hr intervals. The number of studs welded by a single operator in 1 hr shall be considered a production lot of studs. The operator shall then proceed to inspect the production lot of studs.

If a visual inspection reveals any stud that does not show a full 360 deg weld flash, the stud shall be measured to determine whether the after-weld length is within the satisfactory weld length reduction listed in Table 6.2.3(a). Studs with satisfactory length reduction, but lacking a full 360 deg flash, shall then be bent approximately 15 deg from the original axis in a direction opposite to the missing portion of the weld flash. After bending, the stud shall be straightened by applying a slow, continuous load with a suitable bending device. If no failure occurs, the stud weld shall be considered satisfactory. Threaded studs, which exhibit the lack of a full 360 deg weld flash, shall be torque tested to the required proof load to produce 90% of the specified stud yield strength.

At the option of the welding operator, studs with a satisfactory after-weld length, but lacking a full 360 deg weld flash, may be repaired by adding a minimum fillet weld as required in Table 6.2.3(b). The repair weld shall extend at least 3/8 in. (10 mm) beyond the end of the discontinuities being repaired.

**Visual Inspection of Stud Welding.** The weld flash around the stud base is inspected for consistency and uniformity. Lack of a flash may indicate a faulty weld. Figure C6.2.3(a) shows typical acceptable and unacceptable weld flash appearances. Figure C6.2.3(a) (A) shows a satisfactory stud weld with a good weld flash formation. In contrast, (B) shows a stud weld in which the plunge was too short. Prior to welding, the stud should always project the proper length beyond the bottom of the ferrule. This type of defect may also be caused by arc blow. Also in Figure C6.2.3(a), (C) illustrates "hang-up" where the stud did not plunge into the weld pool. This condition may be corrected by realigning the gun accessories to ensure completely free movement of the stud during lift and plunge. Arc length may also require adjustment. In (D), poor vertical alignment is shown. This may be corrected by positioning the stud gun perpendicular to the work. Low weld power (heat) results in the condition shown in (E). To correct this problem, the ground and all connections should be checked. Also, the current setting or time setting, or both, should be increased. It may also be necessary to adjust the arc length. The effect of too much weld power (heat) is shown in (F). Decreasing the current setting or the dwell time, or both, will lower the weld power.



**Figure C6.2.3a. Satisfactory and unsatisfactory arc stud welds**

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**Table 6.2.3(b). Minimum fillet weld size for studs**

| Stud diameter,<br>in. (mm) | Minimum size fillet *,<br>in. (mm) |
|----------------------------|------------------------------------|
| 1/4 (6) through 7/16 (11)  | 3/16 (5)                           |
| 1/2 (12)                   | 1/4 (6)                            |
| 5/8, 3/4, 7/8 (16, 20, 22) | 5/16 (8)                           |
| 1 (25)                     | 3/8 (10)                           |

\* Welding shall be done with low-hydrogen electrodes 5/32 in. (4 mm) or 3/16 in. (5 mm) in diameter, except a smaller-diameter electrode may be used on studs 7/16 in. (11 mm) in diameter or under or for out-of-position welds. WPS shall be qualified for all size fillet welds.

Studs with unsatisfactory weld burn off and lack of a full circumferential flash shall be repaired with a fillet weld, bent 15 deg, and straightened or torque tested.

Studs that fail the inspection test by breaking off or tearing in the weld zone shall be removed. The weld spot shall be ground smooth and the stud replaced.

**Testing of production stud welds.** The welding supervisor shall verify that these inspections have been made and identify any studs repaired or replaced.

Inspection and testing during production welding for studs welded in positions other than down-hand shall be identical to those procedures listed above. In addition, because of greater risk of incomplete welding, these studs (except for threaded studs) shall receive 100% testing by striking with sufficient force using a heavy, short-handled machinist's hammer. Any studs that break off shall be shown to the supervisor and replaced with new studs or repaired by arc welding. Repaired or replaced studs shall be inspected by bending 15 deg and straightening without failure.

Threaded studs should be proof loaded to demonstrate acceptable torque values as shown in Table C6.2.3(a).

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After a production-welding period of 1 hr, the two stud preproduction testing procedures outlined above shall be repeated for studs welded down-hand or in any other position. If either of the two studs fails the test, the supervisor and the operator together shall proceed as follows:

- a. Working backward with respect to the direction of application of the studs welded for this test, test the previous 10 most recently welded studs. If any fail, test 10 more and continue working backward until studs are tested successfully without failure.
- b. In addition, the supervisor shall visually inspect all studs welded from the 10 successful stud tests backward to the previous regular production test.
- c. The preproduction test shall be repeated with appropriate equipment and weld setting adjustments until satisfactory welds are achieved before proceeding with further production.

The stud-welding operator shall maintain a record of the startup and hourly testing program and record the date, time of test, type, lot number of hardware, and conformance or nonconformance of the results. The sheet shall be kept in the stud-welding operator's work area and shall be inspected at least daily by the quality control inspector as a monitoring technique. In addition, the quality control inspector shall perform bend tests and visual inspection on one stud for every 50 assemblies.

Successfully completing 10 stud tests shall be considered as adequate qualification of the process and the operator for production welding in the out-of-position configuration or for other application details.

When the temperature of the base metal is below 32 °F (0 °C), one additional stud in each 100 studs shall be tested by methods described above, except that the angle of testing shall be approximately 15 deg. This is in addition to the first two studs tested for each start of a new production period or change in setup.

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**Table C6.2.3(a). Proof Loads – Threaded Studs of Carbon Steel.**

| Torque Proof Loads – Threaded Studs<br>A-108 Carbon Steel |      |                                   |        |                       |        |
|-----------------------------------------------------------|------|-----------------------------------|--------|-----------------------|--------|
| Stud Size<br>(Diameter)                                   |      | Proof Load<br>(90% of Min. Yield) |        | Minimum Stud<br>Yield |        |
| in.                                                       | UNC  | ft-lbs                            | lbs    | ft-lbs                | Lbs    |
| 1/2                                                       | (13) | 53                                | 6,310  | 59                    | 7,100  |
| 5/8                                                       | (11) | 105                               | 10,170 | 118                   | 11,300 |
| 3/4                                                       | (10) | 188                               | 15,030 | 209                   | 16,700 |
| 7/8                                                       | (9)  | 303                               | 20,790 | 337                   | 23,100 |
| 1                                                         | (8)  | 454                               | 27,270 | 505                   | 30,300 |
| Torque Proof Loads<br>A-276 / A-493 Stainless Steel       |      |                                   |        |                       |        |
| 1/2                                                       | (13) | 37                                | 4,473  | 41                    | 4,970  |
| 5/8                                                       | (11) | 74                                | 7,119  | 82                    | 7,910  |
| 3/4                                                       | (10) | 132                               | 10,521 | 146                   | 11,690 |
| 7/8                                                       | (9)  | 212                               | 14,553 | 236                   | 16,170 |
| 1                                                         | (8)  | 318                               | 19,089 | 354                   | 21,210 |

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### **6.2.4 Special Testing**

### **C6.2.4 Special Testing**

#### **1. Heat of hydration**

#### **1. Heat of hydration**

For massive concrete castings or when partly or fully insulated molds are used that may result in excessive concrete temperatures, self-recording thermometers shall be used to record the temperature history of one typical casting. If the temperature exceeds 158 °F (66 °C), additional considerations shall be taken to cool the concrete.

In most precast concrete units, the heat generated by the hydrating cement is dissipated almost as fast as it is generated, and there is little temperature differential from the inside to the outside of the member.

Extreme differences between internal and external temperatures of massive members may result in surface cracking. For example, temperature stresses occur as the temperature of the concrete rises because of heat of hydration, and then cools to the surrounding temperature. As the outer surface cools and tends to shrink, compressive stresses are set up in the center and tensile stresses in the cooler outer surfaces. When these tensile stresses become greater than the tensile strength of the concrete, cracking occurs. Since the interior responds more slowly than the surface to cycles of temperature, it is as though the surface is restrained by the interior concrete. Accordingly, the maximum permissible temperature difference between any points in the element for a nominally reinforced structure generally should not be allowed to exceed 35 °F (20 °C).

#### **2. Freeze-thaw tests**

#### **2. Freeze-thaw tests**

Routine freeze-thaw durability tests of vertical elements are not required. If freeze-thaw tests are specified due to special exposure or environmental conditions, the test conditions of freezing in air and thawing in water (ASTM C666/C666M, Method B) shall be followed. Under this test method, the minimum allowable durability factor as defined by ASTM C666/C666M shall be 70.

Laboratory freezing and thawing tests may be conducted to evaluate the durability of concrete under severe climatic conditions. These tests can be made on prismatic samples prepared from laboratory trial mixtures or even from cores cut from the face of finished production units. Such tests, however, take several months to complete. The verticality of wall units seldom allows concrete to reach the critical moisture saturation point (above 90%) on which such tests are based. However, where horizontal areas allow water or snow to accumulate or where ground level panels may be subjected to splashing by deicing salts and to freezing conditions at moisture contents above critical saturation, an air-entraining admixture should be used in the concrete. In addition, in most instances, it is probably a prudent policy to have air-entrained concrete in all precast concrete exposed to freeze-thaw cycles.

### **6.3 Records**

#### **6.3.1 Record Keeping**

In order to establish evidence of proper

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manufacture and conformance with plant standards and project specifications, a system of record keeping shall be used that will provide full information regarding testing of materials, mixture designs, production tests, and any other information specified for each project. Records shall be designed to allow minimum effort to compile (see Sample Record Forms, Appendix E).

Each precast concrete unit shall be marked on the backside or edges with an identification that can be referenced to production, erection drawings, testing records, and date produced.

Unless otherwise noted herein, record keeping shall be the responsibility of the quality control inspection personnel. In the absence of project specification requirements or state statute, records shall be kept for a minimum of five years after final acceptance of the structure, or for the period of product warranty provided by the manufacturer, whichever is longer. Digital records shall be regularly backed up and stored in another secure location.

### **6.3.2 Suppliers' Test Reports**

Certified test reports for materials not tested in-house shall be required of suppliers. Refer to Section 2.2.4 for this requirement. These reports shall show the results of suppliers' mill or plant tests, tests by an independent testing laboratory, petrographic analysis of aggregates for concrete mixtures, and other testing required by the project specifications. These reports shall state compliance with applicable specifications and standards.

Mill or suppliers' test certificates or standard test results shall be available for the following materials:

1. Cement.
2. Aggregates.
3. Admixtures.
4. Reinforcing steel (all grades).
5. Prestressing tendons.

### **C6.3.2 Suppliers' Test Reports**

Project specifications require standards for materials used in production. A manufacturing facility must obtain certificates of compliance to ensure the integrity of the product and to protect its own interests. Correlation of certificates of compliance to a specific project is needed for conformance with the design and specifications.

Plants that utilize materials fabricated or supplied by outside vendors should periodically inspect the operation of those vendors and request and review their quality assurance programs to ensure compliance with requirements of this manual. All vendors should be required to submit proof of compliance for both material and workmanship.

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6. Studs or deformed anchors.
7. Structural steel or other hardware items.
8. Inserts or proprietary items as specified for individual projects.
9. Pigments.
10. Curing compounds.

These records shall be kept for the same period of time as the other project records

### **6.3.3 Tensioning Records**

An accurate record of all tensioning operations shall be kept and reviewed by quality control personnel. This record shall include, but not be limited to, the following:

1. Date of tensioning.
2. Casting bed identification.
3. Description, identification, and number of elements.
4. Manufacturer, size, grade, and type of strand.
5. Coil or pack number of strand, identifying heat.
6. Sequence of stressing (and detensioning, if critical).
7. Identification of jacking equipment.
8. For all pretensioning:
  - a. Required total force per strand.
  - b. Initial force.
  - c. Calculated and actual gauge pressure for each strand or each group of strands stressed in one operation.
  - d. Calculated and actual elongation for each different jacking force. The

### **C6.3.3 Tensioning Records**

Variations of actual values from computed theoretical values should be computed each day to monitor developing trends and to make personnel aware of tolerances

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tensioning calculations shall show a summary of anticipated operational losses such as strand chuck seating, splice chuck seating, abutment movements, thermal effects, and self-stressing form/mold shortening.

9. For single-strand pretensioning:
  - a. If the setup is open, where no friction is imposed on the strand between strand chucks, the record shall contain jacking force for each strand and the actual elongation of the first strand tensioned in each different stress group and the elongation of at least 10% of the remaining strand.
  - b. If one system is used for determination of the jacking load and friction is expected to be imposed on the strand, the actual elongation of every strand and jacking force shall be recorded.
10. For post-tensioning:
  - a. The jacking force and actual net elongation of each tendon with allowance made for elastic shortening of the member.
  - b. Data on and date of grouting.
11. Any unanticipated problems encountered during tensioning, such as wire breakage, excessive seating, restressing, or other factors having an influence on the net stress.

### **6.3.4 Concrete Records**

Records of concrete operations and tests shall be kept so the following data will be available:

1. Unit and job identification.
2. Production date.
3. Mixture proportions by weight.
4. Mixing-water corrections and/or aggregate corrections due to surface moisture.

### **C6.3.4 Concrete Records**

In evaluating mixture design efficiency or performance, all information as listed is needed to eliminate variables. If a problem occurs, information is needed for evaluation in the same manner.

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5. Yardage, design, and actual yield or unit weight.
6. Identification of production area, mold, or bed.
7. Test specimen identification.
8. Concrete temperature.
9. Air temperature, weather conditions, if applicable, and any measures taken for cold or hot weather concreting.
10. Slump, except that slump flow, VSI, and T-50 records for SCC shall replace the slump measurement records for normal concrete mixtures.
11. Air content.
12. Unit weight (fresh).
13. Inspection of batching, mixing, conveying, placement, consolidating, and finishing of concrete.
14. Method and duration of curing; for example, temperature charts for accelerated curing.
15. Strength at stress release or stripping.
16. 28-day strength.
17. Absorption for concrete exposed to weathering.
18. Cylinder strength tests and air-dry unit weight for lightweight concrete.
19. Fresh unit weight for lightweight concrete.
20. Inspection reports

### **6.3.5 Calibration Records for Equipment**

Calibration records for plant equipment, such as batch plant scales, compression testing machines, impact hammers, nondestructive testing devices, and other necessary equipment, shall be supplied by the testing agency or others involved in calibration, and the equipment

### **C6.3.5 Calibration Records for Equipment**

Calibration records are required as specified for each type of equipment, and equipment should be periodically recalibrated as required. Records that show deviations between instrument readings and actual values should be used by plant personnel to obtain correct readings.

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operator shall have ready access to the records.

### **6.4 Laboratory Facilities**

#### **6.4.1 General**

The plant shall maintain an adequately equipped laboratory or retain the services of a testing agency in which investigation and development of suitable concrete mixtures may be conducted, and ongoing quality control testing may be performed.

The laboratory facilities shall be in a protected area with environmental controls to ensure proper working conditions. Laboratory equipment shall be maintained in proper conditions and calibrated as needed, but not less than annually. Calibration records shall be kept on file.

#### **6.4.2 Quality Control Testing Equipment**

The plant shall have all equipment required for performing the testing procedures. Equipment shall meet the requirements of the test procedure specification.

#### **6.4.3 Test Equipment Operating Instructions**

Operating instructions shall be obtained for all testing equipment, as well as national and industry standards for materials and testing. These instructions shall be kept in the laboratory

#### **C6.4.2 Quality Control Testing Equipment**

The laboratory should have the facilities necessary for the development and assessment of concrete mixtures and the quality control tests to be performed by the manufacturer in accordance with ASTM C1077.

Since the compressive strength of concrete must be determined prior to stripping or stress transfer, testing equipment should be provided at all plants. It is preferable to have this equipment at the plant to avoid delays and possible damage to cylinders by transportation to a central laboratory.

Testing machines should be equipped with a guard that will protect personnel from flying debris.

Care in using high-temperature capping compounds is required due to the potential for fire. If the compound is overheated, a fire may result, so a functioning thermostat is required. Due to fumes produced, the capping compound heater should be vented to the exterior of the testing area

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and shall be carefully followed by all testing personnel.

Compression testing machines shall be kept clean, and no attempt shall be made to use the machines beyond the rated capacity. Machines shall be capable of applying loads at the specified rate.

Testing machines shall be calibrated so that the maximum error is not more than +1% of full scale reading or +2% of the maximum expected test load, whichever is less. Calibration shall be performed when there is reason to question the accuracy of indicated loads, or at least annually. Calibration curves shall be available at all times and used by testing personnel.

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### **7.1 Requirements for Finished Product**

### **C7.1 Requirements for Finished Product**

#### **7.1.1 Product Tolerances – General**

#### **C7.1.1 Product Tolerances – General**

The tolerances listed in this Division shall govern unless other tolerances are noted in the contract documents for a specific project.

Tolerances are divided into three categories: product tolerances, erection tolerances, and interfacing tolerances. See Appendix I for erection tolerances \*.

Applicable product tolerances shall be clearly conveyed to production and quality control personnel.

Tolerance is defined as permissible variation from a specified dimension. A tolerance can be expressed as an additive (+) or subtractive (-) variation from a specified dimension or relation or as an absolute deviation from a specified relation.

It is very important that project tolerances be clearly defined at the onset of the project.

The architect/engineer should be responsible for coordinating the tolerances for precast concrete work with the requirements of other trades whose work adjoins or is incorporated in the precast concrete construction. In all cases the tolerances should be reasonable, realistic, and within generally accepted limits. It should be understood by those involved in the design and construction process that tolerances shown in Section 7.3 should be considered as guidelines for an acceptable range and not limits for rejection. If these tolerances are met, the unit should be accepted. If the tolerances are exceeded, the unit may still be acceptable if it meets any of the following criteria:

1. Exceeding the tolerances does not affect the structural integrity, or architectural performance of the unit, or other trades.
2. The unit can be brought within tolerance by structurally and architecturally satisfactory means.
3. The total erected assembly can be reasonably modified to meet all structural and architectural requirements.

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\* See PCI MNL-135, *Tolerances for Precast and Prestressed Concrete Construction*, for a complete discussion on erection and interfacing tolerances.

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**Handling a pre-pour tolerance discrepancy.** An out-of-tolerance discrepancy discovered in advance of the placement of concrete should always be corrected to nominal tolerance prior to the placement of concrete.

The plant should have documented procedures regarding the manner in which pre-pour discrepancies noted by the quality control personnel are communicated to the production personnel for correction. These procedures should include a follow-up step to ensure that noted discrepancies have in-fact been corrected prior to concrete placement.

**Handling a post-pour / pre-shipment tolerance discrepancy.** An out-of-tolerance discrepancy discovered after the placement of concrete should be documented and evaluated to determine what, if any, corrective action is needed. The plant should have documented procedures regarding the manner in which post-pour discrepancies noted by the quality control personnel are communicated for evaluation. The procedure should outline which individual within the plant is authorized to evaluate the consequences of such discrepancies.

These procedures should include a follow-up step to ensure that noted discrepancies have either been corrected or that other appropriate steps have occurred (such as notification of the field erection crew if the problem can be solved during erection). It is always better to evaluate post-pour tolerance discrepancies before the member is shipped to the construction site. The producer's representative should evaluate whether or not the architect/engineer needs to be involved in the resolution of any specific discrepancy.

Careful inspection of the listed tolerances will reveal that many times one tolerance will override another. The allowable variation for one unit of the structure should not be applicable when it will permit another unit of the structure to exceed its allowable variations. Restrictive tolerances should be reviewed to ascertain that they are compatible and that the restrictions can be met. For example, a requirement that states that "no bowing, warpage, or movement is permitted" is not practical or possible to achieve.

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### **7.2 Measurement**

Accurate measuring devices and methods with a level of precision that is appropriate for the specified tolerances shall be used for both setting and checking product tolerances. To ensure proper accuracy, products shall not be measured in a manner that creates the possibility of cumulative error.

Any special measuring or record-keeping methods specified in the contract documents shall be observed by the plant quality control personnel.

### **7.3 Product Tolerances**

During the pre- and postpour check of dimensions, the inspector shall have the approved shop drawings for reference. Discrepancies shall be noted on the postpour record and transmitted to management or engineering for their evaluation.

Fig. 7.3.1 shows the location of the tolerances listed below.

### **C7.2 Measurement**

Typically, the precision of the measuring technique used to verify a dimension should be capable of reliably measuring to a precision of one-third the magnitude of the specified tolerance. For this reason, the use of standard metallic measuring tapes graduated in feet, inches, and fractions of inches (meters and millimeters) is appropriate for measurement to a tolerance of no less than 1/8 in. (3 mm).

A dimensional layout and measurement plan is needed to control the production of precast concrete elements so that the measurement process does not result in unintended accumulation of tolerances. Measurements should always be made from a fixed reference point, rather than measuring the relative distance between elements, to minimize the potential for cumulative error. For example, the location of multiple embedments should always be measured from the appropriate control surface, rather than measuring some from a member edge and others from intermediate embedments.

The member diagrams in this section show the location of features to which tolerances apply. They are not intended to show the most appropriate reference feature for measurement. The appropriate dimensioning system to achieve the desired tolerances should be established by the precast engineer and shown on the production drawings.

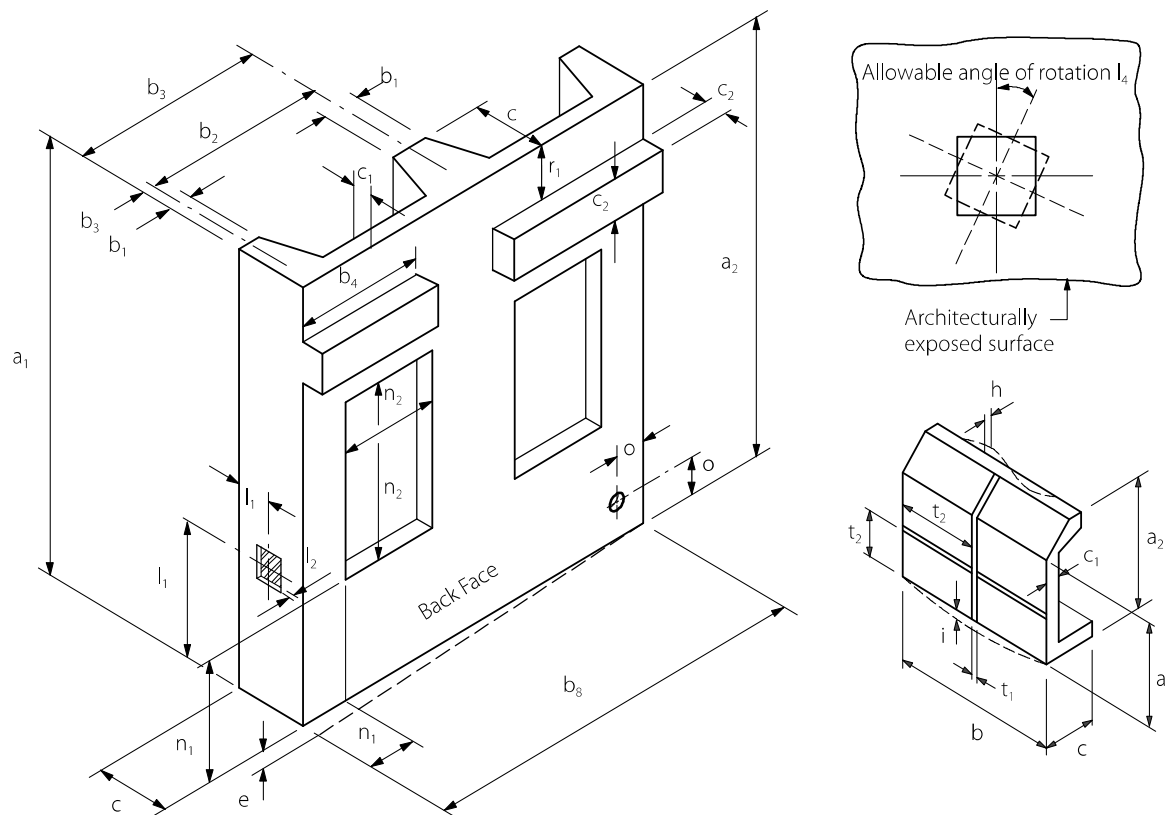
### **C7.3 Product Tolerances**

Product tolerances are necessary in any manufacturing process. They are normally determined by economical and practical production considerations, and functional and appearance requirements.

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**Fig. 7.3.1 Architectural Wall Panels**

Units\* shall be manufactured so that the face of each unit that is exposed to view after erection complies with the following dimensional requirements:

$a_1$  = Overall height of unit measured at the face exposed to view:

Up to 10 ft (3 m)..... $\pm 1/8$  in. ( $\pm 3$  mm)

10 ft to 20 ft (3 m to 6 m) ..... $+ 1/8$  in.,  $- 3/16$  in.  
( $+ 3$  mm,  $- 5$  mm)

$a_1$ . Length or width dimensions and straightness of a unit will affect the joint dimensions, opening dimensions between panels, and perhaps the overall length of the structure. Tolerance should relate to the unit size and increase as unit dimensions increase.

\*Units shall be manufactured so that the face of each unit that is exposed to view after erection complies with the following dimensional requirements. For non-architectural precast concrete units, such as columns, beams, etc., tolerance requirements are given in MNL-116, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products* and MNL-135, *Tolerances for Precast and Prestressed Concrete Construction*.

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20 ft to 40 ft (6 m to 12 m)  $\pm 1/4$  in. ( $\pm 6$  mm)

Greater than 40 ft (12 m)  $\pm 1/16$  in. per 10 ft  
( $\pm 1.5$  mm per 3 m)

$a_2^\dagger$  = Overall height of unit measured at the face  
not exposed to view:

Up to 10 ft (3 m)  $\pm 1/4$  in. ( $\pm 6$  mm)

10 ft to 20 ft (3 m to 6 m)  $+ 1/4$  in.,  $-3/8$  in.  
( $+ 6$  mm,  $- 10$  mm)

20 ft to 40 ft (6 m to 12 m)  $\pm 3/8$  in. ( $\pm 10$  mm)

Greater than 40 ft  $\pm 1/8$  in. per 10 ft  
( $\pm 3$  mm per 3 m)

$b$  = Overall width of unit measured at the face  
exposed to view:

Up to 10 ft (3 m)  $\pm 1/8$  in. ( $\pm 3$  mm)

10 ft to 20 ft (3 m to 6 m)  $+ 1/8$  in.,  $- 3/16$  in.  
( $+ 3$  mm,  $- 5$  mm)

20 ft to 40 ft (6 m to 12 m)  $\pm 1/4$  in. ( $\pm 6$  mm)

Greater than 40 ft (12 m)  $\pm 1/16$  in. per 10 ft  
( $\pm 1.5$  mm per 3 m)

$b_1$  = Rib width  $\pm 1/8$  in. ( $\pm 3$  mm)

$b_2$  = Distance between ribs  $\pm 1/8$  in. ( $\pm 3$  mm)

$b_3$  = Rib to edge of flange  $\pm 1/8$  in. ( $\pm 3$  mm)

$b_8$  = Overall width measured at the face not  
exposed to view:

Up to 10 ft (3 m)  $\pm 1/4$  in. ( $\pm 6$  mm)

10 ft to 20 ft (3 m to 6 m)  $+ 1/4$  in.,  $-3/8$  in.  
( $+ 6$  mm,  $- 10$  mm)

20 ft to 40 ft (6 m to 12 m)  $\pm 3/8$  in. ( $\pm 10$  mm)

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<sup>†</sup> Unless joint width and fit up requirements require more stringent tolerances.

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|                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Greater than 40 ft (12 m)..... $\pm 1/8$ in. per 10 ft<br>( $\pm 3$ mm per 3 m)                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| c = Total thickness..... $+ 1/4$ in., - $1/8$ in.<br>( $+ 6$ mm, - $3$ mm)                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| c <sub>1</sub> = Flange thickness ..... $+ 1/4$ in., - $1/8$ in.<br>( $+ 6$ mm, - $3$ mm)                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| c <sub>2</sub> = Dimensions of haunches .. $\pm 1/4$ in. ( $\pm 6$ mm)                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| e = Variation <sup>†</sup> from square or designated skew:<br><br>..... $\pm 1/8$ in. per 6 ft, or $\pm 1/2$ in. max<br>( $\pm 3$ mm per 2 m, or $\pm 13$ mm max) | e. Panels out-of-square can cause tapered joints and make adjustment of adjacent panels difficult.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| h = Local smoothness, unsealed surfaces<br>..... $1/4$ in. per 10 ft (6 mm in 3 m)                                                                                | h. Surface out-of-planeness is defined as a local smoothness variation rather than a bowing of the entire panel shape. Examples of local smoothness variations are shown in Fig. 7.3.2(a). The tolerance for this type of variation is usually expressed in fractions of 1 in. per 10 ft (25 mm per 3 m).<br><br>Fig. 7.3.2(a) also shows how to determine if a surface meets a tolerance of $1/4$ in. per 10 ft (6 mm per 3 m). A $1/4$ in. diameter (6 mm) by 2 in. long (50 mm) roller should fit anywhere between the 10 ft long (3 m) straightedge and the element surface being measured when the straightedge is supported at its ends on $3/8$ in. (10 mm) shims as shown. A $1/2$ in. diameter (12 mm) by 2 in. long (50 mm) roller should not fit between the surface and the straightedge. |
| i = Bowing ..... $\pm$ Length/360,<br>to a maximum of 1 in. (25 mm)                                                                                               | i. Bowing is an overall out-of-plane curvature, which differs from warping in that while the corners of the panel may fall in the same plane, the portion of the panel between two parallel edges is out of plane. Several possible bowing conditions are shown in Fig. 7.3.2(b). Differential temperature effects, differential moisture absorption between the inside and the outside faces of a panel, the effects of prestress eccentricity, and differential shrinkage between wythes in an insulated panel can all contribute to panel bowing and warping. The design of a panel and its relative stiffness or ability to resist                                                                                                                                                                |

<sup>†</sup>Applies both to panel and to major openings in panel.  
Tolerances apply to the difference of the two diagonal measurements.

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deflection as a plate member should be consistent with the specified tolerances. Panels that are relatively thin in cross section when compared with their overall plan dimensions are more likely to bow or warp as a result of member design, manufacturing, and environmental conditions.

Note that bowing and warping tolerances are of primary interest at the time the panel is erected. Careful attention to pre-erection storage of panels is necessary, since storage conditions can be an important factor in achieving and maintaining panel bowing and warping tolerances.

j = Warp (from adjacent corner)...1/16 in. per ft  
(1.5 mm per 300 mm)

j. Warping is generally the twisting of a member, resulting in an overall out-of-plane curvature in which the corners of the panel do not fall within the same plane. Warping tolerances are stated in terms of the magnitude of the corner variation, as shown in Fig. 7.3.2(c). It is usually stated in terms of the allowable variation per 1 ft (0.3 m) of distance from the nearest adjacent corner with a not-to-exceed maximum value of corner warping.

l<sub>1</sub> = Location of weld plates .....± 1 in. (± 25 mm)

l<sub>2</sub> = Tipping and flushness of plates ..... ± 1/4 in.  
(± 6 mm)

l<sub>4</sub> = Allowable rotation of plate, channel insert,  
electrical box .....2 degrees  
.....1/4 in. (6 mm) maximum  
measured at perimeter of insert

m<sub>2</sub> = Haunch bearing surface tipping and  
flushness of bearing plates...± 1/8 in. (± 3 mm)

m<sub>3</sub> = Difference in relative position of adjacent  
haunch bearing surfaces from specified  
relative position ...± 1/4 in. (± 6 mm)

n<sub>1</sub> = Location of opening within panel  
.....± 1/4 in. (± 6 mm)

n<sub>2</sub> = Length and width of blockouts and  
openings within one unit.....± 1/4 in. (± 6 mm)

n<sub>3</sub> = Location and dimensions of blockouts

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hidden from view and used for HVAC and utility penetrations..... $\pm 3/4$  in. ( $\pm 19$  mm)

$o$  = Position of sleeve..... $\pm 1/2$  in. ( $\pm 13$  mm)

$p$  = Position of inserts ..... $\pm 1/2$  in. ( $\pm 13$  mm)

$q$  = Position of handling devices  
..... $\pm 3$  in. ( $\pm 75$  mm)

$r_1$  = Location of bearing surface from end of member ..... $\pm 1/4$  in. ( $\pm 6$  mm)

$s_1$  = Reinforcing steel and welded wire reinforcement:

Where position has structural implications or affects concrete cover

..... $\pm 1/4$  in. ( $\pm 6$  mm)

Otherwise ..... $\pm 1/2$  in. ( $\pm 13$  mm)

$s_3$  = Reinforcing steel extending out of member  
..... $\pm 1/2$  in. ( $\pm 13$  mm) of plan dimensions

$s_4$  = Location of strand:

Perpendicular to panel ..... $\pm 1/4$  in. ( $\pm 6$  mm)

Parallel to the panel ..... $\pm 1$  in. ( $\pm 25$  mm)

$t_1$  = Dimensions of architectural features and rustications..... $\pm 1/8$  in. ( $\pm 3$  mm)

$t_2$  = Location of rustication joints  
..... $\pm 1/8$  in. ( $\pm 3$  mm)

$w_1$  = Location of flashing reglets ..... $\pm 1/4$  in.  
( $\pm 6$  mm)

$w_2$  = Location of flashing reglets at edge of panel..... $\pm 1/8$  in. ( $\pm 3$  mm)

$w_3$  = Size of reglets for glazing gaskets... $\pm 1/8$  in.  
( $\pm 3$  mm)

$z$  = Electrical outlets, hose bibs, etc. .... $\pm 1/2$  in.  
( $\pm 13$  mm)

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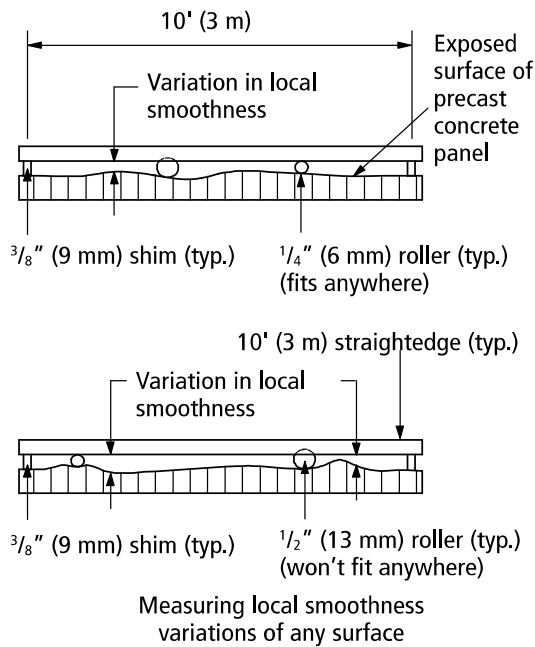
## Standard

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### Natural Stone Veneer-Faced

Tolerances below are for smooth-finish natural stone veneer-faced precast concrete panels:

1. Variation in cross-sectional dimension:  
For thickness of walls from dimensions indicated .....1/4 in. (6 mm)
2. Variation in joint width:....1/8 in. in 36 in.  
(3 mm in 900 mm) or a quarter of the nominal joint width, whichever is less.
3. Variation in plane between adjacent stone units (lipping): ....1/16 in.  
(1.5 mm) difference between planes of adjacent units.

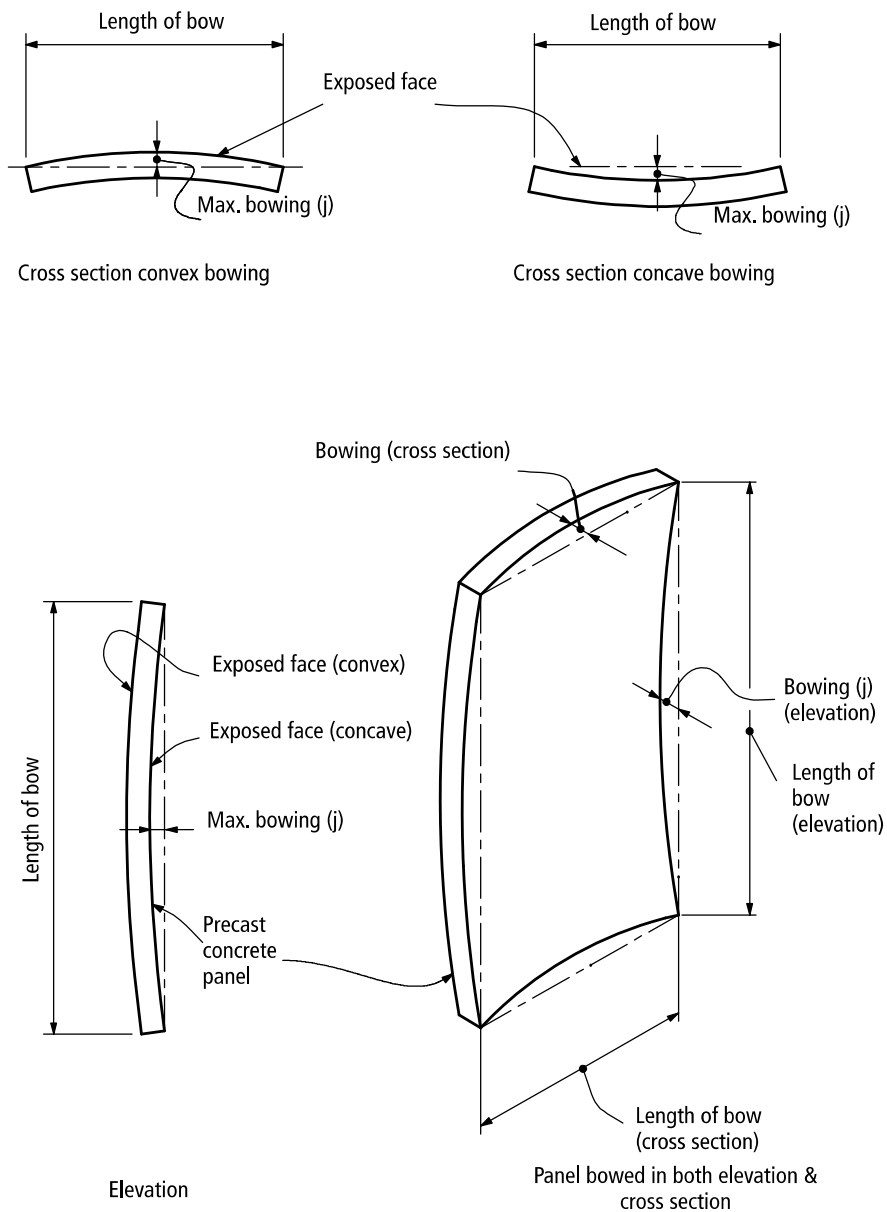


**Fig. 7.3.2(a) Local smoothness variations  
(Not to Scale)**

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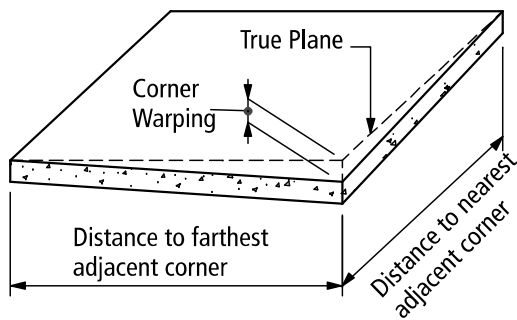


**Fig. 7.3.2(b) Definitions of bowing for panels**

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**Fig. 7.3.2(c) Warping definitions for panels**

### Brick Faced Architectural Elements

a = Alignment of mortar joints:

a<sub>1</sub> Jog in alignment..... 1/8 in. [ $\pm 3$  mm]

a<sub>2</sub> Alignment with panel centerline..... $\pm 1/8$  in.  
[ $\pm 3$  mm]

b = Variation in width of exposed mortar joints  
..... $\pm 1/8$  in. [ $\pm 3$  mm]

c = Tipping of individual bricks from the panel  
plane of exposed brick surface.....- 1/4 in.  
[- 6 mm]  
 $\leq$  depth of form/mold liner joint

d = Exposed brick surface parallel to primary  
control surface of panel .....+ 1/4 in., - 1/8 in.  
[- 6 mm, - 3 mm]

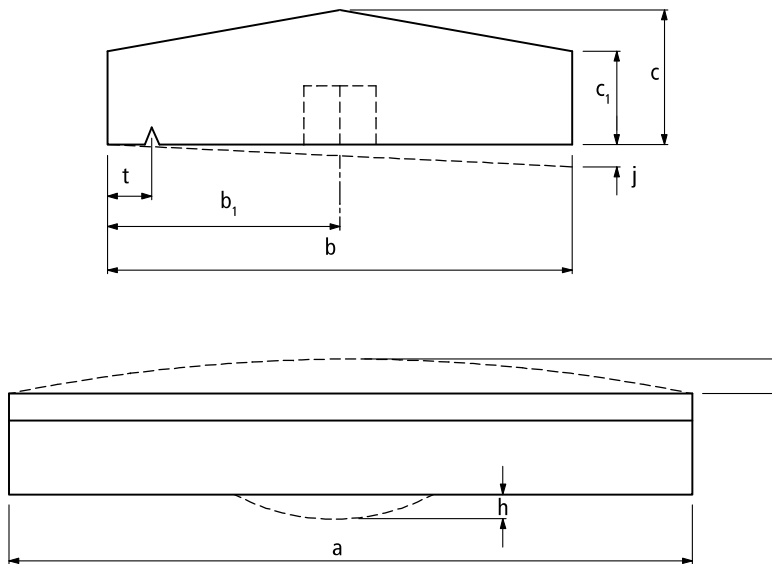
e = Individual brick step in face from the panel  
plane of exposed brick surface .....- 1/4 in.  
[- 6 mm]  
 $\leq$  depth of form/mold liner joint

Note: The number of bricks that could exhibit these misalignments should be limited to 2% of the bricks on the panel.

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**Fig. 7.3.4 Architectural trim units**

### Architectural Trim Units

$a$  = Length .....  $\pm 1/8$  in. [ $\pm 3$  mm]

Where one face will be installed in dead wall space of mortar joint .....  $\pm 1/4$  in. [ $\pm 6$  mm]

$b$  = Overall width of units<sup>§</sup> .....  $\pm 1/8$  in. [ $\pm 3$  mm]

$b_1$  = Location of inserts and appurtenances:

On formed surfaces .....  $\pm 1/8$  in. [ $\pm 3$  mm]

On unformed surfaces .....  $\pm 3/8$  in. [ $\pm 9$  mm]

$c$  = Overall height of units<sup>\*\*</sup> ...  $\pm 1/8$  in. [ $\pm 3$  mm]

<sup>§</sup> Units shall be manufactured so that the face of each unit that is exposed to view after erection complies with the following dimensional requirements. For non-architectural precast concrete units, such as columns, beams, etc., tolerance requirements are given in MNL-116, Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products and MNL-135, Tolerances for Precast and Prestressed Concrete Construction.

<sup>\*\*</sup> Measured at face exposed to view.

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$c_1$  = Total thickness .....  $\pm 1/8$  in. [ $\pm 3$  mm]

Flange thickness.....  $\pm 1/8$  in. [ $\pm 3$  mm]

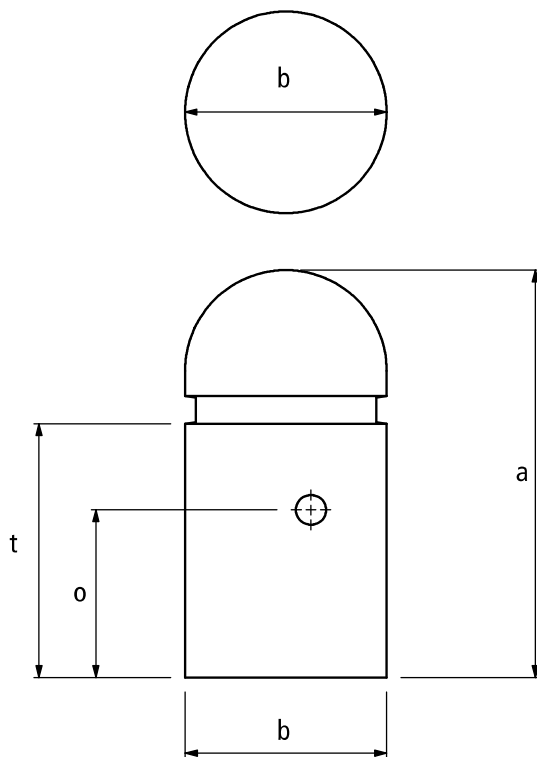
Where one face will be installed in dead wall  
space of mortar joint.....  $\pm 1/4$  in. [ $\pm 6$  mm]

$t$  = Size and location of rustications and  
architectural features .....  $\pm 1/8$  in. [ $\pm 3$  mm]

$h$  = Local smoothness.....  $\pm 1/8$  in. per 5 ft  
[ $\pm 3$  mm per 1.5 m]

$i$  = Bowing.....span/360,  
maximum,  $\pm 1/4$  in. [ $\pm 6$  mm]

$j$  = Warping<sup>††</sup> .....  $\pm 1/16$  in. per ft  
[ $\pm 1.5$  mm per 0.3 m]



**Fig. 7.3.5 Bollards**

<sup>††</sup> Measured per foot of distance from nearest adjacent corner.

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### Bollards, Benches, and Planters

a = Height or length..... $\pm 1/4$  in. [ $\pm 6$  mm]

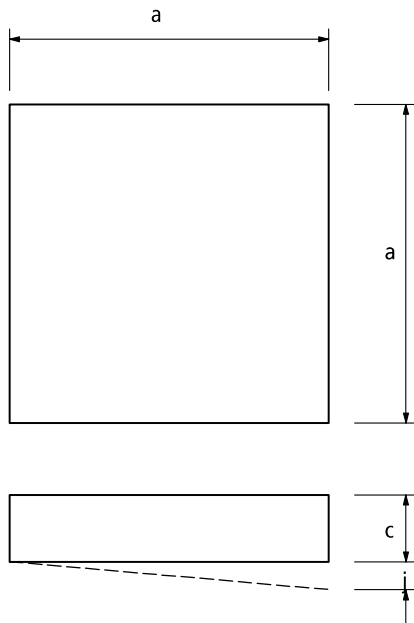
b = Width or diameter..... $\pm 1/4$  in. [ $\pm 6$  mm]

o = Location of inserts and appurtenances:

Formed surfaces..... $\pm 1/4$  in. [ $\pm 6$  mm]

Unformed surfaces..... $\pm 1/4$  in. [ $\pm 6$  mm]

t = Size / location of rustication / features  
..... $\pm 1/4$  in. [ $\pm 6$  mm]



**Fig. 7.3.6 Pavers**

### Pavers

a = Length or width..... $\pm 1/16$  in. [ $\pm 1.5$  mm]

c = Thickness..... $\pm 1/16$  in. [ $\pm 1.5$  mm]

j = Warping<sup>††</sup>..... $\pm 1/32$  in. [ $\pm 0.75$  mm]

<sup>††</sup> Measured per 1 ft [0.3 m] of distance from nearest adjacent corner.

# **APPENDIX A**

## ***Guidelines for Developing Plant Quality System Manual***

### **INTRODUCTION**

Documented quality system procedures should be the basis for the overall planning and administration of activities which impact on quality. These documented procedures should cover all the elements of the company's quality system standard. They should describe (to the degree of detail required for adequate control of the activities concerned) the responsibilities, authorities, and interrelationships of the personnel, who manage, perform, verify, or review work affecting quality. The procedures should also address how the different activities are to be performed, the documentation to be used, and the controls to be applied. All of this is particularly important for personnel who need the organizational freedom and authority to (a) initiate action to prevent non-conformances of any kind; (b) identify and document any problems relating to product, process and/or quality systems; (c) initiate, recommend or provide solutions through designated channels; (d) verify the implementation of solutions; and (e) control further processing, delivery or installation of non-conforming production until the problem(s) have been corrected.

Documented quality system procedures should not, as a rule, enter into purely technical details of the type normally documented in detailed work instructions.

The quality manual should identify the management functions, address or reference the documented quality system and procedures, and briefly cover all the applicable requirements of the quality system standard selected by the organization. Wherever appropriate, and to avoid unnecessary duplication, reference to existing recognized standards or documents available to the quality manual user should be incorporated.

Release of the quality manual should be approved by the management responsible for its implementation. Each copy should bear evidence of this release authorization.

Although there is no required structure or format for a quality manual, it should convey accurately, completely, and concisely the quality policy, objectives, and governing documented procedures of the organization.

One of the methods of assuring that the subject matter is adequately addressed and located is to key the sections of the quality manual to the quality elements of this manual (MNL-117). Other approaches, such as structuring the manual to reflect the nature of the organization, are equally acceptable.

### **MANUAL CONTENTS**

A quality manual should normally contain the following:

#### **Table of Contents**

The table of contents of a quality manual should show the titles of the sections within it and how they can be found. The numbering or coding system of sections, subsections, pages, figures, exhibits, diagrams, tables, etc., should be clear and logical and should include revision status.

## **APPENDIX A                      Guidelines for Developing Plant Quality System Manual**

### **Definitions**

Definitions of terms or concepts that are uniquely used within the plant should be included, although it is recommended, when practical, to use standard definitions and terms shown in MNL-117.

### **I. MANAGEMENT RESPONSIBILITY**

#### **A. Quality Policy Statement**

1. In the most general sense, a quality policy should be a short, clear statement of commitment to a standard of quality. This should include a warranty from the highest level of management that quality will not be compromised when it conflicts with other immediate interests. The quality policy also should define objectives pertaining to quality. The objectives focus and direct the quality system toward concrete goals, giving the plant's personnel the motivation to develop and maintain the system. To the customer, the objectives are an expression of an implied promise that satisfying their needs will be the point of reference in their relationship with the plant.
2. This section should also describe how the quality policy is made known to, and understood by, all employees and how it is implemented and maintained at all levels. Management should ensure that individuals are familiar with those contents of the manual appropriate for their position within the organization.

Include a brief description of the documented procedures used to identify the status and to control the distribution of the quality manual, whether or not it contains confidential information, whether it is used only for the plant's internal purposes, or whether it can be made available externally.

#### **B. Organization**

1. Responsibility and Authority
  - a. This section of the manual should provide a graphical organization chart showing key personnel, their duties and responsibilities, authorities and the interrelationship structure. This is the most effective and straightforward way to define and document an organization's structure. Include a general organization chart for the whole company, supplementing it with more detailed charts that present internal organizations of departments directly concerned with the QA and QC activities. It is neither practical nor required to include in the charts the names of assigned personnel. Documents evidencing individual assignments to organizational functions shall be maintained elsewhere - for example, in the personnel department.
  - b. Although the charts document general functional responsibilities, there is also a need to assign personnel the authority and responsibility to carry out specific actions referenced in the quality system. Details of the responsibilities, authorities, and hierarchy of all functions that manage, perform, and verify work affecting quality should be provided. Assignment and documentation of those specific responsibilities is best made directly within procedures dealing with the corresponding actions. For example, personnel responsible for identifying and recording product quality problems can be defined in the inspection and testing procedures sections.

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### **2. Verification Resources and Personnel**

- a. Procedures and quality plans should completely define the review, monitoring, inspection and testing needs at specific points in purchasing, receiving, manufacturing and shipping. The extent and scope of the verifications must be established by the plant.

The verification activities should be supported with qualified personnel and adequate resources. The plant should identify the level of training and experience needed to perform specific verification functions and indicate that the assigned personnel meet those requirements. All training, no matter how informal, should be documented and recorded.

- b. Self-inspection may be adopted provided that it is qualified, documented and regularly audited. Audits should be carried out by personnel independent from those having direct responsibility for the work. Inspection and testing are excluded from this requirement of independence.

### **C. Management Review**

In addition to an analysis of PCI Plant Certification audit results, rules for scheduling, conducting and recording management reviews of the quality system should be established.

## **II. QUALITY SYSTEM**

The manual should describe and document the applicable elements of the plant quality management system. The description should be divided into logical sections revealing a well-coordinated quality system. The quality manual should include policies, operating procedures, work instructions, process procedures, company standards, PCI standards, and the production and quality plans. This may be done by inclusion of, or reference to, documented quality system procedures. Auditing and review of the implementation of the quality system should be discussed.

The purpose is to:

1. Define purpose, contents and format of the quality system documentation.
2. Assign responsibility for establishing and maintaining the quality system documentation.

## **III. DOCUMENT CONTROL**

The purpose, scope and responsibility for controlling each type of quality system document should be defined. This section should provide a system and instructions and assign responsibilities for establishment, review, authorization, issue, distribution and revisions of the quality system documents.

Provide a brief description of how the quality manual is revised and maintained, who reviews its contents and how often, who is authorized to change the quality manual, and who is authorized to approve it. A method for determining the history of any change in procedure may be included, if appropriate.

To ensure that each manual is kept up to date, a method is needed to assure that all changes are received by each manual holder and incorporated into each manual. A table of contents, a separate revision-status page, or other suitable means should be used to assure the users that they have a copy of the authorized manual.

### **IV. PURCHASING**

There should be a clear and full description of ordered products and the vendor monitoring procedures to verify that quality requirements of the plant are met. Procedures for disposition of non-conforming materials should be described.

Rules applicable to preparation, review and approval of purchasing documents and the use of approved vendors should be provided.

### **V. PRODUCT IDENTIFICATION AND TRACEABILITY**

Describe the system to readily identify each unit produced and to distinguish between different grades of otherwise similar materials, components, subassemblies and products and maintenance procedures for records.

### **VI. PROCESS CONTROL**

Process refers to all activities connected with production planning, environment, equipment, technology, process control, work instructions, product characteristics control, criteria for workmanship, and so forth.

The production plan should define, document and communicate all manufacturing processes and inspection points as well as workmanship standards. A production flow chart should be included. Work instructions should indicate how to operate and adjust equipment, describe steps required to perform certain operations and inspections, warn against safety hazards, etc. Maintenance and calibration of equipment and testing apparatus schedules should be established and recorded.

Establish a system and instructions that assigns the responsibilities for:

1. Establishing and use of work order, work instructions and change orders.
2. Checking and monitoring Production equipment.
3. Qualification and control of special processes such as welding.
4. Establish criteria and responsibility for maintenance of the production environment or such conditions that adversely affect performance.

### **VII. INSPECTION AND TESTING**

#### **A. Receiving Inspection and Testing**

The purpose of this section is to provide for a system and instructions that assigns responsibility for performing and recording the receiving inspections of purchased products. The scope and form of receiving inspections should be established.

As a minimum, the scope of receiving QC inspections comprises:

1. Review of material certification, source inspection and test records, compliance certificates and other such documentation delivered with the product.

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2. Visual inspection to detect any damage or other visible quality problems.
3. Taking measurements and testing, as required.
4. Recording actual measurements and test results.

### **B. In-Process Inspection and Testing**

Degree, scope and manner of in-process inspections should be established to ensure products are produced in accordance with production drawings and approved samples. Inspection of special processes such as welding must be monitored and controlled. Include sample copies of checklists or forms used by plant personnel for quality control functions.

Specific items to be covered are:

1. Planning and documentation of inspection in the company's quality plans or procedures.
2. Handling of changes to shop drawings during production.
3. Identification of inspection status of product.
4. Handling of non-conforming product.
5. Identify those product characteristics that can be inspected only at specific stages of production.

### **C. Final Inspection**

The quality plan and procedures should define the extent and scope of the final inspections and tests to verify that all receiving and in-process inspections specified for the product have been carried out with satisfactory results. The means of identifying non-conforming products should be described.

### **D. Inspection and Test Records**

Describe the recording of each inspection, sign-off procedure and the maintenance of the records.

## **VIII. INSPECTION, MEASURING AND TEST EQUIPMENT**

The purpose of this section is to provide for a system and instructions, and to assign responsibilities for calibration at prescribed intervals, identification including type, model, range and accuracy, and maintenance of measuring and test equipment. Calibration procedures and records should be established and maintained.

Identification of measurements to be made with the allowable tolerances should be documented in the quality plan, product drawings and specifications for use by production and inspection personnel.

The system of checking and certifying jigs, templates and patterns or molds used in manufacturing or inspection should be established.

## **IX. INSPECTION AND TEST STATUS**

The purpose of this section is to provide for a system and instructions, and to assign responsibilities for:

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1. Identification of a product's inspection status.
2. Release of conforming product for storage or shipment.

The most common methods for inspection status identification are marking, tagging or labeling the product itself, entering an inspection record in a traveler accompanying the product, and physical segregation of products according to their inspection status. Whatever system is adopted, it must be clearly documented in appropriate procedures.

### **X. CONTROL OF NON-CONFORMING PRODUCT**

The purpose of this section is to provide for a system and instructions, and to assign responsibilities for:

1. Identifying, documenting and evaluating non-conforming incoming materials, materials in production, products that preclude repair and products that are repairable.
2. Disposition of a non-conforming product.

Procedures in this section must demonstrate clearly that the non-conforming product is being prevented from shipping and that the non-conformity is recorded. Reinspection procedures for repaired or reworked products should be described.

A non-conformity may be an isolated minor defect that can be repaired immediately by a simple process or, at the other extreme, a serious public safety hazard potentially involving a large number of already shipped products. In dealing with this problem, it is useful to divide the possible non-conformities into categories such as minor or major or cosmetic or structural defects and assign to them different levels of authority for disposition. The classes should distinguish between small and large number of products affected, isolated errors and system problems, possibility of impact on already shipped products and seriousness of the non-conformity. Such classification will also be very helpful in planning and implementing corrective actions. The responsibility and procedure for the preparation of concrete repair mixtures should be defined.

### **XI. CORRECTIVE ACTION**

All activities relating to corrective actions should be covered by written procedures. The corrective action system should comprise an investigation of causes, implementation of corrective actions and verification of their effectiveness.

### **XII. HANDLING, STORAGE, AND LOADING/DELIVERY**

#### **A. General**

The purpose of this section is to define specific rules for handling different units, prescribe a management system for stored units, and specify arrangements for protection of products during transportation

#### **B. Handling**

Describe procedures to regulate the use of and instruct in operating handling equipment as well as handling equipment maintenance.

### **C. Storage**

The purpose of this section is to provide for a system with instructions and responsibility assignments for:

1. Ensuring products are stored in accordance with drawings.
2. Use and maintenance of storage areas for both materials and finished product.
3. Periodic assessment of stored materials and product to check for damage, stains, contaminants, stability of dunnage, and plumbness of stacks.

### **D. Loading/Delivery**

Describe the procedure for providing a system with instructions and responsibility assignments for loading and protecting products during delivery whether or not delivery is required by contract.

## **XIII. QUALITY RECORDS**

Compliance with the following requirements should be documented in written procedures:

1. Identifiable and legible records.
2. Easily retrievable records from files in a suitable environment.
3. Retention of records for a specified period of time.

Format, identification, applicable processing and filing location for a record should be stipulated in the procedure that requires creation of the record. There should be an index listing types of records and their locations.

## **XIV. INTERNAL QUALITY AUDITS**

The purpose of this section is to provide for a system with instructions and responsibility assignments for conducting and documenting internal quality audits. Internal quality audits should be used to verify compliance with the quality manual and to measure the effectiveness of activities in achieving defined quality objectives. The audit plan should list all the activities in the various sections of the company's quality manual, identify the location where the activities are taking place, and schedule the audit for each activity and location. Activities that receive more frequent auditing by plant personnel should be described. A corrective action and follow-up procedure for any deficiencies found during an audit should be established and documented to verify the implementation and effectiveness of the corrective action. In addition, discuss the external audit procedures of the PCI Plant Certification program and the corrective action and follow-up procedures.

## **XV. TRAINING**

The purpose of this section is to provide for a system and instructions and responsibility assignments for determining training needs, providing the training and keeping training records.

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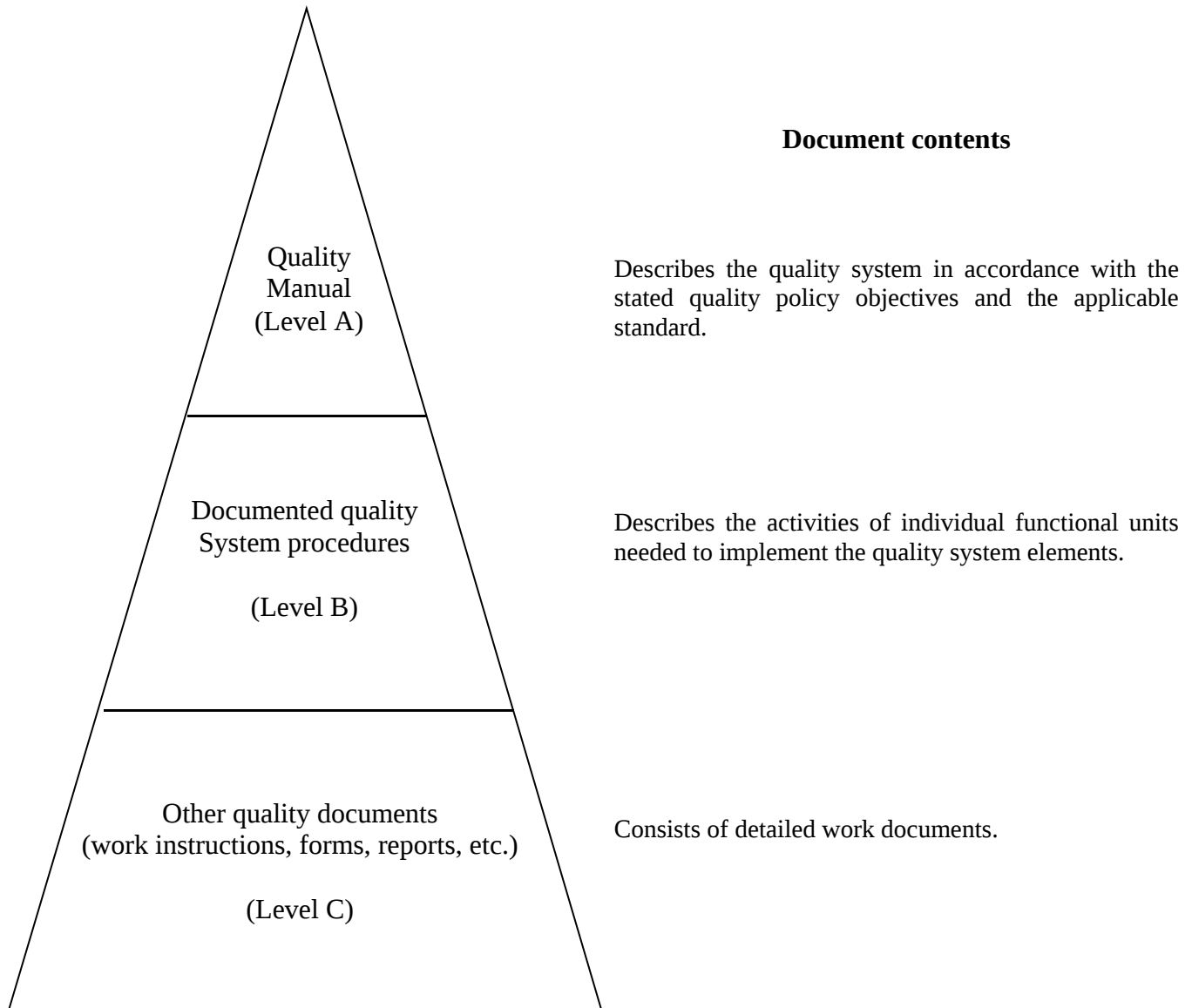
As a minimum, the training should comprise:

1. Product orientation with emphasis on crucial quality characteristics.
2. Presentation of the company's quality system.
3. The role of employees in maintaining the quality system and improving its efficiency.

Recording procedures for employee participation in training and maintenance of the records should be discussed.

| EXAMPLE OF POSSIBLE FORMATTING FOR A SECTION OF A QUALITY MANUAL                                                                                                                                                                                                                                                               |             |               |          |        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------|----------|--------|
| Organization                                                                                                                                                                                                                                                                                                                   |             | Title-Subject |          | Number |
| Unit issuing                                                                                                                                                                                                                                                                                                                   | Approved by | Date          | Revision | Page   |
| <b>Policy or Policy Reference</b><br>Giving governing requirement.                                                                                                                                                                                                                                                             |             |               |          |        |
| <b>Purpose and Scope</b><br>List why, what for, area covered, and exclusions.                                                                                                                                                                                                                                                  |             |               |          |        |
| <b>Responsibility</b><br>Give organizational unit responsible for implementing the document and achieving the purpose.                                                                                                                                                                                                         |             |               |          |        |
| <b>Actions and Methods to Achieve System Element Requirement</b><br>List, step by step, what needs to be done. Use references, if appropriate. Keep in logical sequence. Mention any exceptions or specific areas of attention. Consider the use of flowcharts.                                                                |             |               |          |        |
| <b>Documentation and References</b><br>Identify which referenced documents or forms are associated with using the document, or what data have to be recorded. Use examples, if appropriate.                                                                                                                                    |             |               |          |        |
| <b>Records</b><br>Identify which records are generated as a result of using the document, where these are retained, and for how long.                                                                                                                                                                                          |             |               |          |        |
| <b>Notes:</b><br><ol style="list-style-type: none"> <li>1. This format may also be used for a documented quality system procedure.</li> <li>2. The structure and order of the items listed above should be determined by organizational needs.</li> <li>3. The approval and revision status should be identifiable.</li> </ol> |             |               |          |        |

**Typical Quality System Document Hierarchy**



NOTE: Any document level in this hierarchy may be separate, used with references, or combined.

# **APPENDIX B**

## ***Design Responsibilities and Considerations***

### **General**

Design and construction of a structure is a complex process. Clearly defining the scope of work and the responsibilities of the involved parties by means of the contract documents is critical to achieving the desired result. This section provides a guide for all parties involved in a precast concrete project and defines the responsibilities of each party. These responsibilities and relationships between the parties are defined in the contract documents for a particular project.

A successful precast concrete project requires teamwork, close cooperation and coordination between all of the participants, including the owner, architect, structural engineer of record (SER), precast concrete manufacturer, erector, general contractor (GC)/construction manager (CM), and all other affected trades. The scope of the precast concrete work and the responsibilities of each party (typically defined by the contract documents) should be established at an early stage in the development of a project to achieve the desired quality and keep the project on schedule (see Table B.1). During construction, each party is responsible for communicating with all other parties through the GC/CM or architect. This helps to prevent misunderstandings and confusion. When authority and responsibility roles are clearly defined by the contract documents, problems and conflicts are avoided. Local practices regarding the assignment and acceptance of responsibility in design and construction can vary.

One of the basic principles of the construction industry is that responsibility and authority should go hand in hand. Another principle is that every party should be responsible for its own work. These principles are frequently not followed in practice. There have been cases where owners have sued architects or engineers for approving non-conforming work without giving them authority to monitor the work as it progressed. Safety enforcement agencies (OSHA) and plaintiffs' lawyers have charged engineers or architects with the responsibility for construction accidents contrary to language and responsibilities listed in the contract documents. These last two situations typically are cases of responsibility without authority, although there could be instances where a design team's work or direction can affect jobsite safety. If the design team is involved with construction-management functions, they could be making decisions affecting worker safety as well as quality of construction. When agents of the owner give instructions directly to the construction workforce regarding how work is to be performed, they step over the line into the contractor's area of responsibility.

The increased complexity of structures today makes it essential to have design input from the subcontractors. This input, whether submitted as value engineering proposals, in response to performance requirements, or simply offered as design alternatives, plays a legitimate role in construction. For example, a precast concrete subcontractor may propose alternatives that improve the efficiency of the fabrication or erection operation. In approving the alternatives, the design team retains responsibility for properly interfacing with other materials in contact with or adjacent to the precast concrete elements.

The SER always has to take overall responsibility for the structural design of the completed structure. However, certain aspects of the design are often delegated to specialty structural engineers (SSEs) working for the material suppliers or subcontractors. When any of this delegated structural design work for a portion of the structure involves engineering (as opposed to simply detailing), the design work should be reviewed and approved by the SER registered in the same state as the project or as required by the local jurisdiction. The SER then accepts responsibility for the overall structural design. Additionally, local regulatory authorities should be consulted for their specific requirements. Contract documents typically require the structural design be the responsibility of a professional engineer, regardless of conflicts with other governmental requirements.

**Responsibilities of the Architect**

The architect develops the project design concept, establishes overall structure geometry, selects the cladding material for appearance and function, provides details and tolerances for proper material interfacing and weatherproofing, and specifies performance characteristics, as well as inspection parameters and testing requirements in the contract documents.

The architect and SER have responsibility to coordinate the design aspects of the precast concrete panels such as aesthetics, dimensions and loads to structure. The architect or SER may specify in the contract documents that design services for portions of the work are to be provided by the precaster. Typically design services are performed for the precaster by a licensed engineer who can be an employee of the precaster or an SSE. The contract documents should clearly define the scope of the precast concrete design requirements and document review responsibilities, as well as the responsibilities of other parties providing design services.

The contract drawings prepared by the design team should provide the overall geometry and dimensions of the structure, member or panel dimensions and cross-sections, typical connection locations and details, and concepts so all precasters are estimating based on the same information. The architect's drawings may only show reveals or design articulation, allowing the precaster to determine panel sizes suitable to their handling and erection capabilities. In addition, the contract documents (specifications and design drawings) also should provide the general performance criteria, design loads, including concrete strength requirements, deflection requirements, temperature considerations, and any tolerance or clearance requirements for proper interfacing with other elements of the structure.

The order in which the project contract, specifications, or drawings prevail in the event of conflicts should be clearly defined. All aesthetic, functional, and structural requirements should be detailed.

The design team should provide complete, clear, and concise drawings and specifications. Contract documents should clearly define: (1) precast concrete components that are to be designed by the precaster (state who takes responsibility for design of elements at interfaces with other parts of the structure, such as the secondary steel bracing of the structure, to prevent rotation of beams or columns); (2) details or concepts of supports, connections, and clearances that are part of the structure designed by the design team and that will interface with the precast concrete components; and (3) permissible design load transfer points and indicate generic connection types to avoid having the precaster make assumptions on connection types and piece counts during bidding and design. It is preferable to leave specific panel and connection design to precasters so they can design details and connections suitable for their production and erection techniques.

The architect and SER should review designs, calculations, and shop drawings submitted by the precaster for conformance with design criteria, loading requirements, connection points, and design concepts as specified in the contract documents. This review, however, does not relieve the precaster and the precast concrete engineer of their design responsibilities.

**Key design issues for the design team.** The contract drawings prepared by the design team should provide a clear representation of the configurations and dimensions of individual precast concrete units and their relationship to the structure and to other materials. Contract documents that are unclear and lack detail may extend shop drawing preparation time, lead to confusion over work scope, and impact the project schedule.

The contract documents should supply the following information:

- Elevations, sections, and dimensions necessary to define the sizes and shapes (profiles) of each different type of precast concrete element;
- Locations of joints, real (functional) or false (aesthetic);
- Required materials, color and finish treatment for all surfaces with a clear indication of which surfaces are to be exposed to view when installed;
- Corner details;
- Details for jointing and interfacing with other materials (coordinated with the general contractor), including windows, roofing, and other wall systems;
- Openings for services and equipment, with their approximate size and location;
- Details for special or unusual conditions including fire endurance requirements;
- Governing building codes, design loads, and deflection limitations;
- Specified dimensional tolerances for the precast concrete and the supporting structure, location tolerances for the contractors' hardware, clearance requirements, and erection tolerances for the precast concrete. Exceptions to PCI MNL-117 or MNL-135 tolerances are not recommended;
- Support locations for gravity and lateral loads;
- Building location and site access; and
- Delineation of lateral bracing for structural beams or any unusual erection sequence requirements.

The precaster uses the information from the contract drawings and documents to generate shop and erection drawings and design calculations. These drawings should detail elevations showing panel sizes, surface features, and panel relationships; detail sheets should show panel cross sections, special edge conditions, and feature details; and should specify connection details showing mechanisms and locations of load transfers to the supporting structure. Allowing the precaster to suggest configurations of the precast concrete units and the opportunity to select which joints are false and which are real (panelization) will achieve greater economy and flexibility in production and erection.

The design team should review shop drawings in a timely manner to ensure their general conformance with the contract documents, to avoid delay in the project schedule, and to respond to aesthetic questions raised by the construction team. Architectural and structural review and clarification of dimensions and detailing should be anticipated. Following this review, the precaster will make the appropriate revisions to the shop drawings. Open discussion between the architect and precaster should be allowed and encouraged in order to achieve the best possible design for the project.

Producing small mockups is encouraged to help verify the appearance of the completed façade and clarify actual field-construction techniques and material interface issues. If the units have returns, the same size return should appear in the mockup panels. The architect establishes the standards of acceptability for surface finish, color range, and remedial procedures for production and construction defects and damage. This can be best accomplished by the precaster producing at least three sample panels, 15 to 20 ft<sup>2</sup> (1.4 to 1.9 m<sup>2</sup>) each, before the initial production to establish the range of acceptability with respect to color and texture variations, surface blemishes, and overall appearance. In addition the architect should visit the plant during the first week of production to evaluate conformance with approved samples.

Panel-to-panel joint design and the proper sealing at windows and other penetrations in the exterior wall is necessary to prevent air and water infiltration. The architect is responsible for providing these designs and details. Precast concrete is inherently watertight and impermeable and therefore it is important to have watertight joints at the window-to-precast concrete interface to prevent water leaks. The architect should examine and modify these details, as required. The contract documents should require that the same sealant contractor seal all joints in order to avoid sealant incompatibility thereby providing single source responsibility.

For large projects or for special conditions where moisture protection is a concern, specifications can call for the production, shipping, and erection of a full-scale mockup at a testing lab. This mockup would include various precast concrete and window elements assembled and caulked. While, a wind-driven rain test, can be costly and time consuming, it can verify moisture protection details and satisfy any moisture penetration concerns or requirements. The cost of these tests must be included in the project budget. These mockups and tests can be expensive and should be specified only where there is a demonstrated need. When such tests are needed, sufficient time must be provided in the project schedule to evaluate the test results and incorporate any consequent modifications into the final design.

After the product is erected and detailed, the architect should promptly prepare a punch list setting forth, in accurate detail, any items of the work that are not found to be in accordance with the contract documents so that proper corrective action may be taken. A meeting between the contractor, precaster, erector, and design team should then be held promptly to discuss any questions concerning what the design team requires to be done before the work can be accepted as complete. All repairs should conform to the contract documents and the architect's requirements (for matching the color and finish of the approved sample) and should be structurally sound. If the repairs cannot be completed to a satisfactory level the repairs may be rejected. The industry standard for evaluating the visual acceptability of repairs is at a 20 ft (6 m) viewing distance with the unaided eye.

When advised by the precaster that the punch list items have been completed, the GC/CM and design team should check the corrections. After the precast concrete units have been accepted, subsequent responsibility and liability for their condition rest with the GC/CM.

### **Responsibilities of the Structural Engineer of Record (SER)**

The SER has responsibility for specifying the design criteria for the design of the precast concrete elements and for describing the intended load paths. The SER should anticipate the loadings in the structural design and provide a structural system adequate to support these loads. The SER should define the type of loading to be applied to the panels and the structure, as well as provide information, applicable codes (design criteria), including wind, seismic or blast design, when applicable. The SER should consider the consequences of the eccentricities of the weight of the precast concrete panels when designing the supporting structure. Any special erection procedures or sequences should be clearly defined, prior to bidding, in the contract documents. For example, can one elevation be erected at a time (less crane movement), or must the erection be one level at a time to prevent undue stresses on the structure? Observations in the field have shown that where precast concrete panels are erected to a greater height on one side of a multistory building than on the other, the steel framing can be pulled out of alignment. Precast concrete panels can be erected at a relatively uniform rate around the perimeter of the structure or the designer of the structural frame should determine the degree of imbalanced loading permitted. Other limitations may involve the rigidity of the structure, requiring that walls not be erected prior to completion of floors designed to carry the lateral loads. The SER has the responsibility of reviewing the precast concrete design work for compatibility with the overall structural design and structural stability. This does not, however, relieve the SER from the overall design responsibility for the safety and proper performance of the completed structure.

The SER should determine and show on the contract documents the locations for supporting the gravity and lateral loads of the precast concrete units, including intermediate lateral (tieback) connections, if necessary. The SER's review of the erection drawings confirms that the structure is adequate, within defined deflection limitations, to resist the anticipated loads and forces from the precast concrete, and verifies that the magnitude and location of the loading points on the structure agree with the original design intent. It is important that preliminary meeting(s) between the architect, SER, and precaster be held before structural members are ordered and fabricated so panel sizes, shapes, and basic connections and their locations can be established. For steel frame structures, the SER should determine how far in advance the final connections of the frame must be completed prior to precast concrete panel erection.

The gravity supports of precast concrete panels are generally eccentric to the centerline of the supporting steel or concrete members. The SER should design the structural members to prevent excessive deflection and rotation of the supporting structure during and after erection of the precast concrete, as well as determining the need for diagonal bracing or stiffening of supporting structural members. Supplemental framing necessary to support the precast concrete should be noted on the structural drawings. Responsibility for designing, supplying, and installing the bracing for the structure and the secondary steel should be clearly addressed in the contract documents and discussed in a prebid meeting. Typically, the steel subcontractor supplies all supplemental support, such as diagonal bracing and stiffeners based on the SER's design, and coordinates locations with the precast concrete erection drawings.

### **Responsibilities of the General Contractor/Construction Manager**

The responsibilities of the CM, who is engaged by the owner to manage and administer the construction, may be different from those of the GC, depending on the CM's agreement with the owner and local practice. The responsibilities of the CM, while generally similar to those of the GC, should be clearly defined in the contract documents.

The GC/CM should have the responsibility and authority of implementing the design intent of the contract documents, which includes furnishing materials, equipment, and labor; maintaining specified quality and schedule requirements; and coordinating of all trades. The GC is responsible for construction means, methods, techniques, sequences, and procedures. Also, the GC should initiate, maintain, and supervise all safety procedures and programs on the construction site. Site access to the structure for erection of the precast concrete elements is an important issue. The GC is responsible for providing and maintaining clear, level, well-drained unloading areas and stabilized road access around and into the structure so the hauling and erection equipment are able to operate under their own power.

The GC/CM generally has no direct design responsibility but does, however, have considerable impact on the design process through their coordination role. The GC/CM is responsible for coordinating the information necessary to allow the preparation of the precast concrete erection drawings as well as reviewing and securing approval for the shop drawings, samples, mockups, and range samples. The GC/CM receives the shop drawing submittals from the various trades and together they form the completed project design. The GC/CM is responsible for the timely transmission and resolution of requests for information (RFI). The GC/CM is normally responsible for project schedule, grid dimensions at each floor level (which includes control points, benchmarks, lines on the building, and work points for angled or curved building elevations), so all trades are working from uniform data and common reference points. Dimensional interfacing of the precast concrete with other materials and construction trades, and the maintenance of the structure's specified tolerances to ensure proper fit, is also a responsibility of the GC/CM. The GC should notify the precaster and erector when as-built conditions (dimensions) of the structural framing vary beyond the tolerances stated on the contract drawings. Dimensional tolerances between interfacing materials, such as precast concrete units and glazing, should also be considered.

The GC/CM should encourage direct communication between the precaster, SER, and the architect. All communications should be confirmed in writing and distributed to all parties in order to avoid misunderstandings.

Typically, the GC is responsible for placing embedded items in cast-in-place concrete and coordinating steel attachments with the steel fabricator according to a layout or anchor plan supplied by the precaster. In most instances, the most economical approach is to have required connection hardware attached to steel columns or beams by the steel fabricator. This necessitates awarding the precast concrete contract simultaneously with the steel contract so that early coordination between these trades can occur. Changes to panel bearing surface and anchorage locations other than adjustments within prescribed tolerances require approval by the design team. The

precaster should perform a survey or the GC/CM should provide the precaster with as-built surveys of embedded items, anchor bolts, and other attached hardware so that misaligned or missing hardware can be identified and remedial actions undertaken by GC/CM prior to erection of precast concrete units.

For concrete frames, the GC/CM should provide the erector with authorization to begin erection after the concrete has reached design strength and any interfering formwork or shoring has been removed. For steel frame structures, the GC/CM should provide the erector with the authorization to begin erection after the steel frame has been adequately detailed and stabilized, which is typically after concrete floors have been placed.

After erection of the precast concrete panels, the GC/CM should notify the architect for the inspection of the precast concrete work. Representatives of the precaster and the erector participate in this inspection tour and answer any questions posed by the architect. The GC/CM should request a final punch list from the architect so that remedial items can be finished in a timely manner to avoid delaying subsequent trades. After the precast concrete units have been installed on the structure in conformance with plans and specifications and the installation is accepted by the architect, subsequent responsibility and liability for the protection of the precast concrete during the construction phase of the project should rest with the GC. Provisions for any construction loads that are in excess of stated design requirements and may occur after precast concrete unit installation are the responsibility of the GC, not the precaster or erector.

### **Bid Process**

Where the selection of a precaster is not negotiated or controlled by the owner or architect, but is instead governed by an open-bid situation, the following bid process is recommended.

**STEP 1 — Verification of architect's concepts and systems.** A review of the proposed precast concrete concepts during the early design development stage of the architectural contract documents should be arranged with at least one local precaster. This review confirms or modifies the architectural concept so that a realistic design is presented on the bid drawings.

Items to be discussed or reviewed:

- Panelization, form families, piece sizes and weights, and reveals;
- Shipping and erection issues;
- Architect's concept for structural support or connections for the precast concrete units so that the architect can communicate support requirements to the SER;
- Desired aesthetic issues relative to mixture(s) and finish(es) and the sample process;
- The architect's intent for any interfaces with adjacent systems, such as windows, roofing, or building entrances; and
- Requirements for mockups or other special testing requirements.

**STEP 2 — The prebid conference.** This is a recommended meeting for all precasters intending to bid the project, usually held at least three weeks before the bid date. The design team presents the precast concrete concepts for the project so that competitive and responsive bids will be obtained. This will improve communications and resolve outstanding questions prior to preparation of cost estimates and bids.

Items to be discussed include:

- Specifications, PCI plant certification requirements, and any special provisions;
- Design responsibilities and lines of communication;
- The architect's approved finish samples with information on the mixture proportions, where applicable;
- Prebid submittal requirements, such as proposal drawings and finish samples;
- Project schedule, shop drawing submittal requirements, and architectural review turnaround times;

- Panelization of precast concrete units;
- Mockups, if applicable;
- Potential problems, discrepancies, or both, found in the contract documents;
- How and where the project's precast concrete units will be structurally attached to the building frame;
- Interfacing with other trades;
- Responsibility for designing, providing, and installing embedded items, anchor bolts, connection hardware attached to structural steel, bracing, and other structural items;
- Hardware and reinforcement finishes;
- Special erection needs (access, crane limitations, and sequence) and logistics; and
- Responsibility for caulking of precast concrete panel joints.

**STEP 3 — Post-Bid scope review:** This review allows the architect and GC/CM to review the precaster's proposal and confirms the precaster's ability to satisfactorily meet the project requirements and conform to design concepts and finish requirements. This material should include:

- Proposal drawings, which express the architectural precast concrete panelization and structural connection concepts;
- Finish samples;
- The history of the precaster's organization as well as confirmation of the plant's PCI quality-assurance (plant certification) program;
- A list of comparable projects, references, and financial capability;
- Key schedule items, such as mockup panels, shop drawings and design submittals, mold production, production start and durations, and erection start and durations (if applicable); and
- Qualifications to the bid that can be listed and reviewed.

If the project allows for a negotiated precast concrete contract, and the precaster is brought on board during the initial stages of development, prebid and bid submittal information can be minimized.

**STEP 4 — Preconstruction coordination.** A preconstruction conference should be held at the jobsite after award of the precast concrete and erection contracts. The GC/CM should conduct frequent jobsite meetings to coordinate precast concrete design and erection with the work of other trades and general building construction.

The coordination meetings should consider all details of loading, delivery sequences and schedules, types of transportation, routes of ingress and egress for delivery trucks and erection cranes, handling techniques and devices, connections, erection methods and sequences, the effects of temporary bracing on other trades, and onsite storage and protection. Questions regarding site access, street use, sidewalk permits, oversized loads, lighting, or unusual working hours should be addressed at this time.

### **Responsibilities of the Precaster**

Precasters will perform component and connection design of the members they produce when required by the contract documents. Precast concrete reinforcement is determined by building codes and industry standards and the design criteria defined by the contract documents.

All drawings and specifications that convey the requirements for the precast concrete scope should be provided to the precaster. Pertinent drawings might include architectural, structural, electrical, plumbing, and mechanical drawings depending on the size and scope of the project; approved shop drawings from other trades; and site plans showing available erection access and storage areas.

For practical reasons and economy, the precaster first determines the panelization (panel sizing and joints) and then the connections. Ideally, a precaster performs value engineering early in the preliminary design phase (in a partnering relationship) to reduce construction costs, improve structural efficiency, facilitate erection and precast concrete performance.

The precaster should request clarification of ambiguities in writing from the design team through contractual channels on special conditions not clearly defined by the design documents. Precast concrete erection and shape drawings should be submitted to the design team for approval or acceptance. This submittal is typically done through the general contractor. When the construction schedule demands a rapid turn-around time for review of drawing submittals, the precaster should notify the design team of their obligations to review and return submitted drawings within the agreed upon time period to avoid costly delays in the project schedule. Review meetings for information exchange and resolution of conflicts can expedite the approval process.

The precaster prepares detailed shape and erection drawings and design calculations that are usually signed and sealed by a professional engineer registered in the state where the project is located. These drawings and calculations should show all design criteria, identify all materials, illustrate precast concrete panel interfacing with other precast concrete units, the structure and adjacent materials, and indicate the magnitude and location of all design loads imparted to the structure by the precast concrete connections. Design modifications should be permitted only after the design team's approval of the proposed change.

The precaster designs the precast concrete panels and connection hardware for the design loads defined by the SER and is responsible for selecting, designing, and locating hardware and panel reinforcement or items associated with the precaster's methods of handling, storing, shipping, and erecting the precast concrete units. If necessary, this also includes an erection and bracing sequence developed in conjunction with the erector, SER, and GC to maintain the stability of the structure during the erection phase.

Additional design responsibilities for the precaster should be clearly defined in the contract documents and may occur when the design team uses Options II and III (Table B.1). Option III might be used for design-build or with performance specifications.

Quality control for product manufacturing is provided by the precaster according to provisions contained in a comprehensive quality system manual developed by the precaster in addition to requirements contained in PCI MNL-117. Quality assurance is provided through the precaster's participation in the PCI Plant Certification Program. Additional inspection at the owner's expense may be required, by specification, through the owner's quality assurance agency.

### **Responsibilities of the Erector**

The responsibility for erection of the precast concrete units may be part of the precaster's contract, to be performed by the precaster's own crews or subcontracted to specialized erection firms, or it may be assigned separately by the GC. Fabrication and erection included in one contract is recommended by precasters because this improves coordination and provides single source responsibility.

Erectors and precasters coordinate development of efficient connections to facilitate erection for each project based on their equipment and expertise. The erector should coordinate the erection plan including the sequence of erection with the GC/CM and the precaster.

The precast concrete erector should layout the panels based on the GC/CM's control lines and elevation data. This layout should provide panel and joint locations and elevations. This survey should identify any potential problems caused by building-frame columns, or beams that are misaligned or out of dimensional tolerance. Any discrepancies between site conditions and the erection drawings, which may cause problems during erection, should be noted in writing and sent to the GC/CM for resolution prior to the start of erection. Some of these

potential problems could include improper structural steel alignment or hardware installation, errors in bearing elevation or location, and obstructions caused by other trades. Erection should not proceed until these discrepancies are corrected by the GC/CM, or until the erection requirements are modified. This survey will also keep the differential variation in joint widths to a minimum and expedite precast concrete panel erection.

Installation quality assurance will be in accordance with industry standards, such as the PCI Erectors' Manual- Standards and Guidelines for the Erection of Precast Concrete Products (MNL-127). Additional quality assurance can be provided by requiring installation by an industry-qualified or certified erector.

**Table B.1 Design Responsibilities**

| Contract Information Supplied<br>by Design Team                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Responsibility of the<br>Precaster                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>OPTION 1</b></p> <p>Provide complete drawings and specifications detailing all aesthetic, functional, and structural requirements including design criteria, plus dimensions.</p>                                                                                                                                                                                                                                                                                                                                                                    | <p>The precaster should make shop drawings (erection and production drawings), as required, with details as shown by the designer. Modifications may be suggested that, in precaster's estimation, would improve the economics, structural soundness, or performance of the precast concrete installation. The precaster should obtain specific approval for such modifications. Full responsibility for the precast concrete design, including such modifications, remains with the designer. Alternative proposals from a precaster should match the required quality and remain within the parameters established for the project. It is particularly advisable to give favorable consideration to such proposals if the modifications are suggested so as to conform to the precaster's normal and proven procedures.</p>                                                                                                                                                                                                                                                                                 |
| <p><b>OPTION II</b></p> <p>Detail all aesthetic and functional requirements but specify only the required structural performance of the precast concrete units. Specified performance should include all limiting combinations of loads together with their points of application. This information should be supplied in such a way that all details of the unit can be designed without reference to the behavior of other parts of the structure. The division of responsibility for the design should be clearly stated in the contract documents.</p> | <p>The precaster has two alternatives:</p> <ul style="list-style-type: none"> <li>(a) Submit erection and shape drawings with all necessary details and design information for the approval and ultimate responsibility of the designer.</li> <li>(b) Submit erection and shape drawings, and design information for approval and assume responsibility for the panel structural design; that is, the individual units, but not their effect on the building. Precasters accepting this practice may either stamp (seal) drawings themselves, or commission engineering firms to perform the design and stamp the drawings.</li> </ul> <p>The choice between the alternatives (a) and (b) should be decided between the designer and the precaster prior to bidding with either approach clearly stated in the specifications for proper allocation of design responsibility.</p> <p>Experience has shown that divided design responsibility can create contractual problems. It is essential that the allocation of design responsibility is understood and clearly expressed in the contract documents.</p> |
| <p><b>OPTION III</b></p> <p>Cover general aesthetic and performance requirements only and provide sufficient detail to define the scope of the precast concrete work.</p>                                                                                                                                                                                                                                                                                                                                                                                  | <p>The precaster should participate in the preliminary design stage and the development of the final details and specifications for the precast concrete units and should work with the design team to provide an efficient design. The precaster provides the engineering design of the precast concrete units and their connections to the structure and should work with the design team to coordinate the interfacing work. The precaster should submit design information for approval and shop drawings at various stages of completion for coordination with other work.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

## **APPENDIX C**

### **Finish Samples**

#### **PRE-BID SAMPLES**

Pre-bid samples, as for all samples, shall only be regarded as a standard for performance within the variations of workmanship and materials to be expected.

Due to individual preferences, differences in sources of supply, or different techniques developed in various plants serving the same area, the architect/engineer should not expect to select one sample and obtain exact matching by all precast concrete producers.

Many architects have developed a practice of making sample selection and approval just prior to bid closing. Thus, for a specific project, the approved precaster's names and corresponding sample code numbers may be published in an addendum or approval list given in writing to the general contractor.

This practice may result in a slight variation in color, aggregate or texture (but not necessarily quality) from different bidders, since the individual precaster, within specification limits, selects the materials and employs the placing and finishing techniques best suited to their plant operation. The architect/engineer, when making prebid approval of samples part of the specifications, should adhere to the following requirements:

1. Sufficient time should be allowed for the bidder to submit samples or information for approval. Time should also be provided to enable such approvals to be conveyed to the precaster in writing so that the precaster can estimate and submit a bid.
2. Any pre-bid submittal should be treated in confidence, and the individual producer's solutions and/or techniques protected both before and after bidding.

If the characteristics of submitted pre-bid samples in any way deviate from the specifications, the precaster should make this clear to the architect/engineer when submitting the samples and other required information. For proper evaluation and approval of the samples, the precaster should state the reasons for the deviations. These reasons might be the precaster's concern over controlling variation in either color or texture within specified limits. In regard to adequacy of specified materials, concerns about satisfying all conditions of the specifications must be based upon practical plant production requirements and the performance or weathering of the product in its final location.

The architect/engineer may request data as described in Section 1.5.1 in order to evaluate these deviations. If such deviations and samples are approved, the original project specifications and contract drawings should be changed accordingly by the architect/engineer.

Since some samples are developed for specific projects with particular shapes or other characteristics, while others are more general for simple applications, it is the responsibility of the precaster either to make sure that the architect/engineer does not retain these specific project samples, or that they are clearly marked with respect to limits of application to prevent their use for unsuitable applications.

Some examples of use of samples for specific applications are sandblasted lightweight aggregate units for interior applications, or units that use mixtures with lower compressive strength and/or higher absorption percentages for

dry, non-corrosive atmospheric conditions, or the use of concrete elements in temporary buildings, such as exhibit halls.

## **IDENTIFICATION**

A file of sample code numbers with all related data should be maintained by the precaster to ensure future duplication of any sample submitted.

## **MOCKUPS AND PRODUCTION APPROVAL**

Aesthetic mockups can offer the opportunity to evaluate the following factors:

1. Acceptable appearance in regard to color, texture, details on the exposed face, and uniformity of returns.
2. Sequence of erection.
3. Available methods of bracing units prior to final structural connections being made.
4. Desirability of the method of connection in light of handling equipment and erection procedures.
5. Colors and finishes of adjacent materials (window frames, glass, sealants, etc.)
6. Dimensional accuracy of the precast concrete work and the constructibility of the specified tolerances.
7. The acceptability of the precast concrete panel inside surface finish (where exposed).
8. Available methods for the repair of chips, spalls or other surface blemishes. The mockup will also establish the extent and acceptability of defects and repair work.
9. Suitability of the selected sealers.
10. The weathering patterns or rain run-off on a typical section of precast concrete panel facade.

Mockups should be produced using standard production equipment and techniques. Some important variables that should be controlled as close to actual cast conditions include: retarder coverage rate and method of application, mixture design and slump, admixtures, heat of fresh and cured concrete, age, vibration, piece thickness and method of cleaning. This is especially important with light etches which are particularly affected by changing conditions.

Special details such as reveal patterns and intersections, corner joinery, drip sections, patterns, color and texture, and other visual panel characteristics should be demonstrated in large production samples for approval. Changes in aggregate orientation, color tone, and texture can easily be noted on full-scale mockup panels.

The objective of the mockup sample can also be to demonstrate the more detailed conditions that may be encountered in the project (recesses, reveals, outside/inside corners, multiple finishes, textures, veneers, etc.). This sample may not be fully representative of the exact finishes that can be reasonably achieved during mass production.

Mockup panels should contain typical cast-in-inserts, reinforcement, and plates as required for the project. Handling the mockup panels serves as a check that the stripping methods and lifting hardware will be suitable.

The architect should visit the precast concrete plant for examination and approval (sign and date) of the first production units. To avoid possible later controversies, this approval should precede a release for production. The architect should realize, however, that delays in visiting plants for such approvals may upset normal plant operations and the job schedule. It should be clearly stated in the contract documents how long the production units or the mockup structure should be kept in the plant or jobsite for comparison purposes. It is recommended that the contract documents permit the approved full-sized units to be used in the job installation in the late stages of construction. The units should remain identifiable even on the structure, until final acceptance of the project. The panels should be erected adjacent to each other on the building to allow continued comparison, if necessary.

The face of each sample should contain at least two areas of approved size and shape which have been chipped out and then patched and repaired. The color, texture and appearance of patched areas should match that of adjacent surface; see Sections 2.9 and 2.10.

Plant inspection by the architect during panel production is encouraged. This helps assure both the architect and the precaster that the desired end results can and are being obtained.

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# **APPENDIX D**

## ***Chuck Use and Maintenance Procedure***

Strand chucks are precision pieces of equipment designed to hold thousands of pounds of force. It is critical that inspections and preventive maintenance be performed periodically to insure their performance. The following procedure lists both general rules for using chucks on a bed and for their maintenance in the shop.

### **Reusable Strand Chucks-Use and Maintenance**

#### **1. General Safety Considerations**

The reusable strand chuck is a high precision device which requires systematic inspection and maintenance. The reusable strand chuck is designed to be used many times. Like any precision tool, the number of uses will depend upon both the quality of parts and the care and maintenance the user provides. Strand chucks should never be hit with a hammer, rebar, concrete or with another strand chuck. Strand chucks should not be thrown on top of one another, thrown on the ground, or placed in an area where dust, dirt or debris will collect on them. All used strand chucks should be placed in appropriate containers and returned to the chuck cleaning station.

Strand chuck parts are made to various specifications to accommodate the many sizes and strengths of strand. Care must be taken that only parts of the same size and same manufacturer are used together. Many new strand grades have been developed with higher load capacities making it critical that the strand chuck and jaws are properly sized for the intended strand use. Strand chuck components produced by different manufacturers are not interchangeable; even if they are marked for the same size, they should never be mixed. To avoid mixing chuck components, it is recommended that only one chuck manufacturer be used in the plant at any given time.

Strand chucks must always be used as a complete unit. Strand chucks designed with spring-equipped caps should always be used with the cap properly secured before stressing.

There are four basic maintenance requirements for the strand chucks: cleaning, inspection, lubrication, and reassembling. All strand chuck components should have these four maintenance requirements performed between each use. Failure to do so will result in shortened life of, or damage to, the strand chuck and is a potential hazard to the stressing crew.

#### **2. Releasing a Strand Chuck**

A properly lubricated strand chuck under normal working load (never more than 80% specified ultimate strength), should release by hand. If this is not occurring, then something is wrong and a review of the maintenance program should take place.

To release the chuck from a piece of strand, simply remove the cap, grasp the chuck body and push forward to dislodge the jaws. If the chuck is difficult to release, twist the barrel in the direction of the strand lay. An alternative would be to use a chuck removal tool that fits over the strand and pushes on the ends of the jaws driving them backwards to dislodge and release from the strand.

Never hit the chuck body with a hammer, rock, steel bar or other strand chucks. This will cause stress fractures to develop in the body, which during subsequent uses can be the cause for a barrel to fail and a

tensioned strand to release prematurely. If a strand chuck will not release, cut the strand approximately one foot on either side of the chuck and take the chuck to the cleaning room for proper removal.

### 3. Strand Chuck Maintenance

A dedicated, well-lit workstation or cleaning room should be assigned for the cleaning of strand chucks. Only trained personnel should be assigned the responsibility of performing strand chuck maintenance. Strand chucks should only be issued to the production crew with the approval of the designated chuck maintenance personnel. The chuck cleaning room shall have the proper tools, ventilation and sufficient workstation area to adequately handle the volume of strand chucks to be cleaned daily.

#### a. Cleaning the Strand Chuck

During cleaning, start with a clean area; separate all strand chucks by size and manufacturer. Work with one strand chuck size completely before moving to the next size. While cleaning chucks, wear safety goggles and leather gloves that will not get caught in brushes. Barrels should be cleaned, using a wire brush; it will ensure the cleaning of concrete build-up, dust, foreign materials, and dry film lubricant build-up. Jaws should be cleaned with a tapered nylon brush prior to removing the retaining ring. Spring and caps should be cleaned of any concrete or foreign debris that may be attached to them.

#### b. Inspection of the Strand Chuck

Visually inspect the chuck body for signs of wear or damage. All chuck bodies should be inspected to assure the absence of nicks, cracks, score marks, pitting, hammer dents, or signs of excessive wear. Chuck bodies which have dimples from hitting with a hammer or other hard object should not be used. Such bodies can rupture at any time, even at very low stress levels. Check the ears, thread, or other cap retaining parts of the body to assure proper fit and retention of the cap will be maintained.

Caps and springs should be checked as a unit since they work together to fulfill their function. Springs which are mushroomed must be replaced. Likewise, springs which have been collapsed from their recommended spring height should be replaced. Look very carefully at the surface-bearing area of the cap where the jack will bear on it. If the surface is not flat or there are severe indentations or deformations on this surface, the cap should be replaced.

Inspect the jaws to assure the absence of scars, nicks, cracking, deformity or other damage which could cause jaws to fail. Jaw damage can also include bent tips, broken retaining ring slots, severe gouges on the tapered surface, severe gouges on teeth, damaged teeth and/or build up of rust, cement, debris, or solid film-release agent in teeth. Excessive wear of wedge teeth will result in reduced efficiency and can lead to slippage and strand failures. If wedge teeth are dull and rounded from use, they reduce the gripping efficiency in the strand chuck and should be discarded. Jaws that have chipped, broken, and/or distorted jaw teeth should also be discarded.

When a second strand chuck is being used in the stressing jack to pull the strand, it is very important these chucks be cleaned, inspected and lubricated as recommended by the strand chuck manufacturer.

#### c. Lubrication of the Strand Chuck

Only use lubricant recommended by your strand chuck manufacturer. As with any moving or working parts under heavy loads, the strand chuck requires lubrication for safe use and long life. Lubrication should only be applied to thoroughly cleaned parts. Lubricant should not be applied on top of existing dry

lubricant, dirt, concrete or debris. Proper lubrication provides controlled seating of the jaw, helps prevent corrosion, and is essential to the release and disassembly of the strand chuck.

d. Reassembling of the Strand Chuck

The last step in the maintenance process is the reassembling of the strand chuck components. Each strand size should be reassembled separately. Re-inspect the wedge-retaining ring, and apply to three identical wedge segments until seated in their groove. Be sure the ring fits properly and does not excessively protrude from the slot on the wedge segments.

Place the wedges into the tapered strand chuck body. Verify from the marking on the body that the wedge is from the same manufacturer as the body, and that the wedges and body are designed for the same size strand.

Verify that the spring is fully seated in the cap, and install the cap onto the strand chuck body. Verify that the wedges are in contact with the spring and the cap fits properly on the strand chuck body. The wedges should never be loose or rattle in the assembled strand chuck.

Note that assembly does not require hand tools. Should tools be required to reassemble the reusable strand chuck, then something is incorrect. Careful inspection should be performed to determine the cause of the improper fit of the components.

4. Strand Splice Chucks

Reusable strand splice chucks should be maintained in a similar manner to reusable strand chucks. Take care that the proper size strand chuck is used with the matching size strand and that the strands are inserted to the full depth prior to loading.

The number of splice strands per bed is not restricted for single strand tensioning. For multiple strand tensioning, correction cannot be made for differential seating between strands. Therefore, if the strand splice chuck is used, all strands must be spliced so that an adjustment can be made for the average seating loss which occurs.

**One-Time Use Chucks**

One-time use chucks are sometimes used by plants where the chuck will be completely encased in the finished concrete structure. Never mix one-time use chuck products with reusable strand chucks. Never use a one-time use chuck as a reusable strand chuck. These products do not have the same resiliency as reusable strand chucks and could fail if used repeatedly.

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# ***APPENDIX E***

## ***Sample Record Forms***

Numerous items that require record keeping for confirmation and evaluation are outlined in this quality control manual. The following record forms are suggested for consideration in a quality control program. These are not the only forms needed for operations, but will provide a beginning point for form development. It should be recognized that these are only **SAMPLE** record forms and that a plant may design its own forms to best serve its operation. The importance of any recording form is the information that it contains and not its format. The reports serve as a record of the manufacturing process in case this information is required at some future date.

Items that can be measured quantitatively are to be recorded in numerical terms. Items that must be evaluated subjectively should be rated in a consistent fashion. Items such as length and width measurements can be given a check mark or “OK” if they are within the tolerances listed in Section 7.3.

When extra attention is required to improve material or product quality, or to improve worker quality performance, or to identify matters beyond the control of the worker, remarks or sketches should be used. Remarks can be made on the back of the forms when there is not room on the front side.

The following forms are included:

1. Aggregate Analysis
  - a. Fine Aggregate Gradation
  - b. Coarse Aggregate Gradation
  - c. Material Finer than 200 Sieve
  - d. Aggregate Moisture Content
  - e. Organic Impurities
2. Batch Plant Scale Check
3. Concrete Test Report
4. Tensioning Report
5. Concrete Batching Report
6. Product Inspection Report

|                           |  |  |  |  |                                                                                              |  |  |
|---------------------------|--|--|--|--|----------------------------------------------------------------------------------------------|--|--|
| <b>AGGREGATE ANALYSIS</b> |  |  |  |  | <b>SHEET</b> _____<br><b>INSPECTOR</b> _____<br><b>QC MANAGER</b> _____<br><b>DATE</b> _____ |  |  |
|---------------------------|--|--|--|--|----------------------------------------------------------------------------------------------|--|--|

| <b>FINE AGGREGATE</b><br>Applicable Spec. _____ Date Det. _____ |                 |            |           |                             |                       |         |  |
|-----------------------------------------------------------------|-----------------|------------|-----------|-----------------------------|-----------------------|---------|--|
| Sieve Size                                                      | Weight Ret. (g) | % Retained | % Passing | ASTM C33 Specs<br>% Passing | Design Specifications | Remarks |  |
| 3/8 in.                                                         |                 |            |           | 100                         |                       |         |  |
| No. 4                                                           |                 |            |           | 95 – 100                    |                       |         |  |
| No. 8                                                           |                 |            |           | 80 – 100                    |                       |         |  |
| No. 16                                                          |                 |            |           | 50 – 85                     |                       |         |  |
| No. 30                                                          |                 |            |           | 25 – 60                     |                       |         |  |
| No. 50                                                          |                 |            |           | 10 – 30                     |                       |         |  |
| No. 100                                                         |                 |            |           | 2 - 10                      |                       |         |  |
| Pan                                                             |                 |            |           |                             |                       |         |  |
|                                                                 |                 | F.M. =     |           |                             |                       |         |  |

| <b>COARSE AGGREGATE</b><br>Applicable Spec. _____ Date Det. _____ |                 |            |           |                                |                                 |                       |         |
|-------------------------------------------------------------------|-----------------|------------|-----------|--------------------------------|---------------------------------|-----------------------|---------|
| Sieve Size                                                        | Weight Ret. (g) | % Retained | % Passing | ASTM C33<br>Specs<br>% Passing | ASTM C33<br>Size 8<br>% Passing | Design Specifications | Remarks |
| 1 in.                                                             |                 |            |           | 100                            | -                               |                       |         |
| 3/4 in.                                                           |                 |            |           | 90 - 100                       | -                               |                       |         |
| 1/2 in.                                                           |                 |            |           | -                              | 100                             |                       |         |
| 3/8 in.                                                           |                 |            |           | 20 - 55                        | 85 - 100                        |                       |         |
| No. 4                                                             |                 |            |           | 0 - 10                         | 10 - 30                         |                       |         |
| No. 8                                                             |                 |            |           | 0 - 5                          | 0 - 10                          |                       |         |
| No. 16                                                            |                 |            |           |                                | 0 - 5                           |                       |         |

| MATERIAL FINER THAN 200 SIEVE (ASTM C117)                              |                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| _____ Coarse Agg. _____ Fine Agg.<br>Supplier _____<br>Date Det. _____ | Original Wt. of Sample _____ (At least 2.5 kg)<br>Dry Wt. of Orig. Sample _____ = B<br>Dry Wt. Sample After Washing _____ = C<br>$A = (\% \text{ Material Finer Than 200 Sieve}) = \frac{B - C}{B} \times 100 = \text{_____} \%$ |

| AGGREGATE MOISTURE CONTENT                                                                                                                                                                                                                                                                                        | ORGANIC IMPURITIES IN SAND (C40)                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wt. Sample & Container (Wet) _____ (D)<br>Wt. Sample & Container (Dry) _____ (E)<br>Wt. of Container _____ (F)<br>Wt. of Moisture (D-E) _____ (G)<br>Net Dry Wt. of Sample (E-F) _____ (H)<br><br>$\% \text{ Moisture} = \frac{G}{H} \times 100 = \text{_____} = \text{_____} \%$<br>Speedy Moisture Test _____ % | Circle Color of Sodium Hydroxide Solution _____<br>Organic Plate No.<br>1<br>2<br>3 (standard)<br>4<br>5<br><br>_____ Sand Supplier<br><br>_____ Date |

|                                |                  |                      |                      |                  |                      |                                                                  |
|--------------------------------|------------------|----------------------|----------------------|------------------|----------------------|------------------------------------------------------------------|
| <b>BATCH PLANT SCALE CHECK</b> |                  |                      |                      |                  |                      | SHEET _____<br>INSPECTOR _____<br>QC MANAGER _____<br>DATE _____ |
| <b>AGGREGATE SCALES</b>        |                  |                      | <b>CEMENT SCALES</b> |                  |                      |                                                                  |
| <b>Bar</b>                     | <b>Test Load</b> | <b>Scale Reading</b> | <b>Bar</b>           | <b>Test Load</b> | <b>Scale Reading</b> | <b>Remarks</b>                                                   |
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|                                |                  |                      |                      |                  |                      |                                                                  |

☐ Balance Point at Zero at Start of Check

☐ Balance Point Off \_\_\_\_\_ Pts.   ☐ Under   ☐ Over

☐ Adjustment Required on Bar to Balance

Scale Report to be Completed on First Day of Each Week

| <h2 style="margin: 0;">CONCRETE TEST REPORT</h2> |          |              |       |         |               |                |               |      |               |               |                         |                         | SHEET NO _____<br>INSPECTOR _____<br>QC MANAGER _____<br>DATE _____ |         |
|--------------------------------------------------|----------|--------------|-------|---------|---------------|----------------|---------------|------|---------------|---------------|-------------------------|-------------------------|---------------------------------------------------------------------|---------|
| Project _____<br>Cast # _____                    |          |              |       |         |               |                |               |      |               |               |                         |                         |                                                                     |         |
| PIECE NO.                                        | POUR NO. | CYLINDER NO. | SLUMP | AIR (%) | YIELD (cu ft) | CONC. TEMP. °F | AMB. TEMP. °F | TIME | DATE AT BREAK | TIME AT BREAK | CURING DURATION (Hours) | MEASURED STRENGTH (psi) | DESIGN STRENGTH (psi)                                               | REMARKS |

FACE MIX      Mix Designation (Sample Number) \_\_\_\_\_      Design Strength \_\_\_\_\_

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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BACKUP MIX      Mix Designation (Sample Number) \_\_\_\_\_

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| CONCRETE YIELD COMPUTATION                            |       |                          |       | AIR MEASUREMENT                                                                                                                                                                                                                       |  |
|-------------------------------------------------------|-------|--------------------------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| CEMENT                                                | _____ | Wt. Container & Concrete | _____ | Aggregate Correction Factor (G)<br><br>$h_1 =$ _____<br>$h_2 =$ _____<br>$G =$ _____<br><br>Apparent Concrete Air Content ( $A_1$ )<br><br>$h_1 =$ _____<br>$h_2 =$ _____<br>$A_1 =$ _____<br><br>$A \text{ (Air)} = A_1 - G =$ _____ |  |
| Fine Aggregate                                        | _____ | Wt. Container            | _____ |                                                                                                                                                                                                                                       |  |
| Coarse Aggregate                                      | _____ | Wt. Concrete             | _____ |                                                                                                                                                                                                                                       |  |
| Admixture                                             | _____ | Slump                    | _____ |                                                                                                                                                                                                                                       |  |
| Water No. Gals _____ x 8.33                           | _____ | Entrained Air            | _____ |                                                                                                                                                                                                                                       |  |
| Total Wt. per cu yd (A)                               | _____ | Wt. per cu ft (B)        | _____ |                                                                                                                                                                                                                                       |  |
| Yield = $\frac{A}{B} =$ _____ = _____ cu ft per cu yd |       |                          |       |                                                                                                                                                                                                                                       |  |

## TENSIONING REPORT

SHEET \_\_\_\_\_

COMPLETED BY \_\_\_\_\_

DATE \_\_\_\_\_

Job No. \_\_\_\_\_ Cast No. \_\_\_\_\_

Bed No. \_\_\_\_\_ Product \_\_\_\_\_

Member Identifications \_\_\_\_\_

Ram Identification \_\_\_\_\_ Ram Area \_\_\_\_\_

Strand Used \_\_\_\_\_

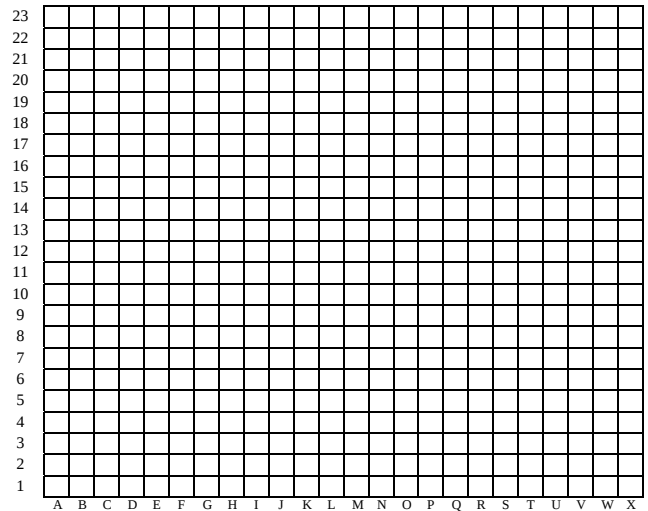
Reel # \_\_\_\_\_ Positions \_\_\_\_\_

Manuf. \_\_\_\_\_

Reel # \_\_\_\_\_ Positions \_\_\_\_\_

Manuf. \_\_\_\_\_

## PLOT STRANDS ON GRID



## TENSIONING CORRECTIONS

Live End Seating \_\_\_\_\_

Dead End Seating \_\_\_\_\_

Thermal (Abutment Beds) \_\_\_\_\_

Expected Concrete Temperature \_\_\_\_\_

Strand Temperature at Stressing \_\_\_\_\_

LOAD CELLS Temperature Correction for Gauge Reading \_\_\_\_\_ lbs = \*\* \_\_\_\_\_ Corrected Reading

| Location | Strand No. | Load By Gauge Press. | Load by Load Cell | Prior To Pour |
|----------|------------|----------------------|-------------------|---------------|
|          |            |                      |                   |               |
|          |            |                      |                   |               |
|          |            |                      |                   |               |

| Strand Pattern ID | COMPUTED TENSIONING DATA |            |                |                | ACTUAL LIVE END |                | ACTUAL DEAD END |                |
|-------------------|--------------------------|------------|----------------|----------------|-----------------|----------------|-----------------|----------------|
|                   | Total Elongation         | Pretension | Net Elongation | Gauge Pressure | Net Elongation  | Gauge Pressure | Net Elongation  | Gauge Pressure |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |
|                   |                          |            |                |                |                 |                |                 |                |

CONCRETE BATCHING REPORT

Cement Type \_\_\_\_\_

Manufacturer \_\_\_\_\_

SHEET \_\_\_\_\_  
OPERATOR \_\_\_\_\_  
QC MANAGER \_\_\_\_\_  
DATE \_\_\_\_\_

Admixture: \_\_\_\_\_ Stone Temp: \_\_\_\_\_  
Air Ent. Agent: \_\_\_\_\_ Mix Water Temp: \_\_\_\_\_  
Ambient Temp: \_\_\_\_\_ Sand % Moist: \_\_\_\_\_  
Cement Temp: \_\_\_\_\_ Stone % Moist: \_\_\_\_\_  
Sand Temp: \_\_\_\_\_ Concrete Temp: \_\_\_\_\_

| Mix No. | Bed No. | Job No. | Cement | Type | Sand | Sand Moist (%) | Stone | Stone Type | Water Added | Retard Admix (lbs) | AE Admix (lbs) | Mix Time | Slump Meter | Cu. Yards |
|---------|---------|---------|--------|------|------|----------------|-------|------------|-------------|--------------------|----------------|----------|-------------|-----------|
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |
|         |         |         |        |      |      |                |       |            |             |                    |                |          |             |           |

# PRODUCT INSPECTION SHEET

Date Produced \_\_\_\_\_

Inspector \_\_\_\_\_

**MOLD NO:** \_\_\_\_\_  
**JOB NO:** \_\_\_\_\_  
**PRODUCT:** \_\_\_\_\_  
**JOB NAME:** \_\_\_\_\_  
**REL. AGENT:** \_\_\_\_\_

| ID.                            | Job No.                       |  |  |  |  |  |  |  |  |  |  |  |
|--------------------------------|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|
|                                | Mark No.                      |  |  |  |  |  |  |  |  |  |  |  |
| SET-UP DETAILS                 | Form Conditions & Cleanliness |  |  |  |  |  |  |  |  |  |  |  |
|                                | Seams Sealed                  |  |  |  |  |  |  |  |  |  |  |  |
|                                | Retarders                     |  |  |  |  |  |  |  |  |  |  |  |
|                                | Design Length (Height)        |  |  |  |  |  |  |  |  |  |  |  |
|                                | Form Set-Up Length (Height)   |  |  |  |  |  |  |  |  |  |  |  |
|                                | As-Cast Length (Height)       |  |  |  |  |  |  |  |  |  |  |  |
|                                | Design Width                  |  |  |  |  |  |  |  |  |  |  |  |
|                                | Form Set-Up Width             |  |  |  |  |  |  |  |  |  |  |  |
|                                | As Cast Width                 |  |  |  |  |  |  |  |  |  |  |  |
|                                | Design Depth (Thickness)      |  |  |  |  |  |  |  |  |  |  |  |
|                                | Form Set-Up Depth (Thickness) |  |  |  |  |  |  |  |  |  |  |  |
|                                | As-Cast Depth (Thickness)     |  |  |  |  |  |  |  |  |  |  |  |
|                                | Out-of-Square                 |  |  |  |  |  |  |  |  |  |  |  |
|                                | Block Outs                    |  |  |  |  |  |  |  |  |  |  |  |
|                                | Squareness of Openings        |  |  |  |  |  |  |  |  |  |  |  |
|                                | Veneer Alignment              |  |  |  |  |  |  |  |  |  |  |  |
|                                | End & Edge Details            |  |  |  |  |  |  |  |  |  |  |  |
|                                | Reinforcement                 |  |  |  |  |  |  |  |  |  |  |  |
|                                | Insulation                    |  |  |  |  |  |  |  |  |  |  |  |
|                                | Reglets                       |  |  |  |  |  |  |  |  |  |  |  |
| Rustications                   |                               |  |  |  |  |  |  |  |  |  |  |  |
| Haunches (Corbels)             |                               |  |  |  |  |  |  |  |  |  |  |  |
| Plates & Inserts               |                               |  |  |  |  |  |  |  |  |  |  |  |
| Lifting Devices                |                               |  |  |  |  |  |  |  |  |  |  |  |
| FINISHED PRODUCT               | Top Finish (Dry)              |  |  |  |  |  |  |  |  |  |  |  |
|                                | Bottom Finish (Dry)           |  |  |  |  |  |  |  |  |  |  |  |
|                                | Surface Textures              |  |  |  |  |  |  |  |  |  |  |  |
|                                | Color Uniformity              |  |  |  |  |  |  |  |  |  |  |  |
|                                | Cracks or Spalls              |  |  |  |  |  |  |  |  |  |  |  |
|                                | Out-of-Square (Max.)          |  |  |  |  |  |  |  |  |  |  |  |
|                                | Camber or Deflection          |  |  |  |  |  |  |  |  |  |  |  |
|                                | Warpage                       |  |  |  |  |  |  |  |  |  |  |  |
|                                | Bowing                        |  |  |  |  |  |  |  |  |  |  |  |
|                                | Exposed Reinforcing or Chairs |  |  |  |  |  |  |  |  |  |  |  |
|                                | Plates & Inserts              |  |  |  |  |  |  |  |  |  |  |  |
|                                | Chamfers & Radius Quality     |  |  |  |  |  |  |  |  |  |  |  |
|                                | Openings & Block Outs         |  |  |  |  |  |  |  |  |  |  |  |
|                                | Lifting Devices               |  |  |  |  |  |  |  |  |  |  |  |
| Panel Sealer Applied           |                               |  |  |  |  |  |  |  |  |  |  |  |
| Blocking                       |                               |  |  |  |  |  |  |  |  |  |  |  |
| Finishing, Patching & Cleaning |                               |  |  |  |  |  |  |  |  |  |  |  |
| Date Approval Stamp Applied    |                               |  |  |  |  |  |  |  |  |  |  |  |
| Field Patching Required        |                               |  |  |  |  |  |  |  |  |  |  |  |
| Strand Slippage                |                               |  |  |  |  |  |  |  |  |  |  |  |

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# **APPENDIX F**

## ***PCI Plant Certification Program***

### **Introduction**

Since 1967, the Precast/Prestressed Concrete Institute has been a leader in the development of innovative quality programs. That year saw the beginnings of the PCI Plant Certification Program, a program that would set the pace for other construction-related certification programs to follow over the years.

The Plant Certification Program was expanded in 1970 to include production of architectural precast concrete and again in 1979 to include glass fiber reinforced concrete products.

In an age when quality is being demanded, the certification of manufacturers, erectors, and personnel provides assurance that quality systems are in place, personnel are trained, and control is practiced through every step of the process. Independent, unannounced audits ensure it.

### **PCI Plant Certification**

The certification of a manufacturing plant by PCI ensures that the plant has developed an in-depth quality system that is based on time-tested industry standards. Each must document their specific practices in a custom Quality System Manual and have the manual approved by PCI.

After undergoing a “Precertification Evaluation,” a plant is audited twice each year. These are unannounced audits. Auditors are independent, specially trained engineers.

Every audit ends with a meeting of auditors and key plant personnel so that if improvements are necessary, they can be started right away. A detailed written report that documents the observations and suggestions for improvements is provided after every audit. The report also includes a numerical grade sheet that determines qualification for continued certification.

The numerical grade sheet is organized exactly like the outline of this manual. The Table of Contents forms the basis of the grade sheet. During an audit, each chapter (division) of the manual is graded separately. Auditing each division must result in a minimum acceptable grade. Then, the grades for all divisions are combined into an overall grade. A minimum overall numerical grade is also required for certification.

**Product Groups** – A plant is evaluated and classified according to the type of products produced. This allows for product-specific inspection and analysis of a plant’s specialized capabilities. Plants may be certified in up to four general groups of products.

The manuals listed in parentheses include the certification standards for the group.

### **Group A**

Architectural Concrete Products (MNL-117)

### **Group B**

Bridge Products (MNL-116)

### **Group C**

Commercial Structural Products (MNL-116)

**Group G**

Glass Fiber Reinforced Concrete Products (MNL-130)

**Groups BA and CA**

A combination of A and B or A and C product groups (MNL-116) (see the detailed description BA and CA below)

**Production Categories** – Product groups A, B, BA, C, and CA are further divided into categories that define a product's reinforcement or the way in which the products is manufactured or used:

**Group A categories:**

- AT – Miscellaneous Architectural Trim Units
- A1 – Architectural Precast Concrete Products

**Group B categories:**

- B1 – Precast Concrete Products (no prestressed reinforcement)
- B2 – Prestressed Miscellaneous Bridge Products
- B3 – Prestressed Straight-Strand Bridge Beams
- B4 – Prestressed Deflected-Strand Bridge Beams

**Group C categories:**

- C1 – Precast Concrete Products (no prestressed reinforcement)
- C2 – Prestressed Hollow-Core and Repetitively Produced Products
- C3 – Prestressed Straight-Strand Structural Members
- C4 – Prestressed Deflected-Strand Structural Members

**Group BA categories** (Group B category products with architectural finishes):

- B1A, B2A, B3A, B4A

**Group CA categories** (Group C category products with architectural finishes):

- C1A, C2A, C3A, C4A

All of the categories listed above are in ascending order. A producer qualified to produce products in a given category is automatically qualified in the preceding categories but not in succeeding categories.

For more descriptive information about the types of products and projects that are represented by these categories, contact PCI, visit the PCI website, or refer to other more detailed literature.

A current listing of all PCI-Certified Plants is maintained on a convenient, searchable list at [www.pci.org](http://www.pci.org), or contact PCI, Director of Quality Programs.

PCI Plant Certification is included in the Master Specification of the American Institute of Architects and is required in the specification of the following federal agencies:

- Unified Facilities Guide Specifications (UFGS), which are a joint effort of the U.S. Army Corps of Engineers (USACE), their Force Civil Engineer Support Agency (AFCEA), and the National Aeronautics and Space Administration (NASA)
- U.S. Department of Transportation, Federal Aviation Administration
- U.S. Department of Agriculture, Food Safety and Inspection Service

- U.S. Department of Interior, Federal Bureau of Reclamation
- General Services Administration
- Federal Bureau of Prisons

PCI Plant Certification is strongly endorsed by the Federal Highway Administration (FHWA) for precast concrete bridge products and is required or accepted by more than one-half of the individual state departments of transportation.

### **Plant Quality Personnel Certification**

Conducting an effective quality control program requires knowledgeable and motivated testing and inspection personnel. Each must understand quality basics, the necessity for quality control, how products are manufactured, and precisely how to conduct tests and inspections. PCI has been training quality control personnel since 1974. In 1985, the first technician training manual was published by PCI and the first qualified personnel were certified.

There are four levels of Plant Quality Personnel Certification.

**PQPC Level I** requires a basic level of understanding of the many quality control issues normally encountered in a precast plant, such as:

- Quality and quality-control programs, testing, and measuring
- Basic concepts about concrete—water—cementitious materials ratio (w/cm), types of cements, accelerated curing concepts
- Control of purchased materials
- Precast production procedures
- Welding practices, including welding of reinforcing bars
- Interpretation of basic shop drawings

Certification at Level I also requires current certification as an American Concrete Institute (ACI) Concrete Field Testing Technician, Grade I. This certification requires a written test and precise field demonstration of seven ASTM methods to test fresh concrete. Level I must be renewed after five years unless a higher level of PCI certification is attained.

**PQPC Level II** requires Level I as a prerequisite. Level II must be renewed after five years unless Level III is attained. Other requirements for Level II include a greater level of knowledge of most of the topics described for Level I, as well as:

- Prestressing concepts and tensioning procedures for straight strands, including basic elongation calculations
- Tensioning and elongation corrections that account for temperature effects, chuck seating, abutment movement, and bed shortening. Calculations are required.
- Effects of accelerated curing and w/cm are further emphasized. Correction to mix proportions must be calculated to account for excess moisture in the aggregates.
- Quality control tests are further explored, including aggregate gradation calculations and analysis.
- Plant topics include more detail in reading shop drawings and in procedures for welding reinforcing bars.

Certification through Level II is accomplished by passing a written examination. Examinations may be administered locally by an approved proctor or at a PCI-conducted training school. A manual for Level I and II, TM-101, is available from PCI for training and self-study.

**PQPC Level III** provides significant instruction in concrete materials and technology. Certification at this level requires attendance at a four-day course and Level II as a prerequisite. Certification at Level III is valid for life, with registration with PCI and verification of continued industry involvement every five years.

There is a training manual, TM-103, available from PCI that covers all course material, such as:

- Properties of basic concrete materials, admixtures, fresh concrete, and hardened concrete
- Mix designs using normal and lightweight aggregates
- Architectural concrete
- Troubleshooting and fine-tuning concrete mixes
- Finished product evaluation
- Stud welding
- Deflected prestressing strands and the calculation of forces

**PQPC GFRC** Certification is accomplished by passing a written examination covering information contained in the two PCI manuals for GFRC.

- Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products, PCI MNL-130
- Recommended Practice for Glass Fiber Reinforced Concrete Panels, PCI MNL-128

Certification requires a basic level of understanding of the many quality issues normally encountered in a GFRC plant, such as:

- Quality assurance and quality control programs
- GFRC production practices
- Raw materials and accessories used
- Mix proportioning, batching, placing, spraying, and curing
- Quality control inspection and testing procedures
- Product dimensional tolerances

Examinations may be administered locally by an approved proctor.

### **Summary**

The architectural precast concrete industry, through PCI, has taken bold steps to establish industry standards. The standards apply to personnel, to production and operation, to quality control, and to field operations. The standards have been published and widely disseminated and are open for evaluation.

The PCI industry standards for quality production are demanding to achieve. But once attained and regularly practiced, they contribute to continued customer satisfaction as well as reduced overall operating costs.

Certification by PCI ensures compliance to the standards for quality production. Certified personnel and producers choose to demonstrate their proficiency by voluntarily undergoing examinations and audits by accredited third-party audit agencies.

PCI Plant and Personnel Certification are your most reliable means for qualifying your GFRC producer. Specify PCI Certification Programs for your projects.

**Guide Qualification Specification****Architectural Precast Concrete**

The architectural precast concrete manufacturing plant shall be certified by the Precast/Prestressed Concrete Institute PCI Plant Certification Program. Manufacturer shall be certified at time of bidding. Certification shall be in product group and category [select one or both: AT-Miscellaneous Architectural Trim Units; A1-Architectural Precast Concrete].

**Personnel Qualifications**

The manufacturer shall employ a minimum of one person, regularly present in the plant, who is certified by the Precast/Prestressed Concrete Institute as a Level I Quality Control Technician, unless prestressing operations are utilized, then a PCI Level II Quality Control Technician is required.

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# APPENDIX G

## Reference Literature

This manual and its commentary refer to many standards and outline recommendations based on the available body of knowledge involving precast and prestressed concrete. This appendix provides a basic outline of applicable standards and reference material. It is essential that a production facility's personnel be furnished with current reference literature and be encourage to read and utilize it.

A minimum reference list should include applicable and current publications of ASTM International; the American Concrete Institute; the Precast/Prestressed Concrete Institute; the Portland Cement Association; and similar agencies having pertinent applicable specifications dealing with manufacture of precast concrete.

### ASTM International

100 Barr Harbor Drive  
West Conshohocken, Pennsylvania 19428-2959  
[www.astm.org](http://www.astm.org)

The 80+ volume Annual Book of ASTM Standards contains specifications and test methods for nearly all construction materials, while most of the materials and standard practices used in the production of architectural precast concrete can be found in a handful of these volumes. They also contain specifications and methods of test for related materials.

The following is a list of individual standards which can be ordered in section groups published by ASTM International.

### ASTM

| Designation | Title                                                                      |
|-------------|----------------------------------------------------------------------------|
| A 27/A 27M  | Standard Specification for Steel Castings, Carbon, for General Application |
| A 36/A 36M  | Standard Specification for Carbon Structural Steel                         |
| A 47/A 47M  | Standard Specification for Ferritic Malleable Iron Castings                |
| A 82/A 82M  | Standard Specification for Steel Wire, Plain for Concrete Reinforcement    |

|              |                                                                                                                                                    |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| A 108        | Standard Specification for Steel Bar, Carbon and Alloy, Cold Finished                                                                              |
| A 123/A 123M | Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products                                                                    |
| A 143/A 143M | Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement |
| A 153/A 153M | Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware                                                                       |
| A 184/A 184M | Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement                                                               |
| A 185/A 185M | Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete                                                                    |
| A 276        | Standard Specification for Stainless Steel Bars and Shapes                                                                                         |
| A 283/A 283M | Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates                                                               |
| A 307        | Standard Specification for Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength                                                               |
| A 325        | Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength                                             |
| A 370        | Standard Test Methods and Definitions for Mechanical Testing of Steel Products                                                                     |
| A 416/A 416M | Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete                                                              |

## APPENDIX G

## Reference Literature

|              |                                                                                                                 |                |                                                                                                                       |
|--------------|-----------------------------------------------------------------------------------------------------------------|----------------|-----------------------------------------------------------------------------------------------------------------------|
| A 421/A 421M | Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete                         | A 882/A882M    | Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand                                   |
| A 496/A 496M | Standard Specification for Steel Wire, De-formed, for Concrete Reinforcement                                    | A 884/A 884M   | Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement                           |
| A 497/A 497M | Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete                              | A 934/A 934M   | Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars                                          |
| A 500/A 500M | Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes  | A 996/A 996M   | Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement                         |
| A 572/A 572M | Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel                          | A 1060/A 1060M | Standard Specification for Zinc-Coated (Galvanized) Steel Welded Wire Reinforcement, Plain and Deformed, for Concrete |
| A 615/A 615M | Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement                      | A 1064/A 1064M | Standard Specification for Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete                 |
| A 641        | Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire                                           | B 201          | Standard Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces                                          |
| A 641/A 641M | Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire (Metric)                                  | B 633          | Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel                                        |
| A 666        | Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel, Sheet, Strip, Plate and Flat Bar | B 766          | Standard Specification for Electrodeposited Coatings of Cadmium                                                       |
| A 675/A 675M | Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties              | C 29/C 29M     | Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate                                          |
| A 706/A 706M | Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement                   | C 31/C 31M     | Standard Practice for Making and Curing Concrete Test Specimens in the Field                                          |
| A 722/A 722A | Standard Specification for Uncoated High-Strength Steel Bar for Prestressing Concrete                           | C 33/C 33M     | Standard Specification for Concrete Aggregates                                                                        |
| A 767/A 767M | Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement                       | C 39/C 39M     | Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens                                       |
| A 775/A 775M | Standard Specification for Epoxy-Coated Reinforcing Steel Bars                                                  | C 40           | Standard Test Method for Organic Impurities in Fine Aggregates for Concrete                                           |
| A 780/A 780M | Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings                       |                |                                                                                                                       |

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## Reference Literature

|              |                                                                                                                                     |              |                                                                                                           |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------------------------------------------------------------------------------------------------------|
| C 42/C 42M   | Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete                                            | C 144        | Standard Specification for Aggregate for Masonry Mortar                                                   |
| C 67         | Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile                                                        | C 150/C 150M | Standard Specification for Portland Cement                                                                |
| C 70         | Standard Test Method for Surface Moisture in Fine Aggregate                                                                         | C 157/C 157M | Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete                   |
| C 88         | Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate                                      | C 171        | Standard Specification for Sheet Materials for Curing Concrete                                            |
| C 94/C 94M   | Standard Specification for Ready-Mixed Concrete                                                                                     | C 172        | Standard Practice for Sampling Freshly Mixed Concrete                                                     |
| C 109/C 109M | Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)                   | C 173/C 173M | Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method                   |
| C 117        | Standard Test Method for Materials Finer than 75- $\mu$ m (No. 200) Sieve in Mineral Aggregates by Washing                          | C 185        | Standard Test Method for Air Content of Hydraulic Cement Mortar                                           |
| C 125        | Standard Terminology Relating to Concrete and Concrete Aggregates                                                                   | C 188        | Standard Test Method for Density of Hydraulic Cement                                                      |
| C 127        | Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate                           | C 191        | Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle                              |
| C 128        | Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate                             | C 192/C 192M | Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory                         |
| C 131        | Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine | C 204        | Standard Test Methods for Fineness of Hydraulic Cement by Air Permeability Apparatus                      |
| C 136        | Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates                                                               | C 227        | Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method) |
| C 138/C 138M | Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete                                    | C 231/C 231M | Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method                     |
| C 142        | Standard Test Method for Clay Lumps and Friable Particles in Aggregates                                                             | C 233        | Standard Test Method for Air-Entraining Admixtures for Concrete                                           |
| C 143/C 143M | Standard Test Method for Slump of Hydraulic-Cement Concrete                                                                         | C 260        | Standard Specification for Air-Entraining Admixtures for Concrete                                         |
|              |                                                                                                                                     | C 295        | Standard Guide for Petrographic Examination of Aggregates for Concrete                                    |

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|               |                                                                                                                        |              |                                                                                                  |
|---------------|------------------------------------------------------------------------------------------------------------------------|--------------|--------------------------------------------------------------------------------------------------|
| C 309         | Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete                                       | C 591        | Standard Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation  |
| C 311         | Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete        | C 595/C 595M | Standard Specification for Blended Hydraulic Cements                                             |
| C 330/C 330M  | Standard Specification for Lightweight Aggregates for Structural Concrete                                              | C 617        | Standard Practice for Capping Cylindrical Concrete Specimens                                     |
| C 370         | Standard Test Method for Moisture Expansion of Fired Whiteware Products                                                | C 618        | Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete |
| C 403/C 403M  | Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance                                | C 641        | Standard Test Method for Iron Staining Materials in Lightweight Concrete Aggregates              |
| C 404         | Standard Specification for Aggregates for Masonry Grout                                                                | C 642        | Standard Test Method for Density, Absorption, and Voids in Hardened Concrete                     |
| C 457         | Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete         | C 666/C 666M | Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing                    |
| C 469         | Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression                   | C 685/C 685M | Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing            |
| C 470/C 470M  | Standard Specification for Molds for Forming Concrete Test Cylinders Vertically                                        | C 702        | Standard Practice for Reducing Samples of Aggregate to Testing Size                              |
| C 494C/C 494M | Standard Specification for Chemical Admixtures for Concrete                                                            | C 805/C 805M | Standard Test Method for Rebound Number of Hardened Concrete                                     |
| C 566         | Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying                                      | C 845        | Standard Specification for Expansive Hydraulic Cement                                            |
| C 567         | Standard Test Method for Determining Density of Structural Lightweight Concrete                                        | C 881/C 881M | Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete                         |
| C 578         | Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation                                              | C 917        | Standard Test Method for Evaluation of Cement Strength Uniformity from a Single Source           |
| C 586         | Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock-Cylinder Method) | C 979        | Standard Specification for Pigments for Integrally Colored Concrete                              |
|               |                                                                                                                        | C 989        | Standard Specification for Slag Cement for Use in Concrete and Mortars                           |
|               |                                                                                                                        | C1017/C1017M | Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete             |

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|              |                                                                                                                                            |              |                                                                                                                                  |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------|
| C1059/C1059M | Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete                                                             | C 1315       | Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete           |
| C1064/C1064M | Standard Test Method for Temperature of Freshly Mixed Hydraulic Cement Concrete                                                            | C1582/C1582M | Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete                     |
| C 1077       | Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation | C1602/C1602M | Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete                                      |
| C 1105       | Standard Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction                                                   | C 1603       | Standard Test Method for Measurement of Solids in Water                                                                          |
| C1107/C1107M | Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)                                                                | C1610/C1610M | Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique                                |
| C 1126       | Standard Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation                                                     | C1611/C1611M | Standard Test Method for Slump Flow of Self-Consolidating Concrete                                                               |
| C1157/C1157M | Standard Performance Specification for Hydraulic Cement                                                                                    | C1621/C1621M | Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring                                                |
| C1218/C1218M | Standard Test Method for Water-Soluble Chloride in Mortar and Concrete                                                                     | C 1712       | Standard Test Method for Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test |
| C1231/C1231M | Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders                         | D 75/D 75M   | Standard Practice for Sampling Aggregates                                                                                        |
| C 1240       | Standard Specification for Silica Fume Used in Cementitious Mixtures                                                                       | D 511        | Standard Test Methods for Calcium and Magnesium In Water                                                                         |
| C 1250       | Standard Test Method for Nonvolatile Content of Cold Liquid-Applied Elastomeric Waterproofing Membranes                                    | D 512        | Standard Test Methods for Chloride Ion In Water                                                                                  |
| C 1252       | Standard Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture and Grading)        | D 513        | Standard Test Methods for Total and Dissolved Carbon Dioxide in Water                                                            |
| C 1260       | Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)                                                     | D 1067       | Standard Test Methods for Acidity or Alkalinity of Water                                                                         |
| C 1293       | Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction                                          | D 3082       | Standard Test Method for Boron in Water                                                                                          |
|              |                                                                                                                                            | D3963/D3963M | Standard Specification for Fabrication and Jobsite Handling of Epoxy-Coated Steel Reinforcing Bars                               |

|        |                                                                                                                   |
|--------|-------------------------------------------------------------------------------------------------------------------|
| D 4191 | Standard Test Method for Sodium in Water by Atomic Absorption Spectrophotometry                                   |
| D 4192 | Standard Test Method for Potassium in Water by Atomic Absorption Spectrophotometry                                |
| D 4327 | Standard Test Method for Anions in Water by Chemically Suppressed Ion Chromatography                              |
| D 4791 | Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate |
| E 4    | Standard Practices for Force Verification of Testing Machines                                                     |
| E 11   | Standard Specification for Woven Wire Test Sieve Cloth for Standard Test Sieves                                   |
| E 105  | Standard Practice for Probability Sampling of Materials                                                           |
| E 329  | Standard Specification for Agencies Engaged in Construction Inspection and Testing                                |

For all materials and equipment used in the manufacture of precast and prestressed concrete, for which an appropriate ASTM designation has not been developed, manufacturer's specifications and directions should be available. Such materials and equipment should be used only when they have been shown by tests to be adequate for the purpose intended and their usage has been approved by the purchasing entity.

## American Concrete Institute

38800 Country Club Dr.  
P.O. Box 9094  
Farmington Hills, MI 48331  
[www.concrete.org](http://www.concrete.org)

1. Manual of Concrete Inspection, SP-002
2. Manual for Concrete Practice, MCP

These volumes contain accepted ACI Standards including the Building Code requirements and appropriate publications covering all aspects of concrete proportioning, batching, mixing, placing, and curing. They should be available in all precast plants. Some of the

more pertinent recommended practices and guides are as follows:

| ACI Designation | Title                                                                                         |
|-----------------|-----------------------------------------------------------------------------------------------|
| ITG-7           | Specifications for Tolerances for Precast Concrete                                            |
| SP-2            | Manual of Concrete Inspection                                                                 |
| 116R            | Cement and Concrete Terminology                                                               |
| 117             | Standard Specifications for Tolerances for Concrete Construction and Materials and Commentary |
| 201.2R          | Guide to Durable Concrete                                                                     |
| 211.1           | Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete        |
| 211.2           | Standard Practice for Selecting Proportions for Structural Lightweight Concrete               |
| 211.3R          | Guide for Selecting Proportions for No-Slump Concrete                                         |
| 212.3R          | Chemical Admixtures for Concrete                                                              |
| 212.4R          | Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete     |
| 213R            | Guide for Structural Lightweight-Aggregate Concrete                                           |
| 214R            | Guide to Evaluation of Strength Test Results of Concrete                                      |
| 221R            | Guide for Use of Normal Weight and Heavy Weight Aggregates in Concrete                        |
| 224.1R          | Causes, Evaluation, and Repair of Cracks in Concrete Structures                               |
| 225R            | Guide to the Selection and Use of Hydraulic Cements                                           |
| 301             | Specifications for Structural Concrete                                                        |
| 303R            | Guide to Cast-in-Place Architectural Concrete Practice                                        |

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|        |                                                                                            |
|--------|--------------------------------------------------------------------------------------------|
| 304R   | Guide for Measuring, Mixing, Transporting, and Placing Concrete                            |
| 304.5R | Batching, Mixing, and Job Control of Lightweight Concrete                                  |
| 305R   | Hot Weather Concreting                                                                     |
| 306R   | Cold Weather Concreting                                                                    |
| 308R   | Guide to Curing Concrete                                                                   |
| 309R   | Guide for Consolidation of Concrete                                                        |
| 309.1R | Report on Behavior of Fresh Concrete During Vibration                                      |
| 309.2R | Identification and Control of Visible Effects of Consolidation on Formed Concrete Surfaces |
| 311.5R | Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete                    |
| 318    | Building Code Requirements for Structural Concrete and Commentary                          |
| 363R   | Report on High-Strength Concrete                                                           |
| 423.3R | Recommendations for Concrete Members Prestressed with Unbonded Tendons                     |
| 439.4R | Report on Steel Reinforcement - Material Properties and U.S. Availability                  |

### Precast/Prestressed Concrete Institute

200 West Adams Street, Suite 2100  
Chicago, IL 60606

[www.pci.org](http://www.pci.org)

### PCI

**Designation Title**

|               |                                                                                                                                           |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| JL-92-MAY-JUN | Sason, Augusto S., "Evaluation of Degree of Rusting on Prestressed Concrete. Strand," PCI JOURNAL, V. 37, No. 3, May-June 1992, pp. 25-30 |
| JL-09-SPR-14  | Peterman, Robert J. "A Simple Quality Assurance Test for Strand Bond," (originally published in Spring 2009 and revised in May 2009)      |

|         |                                                                                                                       |
|---------|-----------------------------------------------------------------------------------------------------------------------|
| CTG     | Architectural Precast Concrete Color and Texture Selection Guide                                                      |
| MNL-116 | Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products                     |
| MNL-119 | PCI Drafting Handbook - Precast and Prestressed Concrete                                                              |
| MNL-120 | PCI Design Handbook - Precast and Prestressed Concrete                                                                |
| MNL-122 | Architectural Precast Concrete                                                                                        |
| MNL-135 | Tolerance Manual for Precast and Prestressed Concrete Construction                                                    |
| SLP-100 | PCI Safety and Loss Prevention Manual                                                                                 |
| TN-3    | Efflorescence on Precast Concrete                                                                                     |
| TR-6    | Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants |

### Portland Cement Association

5420 Old Orchard Road  
Skokie, IL 60077

[www.cement.org](http://www.cement.org)

### PCA

**Designation Title**

|       |                                                |
|-------|------------------------------------------------|
| EB001 | Design and Control of Concrete Mixtures        |
| IS214 | Removing Stains and Cleaning Concrete Surfaces |

### American Welding Society

550 N.W. LeJeune Rd.  
Miami, FL 33126

[www.aws.org](http://www.aws.org)

### AWS

**Designation Title**

|            |                                                                             |
|------------|-----------------------------------------------------------------------------|
| A5.1/A5.1M | Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding    |
| A5.4/A5.4M | Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding |

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|              |                                                                                     |
|--------------|-------------------------------------------------------------------------------------|
| A5.5/A5.5M   | Specification for Low-Alloy Steel Covered Electrodes for Shielded Metal Arc Welding |
| A5.18/A5.18M | Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding     |
| A5.20/A5.20M | Carbon Steel Electrodes for Flux Cored Arc Welding                                  |
| A5.28/A5.28M | Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding  |
| A5.29/A5.29M | Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding             |
| B1.11        | Guide for Visual Examination of Welds                                               |
| B2.1/B2.1M   | Standard for Welding Procedure and Performance Qualification                        |
| C5.4         | Recommended Practices for Stud Welding                                              |
| D1.1/D1.1M   | Structural Welding Code - Steel                                                     |
| D1.4/D1.4M   | Structural Welding Code - Reinforcing Steel                                         |
| D1.6/D1.6M   | Structural Welding Code – Stainless Steel                                           |
| QC1          | Standard for AWS Certification of Welding Inspectors                                |
| WZCD19.0     | Welding Zinc-Coated Steels                                                          |
| Z49.1        | Safety in Welding and Cutting and Allied Processes                                  |

### Canadian Standards Association

5060 Spectrum Way, Suite 100  
Mississauga, Ontario L4W 5N6  
Canada  
[www.csa.ca](http://www.csa.ca)

### CSA

| Designation | Title                                                                                                    |
|-------------|----------------------------------------------------------------------------------------------------------|
| A23.1/A23.2 | Concrete Materials and Methods of Concrete Construction Test Methods and Standard Practices for Concrete |

W178.2 Certification of Welding Inspectors

### National Ready Mixed Concrete Association

900 Spring Street  
Silver Spring, MD 20910  
[www.nrmca.org](http://www.nrmca.org)

### NRMCA

| Designation | Title                                                                                                                                                                                                                                 |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CPMB102     | Recommended Guide Specifications for Batching Equipment and Control Systems in Concrete Batch Plants                                                                                                                                  |
|             | <ul style="list-style-type: none"> <li>Concrete Plant Standards of the Concrete Plant Manufacturers Bureau</li> <li>Truck Mixer, Agitator, and Front Discharge Concrete Carrier Standards</li> <li>Plant Inspector's Guide</li> </ul> |

### U.S. Bureau of Reclamation

Denver Federal Center  
Denver, CO 80225  
[www.usbr.gov](http://www.usbr.gov)

- Concrete Manual

### Concrete Reinforcing Steel Institute

933 N. Plum Grove Road  
Schaumburg, IL 60173  
[www.crsi.org](http://www.crsi.org)

### CRSI

| Designation | Title                                                                                                                                                                                                                                                                                          |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|             | <ul style="list-style-type: none"> <li>Guidelines for Inspection and Acceptation of Epoxy-Coated Reinforcing Steel at the Job Site</li> <li>Recommended Field Handling of Epoxy-Coated Reinforcing Bars</li> <li>Fusion-Bonded Epoxy Coating Applicator Plant Certification Program</li> </ul> |

### American National Standards Institute

25 West 43<sup>rd</sup> Street, 4<sup>th</sup> Floor  
New York, New York 10036  
[www.ansi.org](http://www.ansi.org)

**ANSI**

| <b>Designation</b>      | <b>Title</b>                                      |
|-------------------------|---------------------------------------------------|
| ANSI A108/<br>A118/A136 | Standards for the Installation of<br>Ceramic Tile |

**The Master Painters Institute**

2800 Ingleton Ave.  
Burnaby, B.C. V5C 6G7  
Canada  
[www.paintinfo.com](http://www.paintinfo.com)

**MPI**

| <b>Designation</b> | <b>Title</b>                               |
|--------------------|--------------------------------------------|
| 79                 | Primer, Alkyd, Anti-Corrosive for<br>Metal |

**The Society for Protective Coatings**

[www.sspc.org](http://www.sspc.org)

**SSPC**

| <b>Designation</b> | <b>Title</b>                                                             |
|--------------------|--------------------------------------------------------------------------|
| 20                 | Zinc-Rich Coating (Type I – Inorganic<br>and Type II – Organic)          |
| 25                 | Zinc Oxide, Alkyd, Linseed Oil Primer<br>for Use Over Hand Cleaned Steel |

**Federal Specification**

U.S. General Services Administration  
[www.fss.gsa.gov](http://www.fss.gsa.gov)

**FS**

| <b>Designation</b> | <b>Title</b>                                                                                                  |
|--------------------|---------------------------------------------------------------------------------------------------------------|
| TT-P-641           | Primer Coating; Zinc Dust-Zinc Oxide,<br>Type II (for Galvanized Surfaces) or<br>Type I (for Rusted Surfaces) |

**Military Specification**

[www.wdbg.org](http://www.wdbg.org)

**MIL**

| <b>Designation</b> | <b>Title</b>                                         |
|--------------------|------------------------------------------------------|
| P-21035B           | Paint, High Zinc Dust Content,<br>Galvanizing Repair |

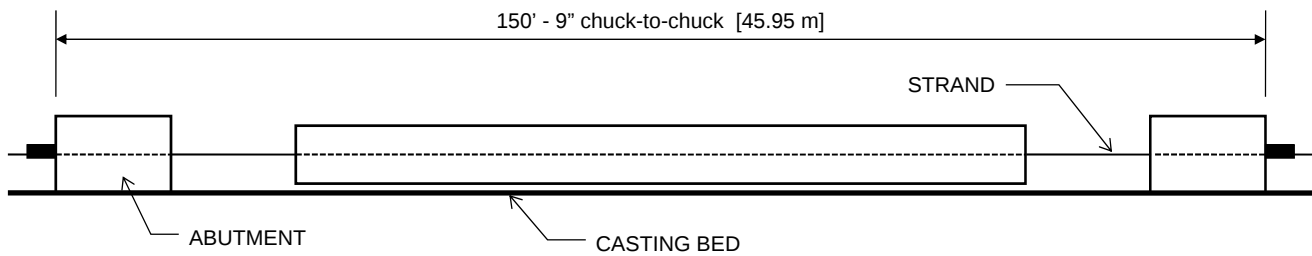
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# APPENDIX H

## Sample Tensioning Data Calculations

### A1. Pretensioned Straight Strand with Abutment Anchorages

The following example details the method for calculating tensioning data for a straight strand in an abutment anchorage set-up. Adjustments for abutment rotation, anchor wedge seating loss, and temperature variation are shown.



#### Material Data and Bed Set-Up Information:

1. Size and type of strand: 3/8 in. [9.53 mm] diameter, 270K [1860 MPa].

2. Physical characteristics of strand:

From the mill certificate supplied by the manufacturer,

$$A = 0.0850 \text{ in.}^2 \text{ [54.8 mm}^2\text{]}$$

$$E = 28,500,000 \text{ psi [196,507 MPa]}$$

*Generally, average or "assumed" values for strand area and elastic modulus can be used without significant error. The variation in these parameters, given current manufacturing techniques, is small. If problems arise in meeting the tolerances for tensioning when average values are used the actual strand properties should be investigated.*

3. Initial load of 1,500 lbs [6,672 N] has proven adequate on strand in this bed in the past.

4. Strand is to be tensioned to 75% of ultimate,  
 $23,000\text{lbs} \times 0.75 = 17,250\text{lbs}$   
 $[102,304\text{N} \times 0.75 = 76,728\text{N}]$

#### Corrections to Tensioning:

- a. Abutment Rotation

Based on ongoing monitoring of abutments under various strand patterns, the abutments are expected to rotate inward under load 1/8 in. [3 mm] each, for a total correction of 1/4 in. [6 mm].

- b. Dead End Anchor Wedge Seating Loss

Based on ongoing monitoring, seating after initial load is applied is expected to be 1/8 in. [3 mm].

- c. Live End Anchor Wedge Seating Loss

Expect 3/8 in. [10 mm] based on past history. Over-pull of 3/8 in. [10 mm] is required.

- d. Temperature Variation

Strands will have a temperature of 50 °F [10 °C] when tensioned. The concrete is expected to be at 85 °F [29 °C] based on current production monitoring, giving an anticipated change of +35 °F [19 °C].

**A1. Pretensioned Straight Strand with Abutment Anchorages (cont'd)**

**Tensioning Computations:**

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

$$\text{Basic Elongation} = \frac{(17,250 - 1,500) \text{ lbs} \times 1809 \text{ in.}}{0.0850 \text{ in}^2 \times 28,500,000 \text{ psi}} = 11.76 \text{ in.} \left[ = \frac{(76.73 - 6.67) \text{ kN} \times 45.95 \text{ m}}{54.8 \text{ mm}^2 \times 196,500 \text{ MPa}} = 299 \text{ mm} \right]$$

Theoretical Elongation = Basic Elongation combined with appropriate corrections.

**Computations of Corrections to Tensioning:**

Based on the assumption that elongation will be measured relative to abutment or live end chuck bearing on the abutment, the following will be required.

a. Abutment Rotation

Add 1/4 in. [6 mm] to elongation. No adjustment to force is required since only one strand is being tensioned. If multiple strands were being individually tensioned, corrections to both the force and elongation would be required similar to bed shortening of a self-stressing form.

*Note that the amount of abutment rotation will vary with the force applied to the abutment and the location of the strands relative to the abutment anchorage. In addition, the layout of the strands will determine the necessity and magnitude of force and elongation adjustments for individual strands.*

b. Dead End Anchor Wedge Seating

Add 1/8 in. [3 mm] to elongation. No adjustment to force is required.

c. Live End Anchor Wedge Seating

Over-pull by 3/8 in. [10 mm]. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.375 \text{ in.} \times 15,750 \text{ lbs}}{11.76 \text{ in.}} = 502 \text{ lbs} \left[ = \frac{9.5 \text{ mm} \times 70,056 \text{ N}}{299 \text{ mm}} = 2,233 \text{ N} \right]$$

d. Temperature Adjustment (required for variations of 25 °F [14 °C] or greater)

Adjust 1% per 10 °F [5.5 °C] variation. Since the strand will be warmed as the concrete is placed, over-pull is required.

$$\text{Force Adjustment} = 17,250 \text{ lbs} \times (0.01/10^\circ\text{F} \times 35^\circ\text{F}) = 604 \text{ lbs} \left[ = 76,728 \text{ N} \times 0.035 = 2,685 \text{ N} \right]$$

$$\text{Elongation Adjustment} = \frac{604 \text{ lbs} \times 1,809 \text{ in.}}{0.085 \text{ in}^2 \times 28,500,000 \text{ psi}} = 0.451 \text{ in.} \left[ = \frac{2,685 \text{ N} \times 45.95 \text{ m}}{54.8 \text{ mm}^2 \times 196,507 \text{ MPa}} = 11 \text{ mm} \right]$$

$$\text{Total Force Required} = 17,250 + 502 + 604 = 18,356 \text{ lbs} \quad [76,728 + 2,335 + 2,685 = 81,748 \text{ N}]$$

## APPENDIX H

## Sample Tensioning Data Calculations

### A1. Pretensioned Straight Strand with Abutment Anchorages (cont'd)

#### Elongation Computation Summary:

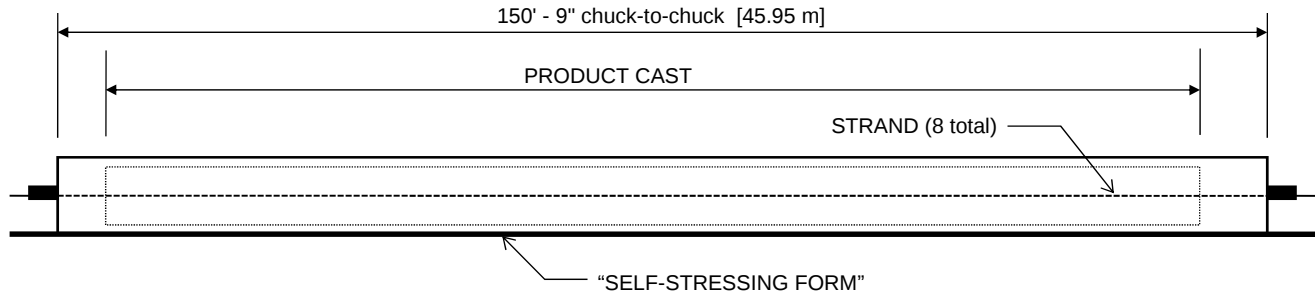
|                        | Gross Theoretical Elongation |        | Net Theoretical Elongation |        |
|------------------------|------------------------------|--------|----------------------------|--------|
| Basic Elongation       | 11.76 in.                    | 299 mm | 11.76 in.                  | 299 mm |
| Abutment Rotation      | 0.25                         | 6      | 0.25                       | 6      |
| Dead End Seating       | 0.125                        | 3      | 0.125                      | 3      |
| Live End Seating       | 0.375                        | 10     | 0.0                        | 0      |
| Temperature Adjustment | 0.451                        | 11     | 0.451                      | 11     |
| Total Elongation       | 12.961 in.                   | 329 mm | 12.586 in.                 | 319 mm |
| Rounded                | 13 in.                       | 330 mm | 12-5/8 in.                 | 320 mm |
| Tolerance Limits       | -5% = 12-3/8 in.             | 312 mm | -5% = 12 in.               | 304 mm |
|                        | +5% = 13-5/8 in.             | 346 mm | +5% = 13-1/4 in.           | 336 mm |

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram, and compare to 18,356 lbs [81,748 N] force. Use Net Theoretical Elongation for comparison, after seating of live end anchorage, against movement of mark on strand from initial tension reference.

Note that if the required temperature differential was greater, the total force required during jacking (in this case, 18,356 lbs [81,748 N]) would exceed 80% of the ultimate tensile strength ( $0.80 \times 23,000 = 18,400$  lbs [81,843 N]). This would require an allowance for temporary strand stress to exceed the 80% limit, or other means to control the temperature differential.

**A2. Pretensioned Straight Strand in a “Self-Stressing” Form**

The following example details the method for calculating tensioning data for a straight strand in a “self-stressing” form. Adjustments for form shortening, anchor wedge seating loss, and temperature variation are shown.



Material data is the same as in Example A1.

**Computations of Corrections to Tensioning:****a. Form Shortening**

Based on previous monitoring of the form under various strand patterns, 1/16" [1.6 mm] shortening is expected for each 3/8 in. [10 mm] diameter strand in the setup. There are eight strands in this casting, giving a total form shortening of 1/2 inch [13 mm]. The average force lost in each strand will correspond to a relaxation of 1/4 inch [6 mm], requiring an initial over-pull. Adjust anticipated elongation by 1/4 in. [6 mm] per strand.

$$\text{Force Adjustment} = \frac{0.25 \text{ in.} \times 15,750 \text{ lbs}}{11.76 \text{ in.}} = 335 \text{ lbs} \left[ = \frac{6 \text{ mm} \times 70,056 \text{ N}}{299 \text{ mm}} = 1,406 \text{ N} \right]$$

**b. Dead End Anchor Wedge Seating Loss**

Based on ongoing monitoring, seating after initial load is applied is expected to be 1/8 in. [3 mm]. Add 1/8 in. [3 mm] to elongation. No adjustment to force is required.

**c. Live End Anchor Wedge Seating Loss**

Expect 3/8 in. [10 mm] based on past history. Over-pull of 3/8 in. [10 mm] is required. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.375 \text{ in.} \times 15,750 \text{ lbs.}}{11.76 \text{ in.}} = 502 \text{ lbs} \left[ = \frac{10 \text{ mm} \times 70,056 \text{ N}}{299 \text{ mm}} = 2,335 \text{ N} \right]$$

**d. Temperature Variation**

Strands will have a temperature of 50 °F [10 °C] when tensioned. The concrete is expected to be at 85 °F [29 °C] based on current production monitoring, giving an anticipated change of +35 °F [19 °C].

Since the steel form holds the strand in the tensioned position, and the form will be exposed to the same temperature change as the strand, no adjustment is required.

$$\text{Total Force Required} = 17,250 + 335 + 502 = 18,087 \text{ lbs} \quad [76,728 + 1,406 + 2,335 = 80,469 \text{ N}]$$

**A2. Pretensioned Straight Strand in a “Self-Stressing” Form (cont’d)**

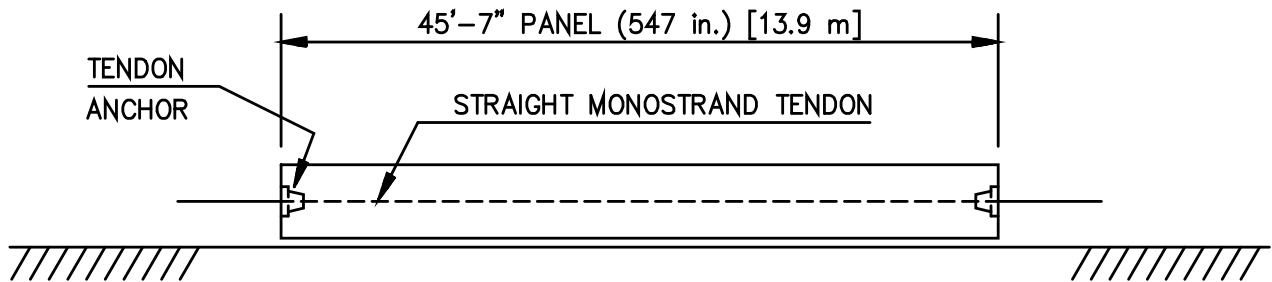
**Elongation Computation Summary:**

|                        | Gross Theoretical Elongation |     |    | Net Theoretical Elongation |     |    |
|------------------------|------------------------------|-----|----|----------------------------|-----|----|
| Basic Elongation       | 11.76 in.                    | 299 | mm | 11.76 in.                  | 299 | mm |
| Form Shortening        | 0.25                         | 6   |    | 0.25                       | 6   |    |
| Dead End Seating       | 0.125                        | 3   |    | 0.125                      | 3   |    |
| Live End Seating       | 0.375                        | 10  |    | 0.0                        | 0   |    |
| Temperature Adjustment | 0.0                          | 0   |    | 0.0                        | 0   |    |
| Total Elongation       | 12.51 in.                    | 318 | mm | 12.135 in.                 | 308 | mm |
| Rounded                | 12-1/2 in.                   | 318 | mm | 12-1/8 in.                 | 308 | mm |
| Tolerance Limits       | -5% = 11-7/8 in.             | 302 | mm | -5% = 11-1/2 in.           | 292 | mm |
|                        | +5% = 13-1/8 in.             | 333 | mm | +5% = 12-3/4 in.           | 323 | mm |

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram, and compare to 18,087 lbs [80,469 N] force. Use Net Theoretical Elongation for comparison, after seating of live end anchorage, against movement of mark on strand from initial tension reference.

**B. Post-tensioned Panel Using Straight Single Strand Tendon**

The following example details the method for calculating the elongation of a straight, greased and plastic coated (unbonded) strand. Adjustments for anchor wedge seating, elastic shortening, and friction losses are shown.



**Material Data and Bed Set-Up Information:**

1. Size and type of strand: 1/2 in. [12.7 mm] diameter, 270 K [1,860 MPa]

2. Physical characteristics of strand:

The average values being used by the plant are:

$$A = 0.1530 \text{ in.}^2 \text{ [98.71 mm}^2\text{]}$$

$$E = 28,500,000 \text{ psi [196,500 MPa]}$$

*See note in Example A1 regarding strand properties.*

From information supplied by the tendon manufacturer:

$\kappa$  (wobble friction coefficient) = 0.0014 per foot of tendon [0.0046 per meter]

$\mu$  (curvature friction coefficient) = 0.05

3. Physical characteristics of concrete:

$$f'_{ci} = 3,000 \text{ psi [20.7 MPa]}$$

$$E_{ci} = 33(150)^{1.5} \left( \sqrt{3,000 \text{ psi}} \right) = 3,320,561 \text{ psi}$$

$$\left[ \frac{0.043(2,400 \text{ kg/m}^3)^{1.5} \left( \sqrt{20.7 \text{ MPa}} \right)}{23,000 \text{ MPa}} \right] =$$

4. Use initial tension of 3,000 lbs [13.344 kN]

5. Strand is to be stressed to 70% of ultimate,

$$41,300 \text{ lbs} \times 0.70 = 28,910 \text{ lbs}$$

$$[183.7 \text{ kN} \times 0.70 = 128.6 \text{ kN}]$$

**Corrections to Tensioning:**

- a. Dead End Anchor Wedge Seating Loss

Based on ongoing monitoring, seating after initial tension is applied is expected to be 1/16 in. [1.5 mm].

- b. Live End Anchor Wedge Seating Loss

Expect 3/16 in. [5 mm] based on past history. Over pull of 3/16 in. [5 mm] is required.

- c. Elastic Shortening of Panel

Over pull will be required to compensate for loss of prestress resulting from elastic shortening of the panel.

- d. Friction Loss

Additional force will be required to overcome frictional forces between the strand and sheathing as the strand is tensioned.

**B. Post-tensioned Panel Using Straight Single Strand Tendon (cont'd)****Tensioning Computations:**

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

$$\text{Basic Elongation} = \frac{(28,910 - 3,000) \text{ lbs} \times 547 \text{ in.}}{0.153 \text{ in.}^2 \times 28,500,000 \text{ psi}} = 3.25 \text{ in.}$$

$$\left[ \frac{(128.6 - 13.3) \text{ kN} \times 13.9 \text{ m}}{(98.71 \times 10^{-6} \text{ m}^2) \times 196,500 \text{ MPa}} = 82.7 \text{ mm} \right]$$

Theoretical Elongation = Basic Elongation combined with appropriate corrections.

**Computations of Corrections to Tensioning:**

- a. Dead End Anchor Wedge Seating: Add 1/16 in. [1.5 mm] to elongation. No adjustment to force is required.
- b. Live End Anchor Wedge Seating: Over-pull by 3/16 in. [5 mm]. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.1875 \text{ in.} \times 25,910 \text{ lbs}}{3.25 \text{ in.}} = 502 \text{ lbs} \left[ = \frac{5 \text{ mm} \times 115.3 \text{ kN}}{82.7 \text{ mm}} = 6.97 \text{ kN} \right]$$

- c. Elastic Shortening:

As prestress force is applied to the panel, it will begin to shorten elastically. This produces corresponding shortening in the strands, resulting in a reduction of prestress force. This reduction may be calculated by:

$$ES = 0.5 (f_{cpa}) \frac{L}{E_c}$$

in which  $f_{cpa}$  is the average compressive stress in the concrete along the member length at the center of gravity of the tendons immediately after tensioning.

$$f_{cpa} = \frac{P}{A} = \frac{5 \times 28,910}{6 \text{ in.} \times 96 \text{ in.}} = 251 \text{ psi} \left[ \frac{5 \times 128.6}{(0.152 \text{ m}) \times (2.44 \text{ m})} = 1.73 \text{ MPa} \right]$$

$$ES = 0.5 \times 251 \times \frac{547 \text{ in.}}{3,320,561 \text{ psi}} = 0.021 \text{ in.} \left[ 0.5 \times (1.73 \text{ MPa}) \times \frac{13.9 \text{ m}}{23,000 \text{ MPa}} = 0.5 \text{ mm} \right]$$

This amount of elastic shortening is small enough that it may be neglected.

**B. Post-tensioned Panel Using Straight Single Strand Tendon (cont'd)**

d. Friction Losses:

Friction in the tendon system will result in a reduced strand stress at the dead (non-jacking) end of the tendon. Thus, some over pull is required to ensure that the average strand stress equals the design value. When friction losses are high, it is recommended that sequential jacking at both ends of the tendon be used to reduce the possibility of overstressing the strand at the live end. Friction loss may be calculated by:

$$\frac{P_D}{P_S} = e^{-(\kappa L + \mu \alpha)}$$

where  $P_D$  equals the force in the strand at the dead end,  $P_S$  equals the force in the strand at the live end,  $L$  is the tendon length, in feet, between anchorages, and  $\alpha$  is the total angular change of the tendon profile, in radians, between the anchorages. For this example,

$$\alpha = 0 \text{ for a straight tendon, and } \frac{P_D}{P_S} = e^{-(0.0014 \times 45.583 \text{ ft})} = 0.938 \quad \left[ e^{-(0.0046 \times 13.9 \text{ m})} = 0.938 \right]$$

Average strand force =  $(1 + 0.938)/2 = 0.969$ , loss = 3.1%.

The total force and elongation at the live end must be increased to compensate for friction losses:

$$\begin{aligned} \text{Force Adjustment} &= 28,910 \times 0.031 = 896 \text{ lbs} \quad [128.6 \text{ kN} \times 0.031 = 3986 \text{ N}] \\ \text{Elongation Adjustment} &= 3.25 \times 0.031 = 0.101 \text{ in.} \quad [82.7 \text{ mm} \times 0.031 = 3 \text{ mm}] \end{aligned}$$

**Total Force Required** =  $28,910 + 896 + 1,495 = 31,301 \text{ lbs}$   $[132.6 + 6.97 = 139.6 \text{ kN}]$

This load is less than 80% of the ultimate strand strength (33,000 lbs [146.8 kN]), therefore it is not necessary to jack at both anchorages.

**Elongation Computation Summary:**

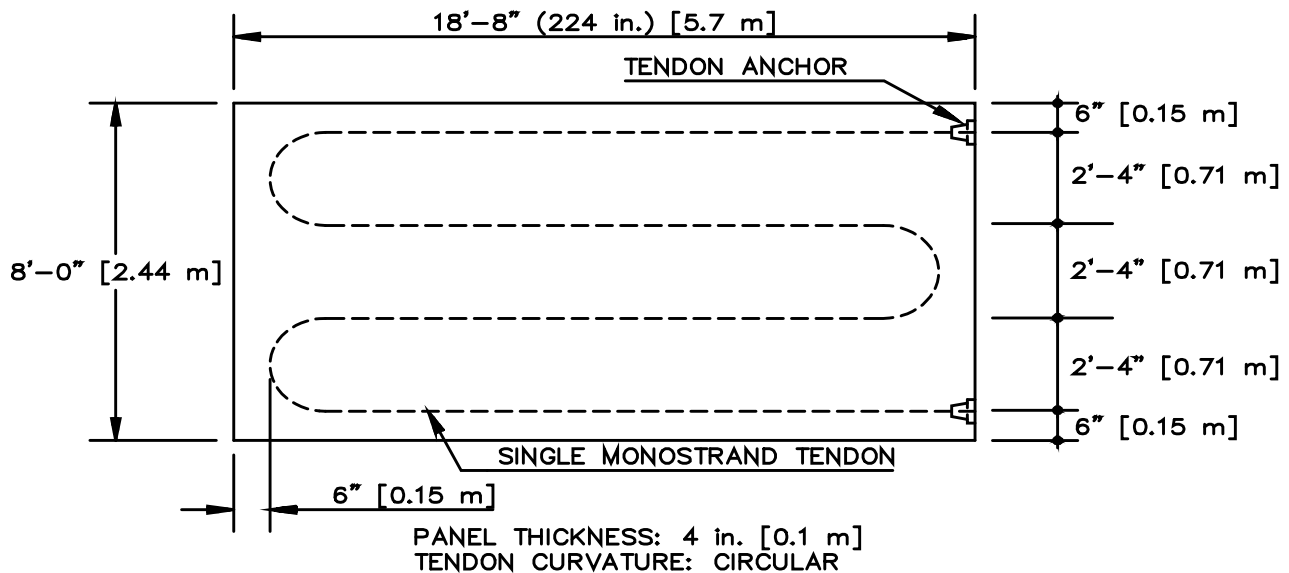
|                       | Gross Theoretical Elongation |         | Net Theoretical Elongation |         |
|-----------------------|------------------------------|---------|----------------------------|---------|
| Basic Elongation      | 3.25 in.                     | 82.7 mm | 3.25 in.                   | 82.7 mm |
| Dead End Seating Loss | 0.0625                       | 1.5     | 0.0625                     | 1.5     |
| Live End Seating Loss | 0.1875                       | 5       | 0.0                        | 0       |
| Friction Losses       | 0.101                        | 3       | 0.101                      | 3       |
| Total Elongation      | 3.601 in.                    | 92.2 mm | 3.4135 in.                 | 87.2 mm |
| Rounded               | 3-5/8 in.                    | 92 mm   | 3-7/16 in.                 | 87 mm   |
| Tolerance Limits      | -5% = 3-7/16 in.             | 87.4 mm | -5% = 3-1/4 in.            | 82.7 mm |
|                       | +5% = 3-13/16 in.            | 96.6 mm | +5% = 3-5/8 in.            | 91.4 mm |

Use Gross Theoretical Elongation for monitoring travel of ram, and compare to 31,301 lb [139.6 kN] force. Use Net Theoretical Elongation for comparison against movement of mark on strand from initial tension reference.

### Sample Tensioning Data Calculations

### C. Post-tensioned Panel Using Looped Single Strand Tendon

The following example details the method for calculating the elongation of a looped, greased and plastic coated (unbonded) strand. Adjustments for anchor wedge seating, and friction losses are shown. Note that with the exception of including the curvature friction loss factor, the procedure for calculating the tensioning parameters is the same as for Sample B.



### Material Data and Bed Set-Up Information:

1. Size and type of strand: 1/2 in. [12.7 mm] diameter, 270K [1,860 MPa].

- ## 2. Physical characteristics of strand:

The average values being used by the plant are:

$$A = 0.1530 \text{ in.}^2 \text{ [98.71 mm}^2\text{]}$$

E = 28,500,000 psi [196,500 MPa]

See note in Example A1 regarding strand properties.

3. From information supplied by the tendon manufacturer:

$\kappa$  (wobble friction coefficient) = 0.0007 per foot of tendon [0.0023 per meter]

$$\mu \text{ (curvature friction coefficient)} = 0.05$$

Use initial tension of 3,000 lbs [13.344 kN]

4. Strand is to be stressed to 70% of ultimate,  
 $41,300 \text{ lbs} \times 0.70 = 28,910 \text{ lbs}$   
 $[183.7 \text{ kN} \times 0.70 = 128.6 \text{ kN}]$

### Corrections to Tensioning:

- a. Dead End Anchor Wedge Seating Loss

Based on ongoing monitoring, seating after initial tension is applied is expected to be 1/8 in. [3 mm].

- b. Live End Anchor Wedge Seating Loss

Expect 1/8 in. [3 mm] based on past history.  
Over pull of 1/8 in. [3 mm] is required.

- ### c. Elastic Shortening

Neglect the effects of axial shortening for this short panel.

- #### d. Friction Loss

Additional force will be required to overcome frictional forces between the strand and sheathing as the strand is tensioned.

**C. Post-tensioned Panel Using Looped Single Strand Tendon (cont'd)**

**Tensioning Computations:**

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension}) (\text{Length of strand between anchorages})}{(\text{Area of strand}) (\text{Modulus of elasticity})}$$

$$\begin{aligned} \text{Tendon Length} &= (224 \text{ in.} - 6 \text{ in.} - 14 \text{ in.}) (2) + (224 \text{ in.} - 12 \text{ in.} - 28 \text{ in.}) (2) + (\pi \times 14 \text{ in.} \times 3) = 908 \text{ in.} \\ &[(5.7 \text{ m} - 0.15 \text{ m} - 0.355 \text{ m}) (2) + (5.7 \text{ m} - 0.305 \text{ m} - 0.71 \text{ m}) (2) + (\pi \times 0.355 \text{ m} \times 3) = 23.1 \text{ m}] \end{aligned}$$

$$\text{Basic Elongation} = \frac{(28,910 - 3,000) \text{ lbs} \times 908 \text{ in.}}{0.153 \text{ in.}^2 \times 28,500,000 \text{ psi}} = 5.40 \text{ in.}$$

$$\left[ \frac{(128.6 - 13.3) \text{ kN} \times 23.1 \text{ m}}{(98.71 \times 10^{-6} \text{ m}^2) \times 196,500 \text{ MPa}} = 137 \text{ mm} \right]$$

Theoretical Elongation = Basic Elongation combined with appropriate corrections.

**Computations of Corrections to Tensioning:**

a. Dead End Anchor Wedge Seating: Add 1/8 in. [3 mm] to elongation. No adjustment to force is required.

b. Live End Seating: Over pull by 1/8 in. [3 mm]. Adjust force accordingly.

$$\text{Force Adjustment} = \frac{0.125 \times 25,910}{5.40} = 600 \text{ lbs} \quad \left[ = \frac{(3 \text{ mm}) \times (115.3 \text{ kN})}{137 \text{ mm}} = 2.53 \text{ kN} \right]$$

c. Friction Losses

Friction in the tendon system will result in a reduced strand stress at the dead (non-jacking) end of the tendon. Thus, some over pull is required to ensure that the average strand stress equals the design value. When friction losses are high, it is recommended that sequential jacking at both ends of the tendon be used to reduce the possibility of overstressing the strand at the live end.

$$\frac{P_D}{P_S} = e^{-(\kappa L + \mu \alpha)}$$

where  $P_D$  equals the force in the strand at the dead end,  $P_S$  equals the force in the strand at the live end,  $L$  is the tendon length, in feet, between anchorages, and  $\alpha$  is the total angular change of the tendon profile, in radians, between the anchorages. For this example,

$$\frac{P_D}{P_S} = e^{-(0.0007 \times 75.67 \text{ ft} + 0.05 \times 9.42)} = 0.59$$

$$\text{Curvature} = \alpha = \pi(3) = 9.42 \text{ radians}$$

$$\left[ e^{-(0.0023 \times 23.1 \text{ m} + 0.05 \times 9.42)} = 0.59 \right]$$

$$\text{Average strand force} = (1 + 0.59)/2 = 0.795, \text{ loss} = 20.5\%.$$

**C. Post-tensioned Panel Using Looped Single Strand Tendon (cont'd)**

We would exceed the breaking strength of the strand if total friction losses for tensioning from one end only were included in the tensioning force. Jacking may be performed from both ends of the tendon to reduce the total jacking force required at each end.

Calculate the friction loss at mid-point of the tendon,

$$\frac{P_M}{P_S} = e^{-\left(\frac{0.0007 \times 75.67 \text{ ft} + 0.05 \times 9.42}{2}\right)} = 0.77$$

$$\left[ e^{-\left(\frac{0.0023 \times 23.1 \text{ m} + 0.05 \times 9.42}{2}\right)} = 0.77 \right]$$

Average strand force over one half of the tendon =  $(1 + 0.77)/2 = 0.885$ , loss = 11.5%

The total force and elongation at the live end must be increased to compensate for friction losses:

$$\begin{aligned} \text{Elongation Adjustment} &= 5.40 \times 0.115 = 0.621 \text{ in. } [137 \text{ mm} \times 0.115 = 15.8 \text{ mm}] \\ \text{Force Adjustment} &= 28,910 \times 0.115 = 3,325 \text{ lbs } [128.6 \text{ kN} \times 0.115 = 14.79 \text{ kN}] \end{aligned}$$

**Total Force Required** = 28,910 + 600 + 3,325 = 32,835 lbs [128.6 + 2.67 + 14.79 = 146.0 kN]

Tension at one anchorage to the Total Force Required and note the elongation achieved. Tension at the other anchorage to the same force value and again note the elongation. Add the two elongation values to obtain the total. This total must agree with the calculated value within 5%.

The Total Force Required is less than 80% of the ultimate strand strength (33,000 lbs [146.8 kN]), therefore our procedure is acceptable. Note that if the result was greater than 33,000 lbs, a multi-stage tensioning procedure would be required with incremental tensioning steps at alternate anchorages until the total Gross Theoretical Elongation was achieved.

**Elongation Computation Summary:**

|                       | Gross Theoretical Elongation |       |    | Second Stage Elongation |       |    |
|-----------------------|------------------------------|-------|----|-------------------------|-------|----|
| Basic Elongation      | 5.40 in.                     | 137   | mm | 5.40 in.                | 137   | mm |
| Dead End Seating Loss | 0.125                        | 3     |    | 0.0                     | 0     |    |
| Live End Seating Loss | 0.125                        | 3     |    | 0.125                   | 3     |    |
| Friction Losses       | 0.621                        | 15.8  |    | 0.621                   | 15.8  |    |
| Total Elongation      | 6.271 in.                    | 158.8 | mm | 6.146 in.               | 155.8 | mm |
| Rounded               | 6-1/4 in.                    | 159   | mm | 6-1/8 in.               | 156   | mm |
| Tolerance Limits      | -5% = 5-15/16 in.            | 151   | mm | -5% = 5-13/16 in.       | 148   | mm |
|                       | +5% = 6-9/16 in.             | 167   | mm | +5% = 6-7/16 in.        | 164   | mm |

For the initial tensioning stage, the elongation may be compared with the Gross Theoretical Elongation for monitoring travel of ram, and the jacking force may be compared to 32,835 lbs [146.0 kN]. At second stage tensioning, the force is the same, but the elongation measurement is reduced by the dead end seating loss, since the strand has already seated at the opposing chuck. The sum of measured elongations from the first and second stage tensioning should be compared to the Gross Theoretical Elongation.

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# ***APPENDIX I***

## ***Erection and Installation Tolerances***

Erection tolerances control the position of the individual precast concrete members as they are located and placed in the assembled structure. Erection tolerances are provided to help achieve uniform joint widths, level floor elevations, and planar wall conditions. Erection tolerances should be determined on the basis of individual unit design, shape, thickness, composition of materials, and overall scale of the unit in relation to the building. The specified erection tolerances may affect the work of several different building trades and should be consistent with the tolerances specified for those trades.

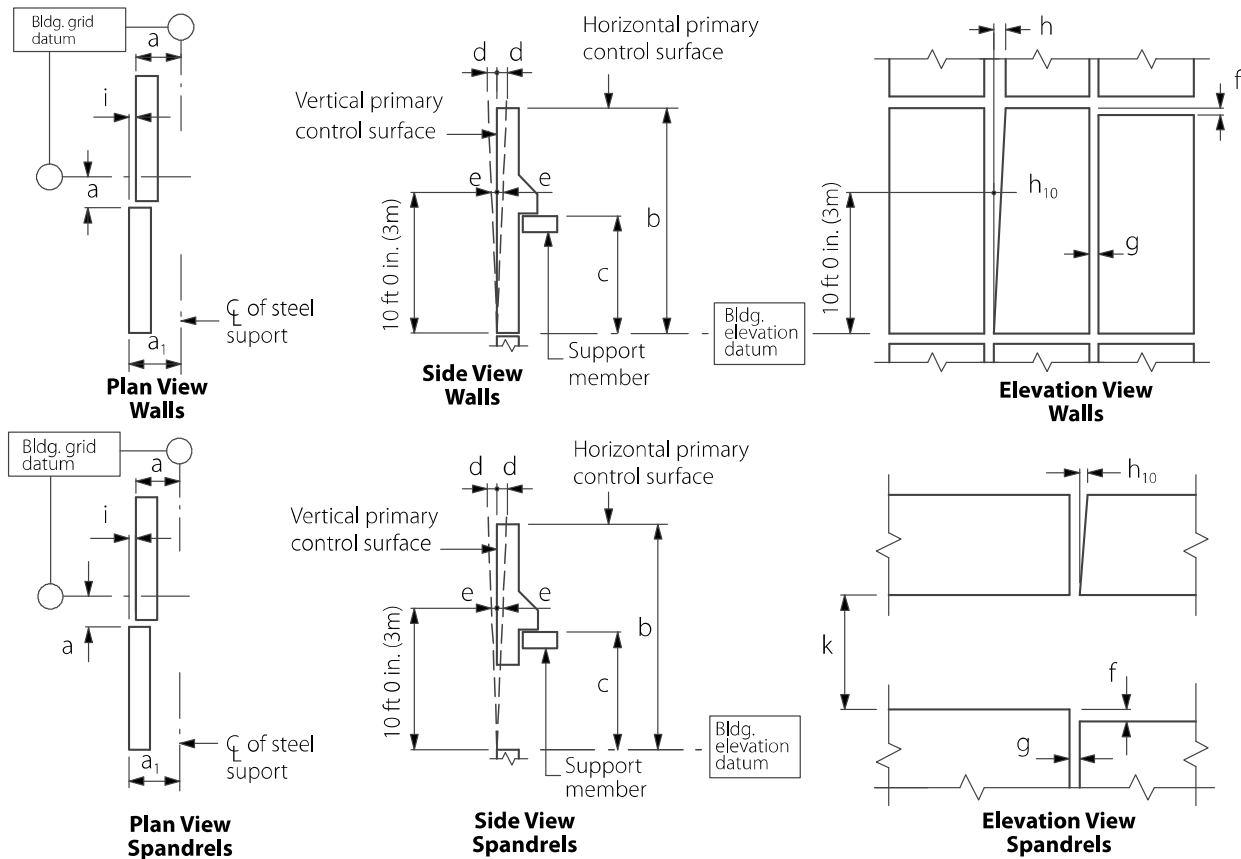
The primary control surfaces or features on the precast concrete members are erected to be in conformance with the established erection and interfacing tolerances. Clearances are generally allowed to vary so that the primary control surface can be set within tolerance. It is important to recognize product tolerances are not additive to the primary surface erection tolerances.

Secondary control surfaces that are positioned from the primary control surfaces by the product tolerances are usually not directly positioned during the erection process, but are controlled by the product tolerances. Thus, if the primary control surfaces are within erection and interfacing tolerances, and the secondary surfaces are within product tolerances, the member should be considered erected within tolerance. The result is that the tolerance limit for secondary surfaces may be the sum of the product and erection tolerances. Product tolerances, in general, must not exceed erection tolerances.

Because erection and product tolerances for some secondary control surfaces of a precast concrete member may be directly additive, the erection drawings should clearly define the primary erection control surfaces. If both primary and secondary control surfaces are critical, provisions for adjustment should be included. The accumulated tolerance limits may be required to be accommodated in the interface clearance. This may occur with window openings between two spandrels when the critical elevation, top or bottom and as indicated on the erection drawings, must be maintained. If more than one critical line is indicated, the erector should balance any deviations between the two edges. Surface and feature control requirements should be clearly outlined in the plans and specifications.

During wall panel installation, priority is generally given to aligning the exterior face of the units to meet aesthetic requirements. This may result in the interior face of units being out-of-plane.

**Architectural Walls/Spandrels Erection Tolerances**



The primary control surfaces are usually as shown, although this needs to be confirmed on a job-by-job basis.

|                |   |                                                                                         |                     |
|----------------|---|-----------------------------------------------------------------------------------------|---------------------|
| a              | = | Plan location from building grid datum*                                                 | ± 1/2 in. (± 13 mm) |
| a <sub>1</sub> | = | Plan location from centerline of steel support **                                       | ± 1/2 in. (± 13 mm) |
| b              | = | Top elevation from nominal top elevation:                                               |                     |
|                |   | Exposed individual panel                                                                | ± 1/4 in. (± 6 mm)  |
|                |   | Nonexposed individual panel                                                             | ± 1/2 in. (± 13 mm) |
| c              | = | Support haunch elevation from nominal elevation:                                        |                     |
|                |   | Maximum low                                                                             | 1/2 in. (13 mm)     |
|                |   | Maximum high                                                                            | 1/4 in. (6 mm)      |
| d              | = | Maximum plumb variation over height of structure<br>or 100 ft (30 m) whichever is less* | 1 in. (25 mm)       |
| e              | = | Plumb in any 10 ft (3 m) of element height                                              | 1/4 in. (6 mm)      |

|                 |   |                                                                                                                            |                                   |
|-----------------|---|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| f               | = | Maximum jog in alignment of matching edges:<br>Exposed relative to adjacent panel<br>Nonexposed relative to adjacent panel | 1/4 in. (6 mm)<br>1/2 in. (13 mm) |
| g               | = | Joint width (governs over joint taper)                                                                                     | ± 1/4 in. (± 6 mm)                |
| h               | = | Joint taper maximum                                                                                                        | 3/8 in. (9 mm)                    |
| h <sub>10</sub> | = | Joint taper over 10 ft (3 m) length                                                                                        | 1/4 in. (6 mm)                    |
| i               | = | Maximum jog in alignment of architectural features, rustications, and matching faces                                       | 1/4 in. (6 mm)                    |
| j               | = | Differential bowing or camber as erected between adjacent members of the same design†                                      | 1/4 in. (6 mm)                    |
| k               | = | Opening height between spandrels                                                                                           | ± 1/4 in. (± 6 mm)                |

\* For precast buildings in excess of 100 ft (30 m) tall, tolerances “a” and “d” can increase at the rate of 1/8 in. (3 mm) per story to a maximum of 2 in. (50 mm).

\*\* For precast elements erected on a steel frame, this tolerance takes precedence over tolerance on dimension “a”.

† Bowing and warping tolerances have an important effect on the edge match up during erection and on the visual appearance of the erected panels, both individually and when viewed together. The requirements for bowing and warping of panels may be overridden by tolerances for panels as installed with reference to joint widths, jog in alignment and step in face.

### Architectural Trim Unit Tolerances

Installation tolerances are as follows:

- |    |                                                                  |                                                                                             |
|----|------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| 1. | Variation from plumb. . . . .                                    | 1/8 in. in 10 ft (3 mm in 3 m) or 1/4 in. in 20 ft (6 mm in 6 m) or more.                   |
| 2. | Variation from level. . . . .                                    | 1/8 in. in 10 ft (3 mm in 3 m), 1/4 in. in 20 ft (6 mm in 6 m), or 3/8 in. (10 mm) maximum. |
| 3. | Variation in joint width . . . . .                               | 1/8 in. in 36 in. (3 mm in 900 mm) or 1/4 of the nominal joint width, whichever is less.    |
| 4. | Variation in plane between adjacent surfaces (Lipping) . . . . . | 1/8 in. (3 mm).                                                                             |

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# APPENDIX J

## Architectural Trim Units

Architectural Precast Concrete Trim Units (AT) is a category of products for certification within the Architectural Products Group. This category is defined as:

Non-prestressed products with an architectural surface finish and of relatively small size that can be installed with equipment of limited capacity, such as bollards, benches, planters, and pavers, and cast stone building units such as sills, lintels, coping, cornices, quoins, and medallions.

This definition includes specialty products specifically designed for a project, and not commodity or ornamental units produced for wholesale or retail purposes. This category does not include dry-cast products such as machine made pavers, or dry-tamped cast stone.

For this class of products, the criteria published in this manual (MNL-117) for quality control govern except as specifically noted below. The section numbers correspond to sections in the manual.

### Standard

### Commentary

#### 1.3 Personnel

#### C1.3 Personnel

##### 1.3.2 Engineering

##### C1.3.2 Engineering

Plants shall have available the services of a registered professional engineer experienced in the design of precast concrete. The precast engineer shall prescribe design policies and be competent to review designs prepared by others. The precast engineer shall be responsible for the design of all products for production and handling.

Engineering personnel should review the design of precast concrete elements prepared by the precast engineer of record. The precast engineer should have the ability to solve problems and devise methods, as required, for the design, production, handling, and/or erection of precast concrete products.

##### 1.3.5 Quality Control

##### C1.3.5 Quality Control

Quality control procedures shall be established by the plant's general management, with duties assigned to qualified personnel such that authority for carrying out the responsibilities of quality control is maintained by general management or engineering, and is not a function of the production staff.

Due to the limited staff at most plants producing Architectural Trim Units as their primary product, it is impractical to require a separate quality control department in the organizational structure. The intent of this section is to assure that authority for maintaining quality requirements is not vested with personnel who are primarily concerned with productivity.

Responsibilities shall include assuring that the following activities are performed at a frequency shown to be adequate to meet quality objectives or as prescribed in this manual.

- a. Inspecting and verifying the accuracy of dimensions and condition of molds.

The qualifications of personnel conducting inspections and tests are critical to providing adequate assurance that the precast concrete products will satisfy the desired level of quality.

All personnel should observe and report any changes

**Standard****Commentary**

- b. Verifying batching, mixing, material handling, placing, consolidating, curing, product handling and storage procedures.
- c. Verifying the proper fabrication and placement of reinforcement, and quantity and location of cast-in items.
- d. Preparing or evaluating concrete mixture designs.
- e. Taking representative test samples and performing all required testing.
- f. Inspecting all finished products for conformance with shop drawings, approved samples and project requirements.
- g. Preparing and maintaining complete quality control records.

in plant equipment, working conditions, weather and other items which have the potential for affecting the quality of products.

**3.2 Reinforcement and Hardware****3.2.2 Prestressing Materials**

This section does not apply to Category AT.

**3.3 Insulation**

This section does not apply to Category AT.

**4.1 Mixture Proportioning****4.1.1 Qualification of Concrete Mixtures**

Concrete mixtures for precast concrete shall be established initially by laboratory methods. The proportioning of mixtures shall be done either by a qualified commercial laboratory or qualified precast concrete plant personnel. Mixtures shall be evaluated by trial batches prepared in accordance with ASTM C192/C192M and plant tests under conditions simulating as closely as possible actual production and finishing.

Each concrete mixture used shall be developed using the brand and type of cement, source and gradation of aggregates, and the brand of admixture proposed for use in the production mixtures. If any of these variables are changed, the proportions of the mixture shall be re-evaluated.

Where a history of use of a concrete mixture with similar proportions and materials to those of the proposed production mixture is available,

**C4.1 Mixture Proportioning****C4.1.1 Qualification of Concrete Mixtures**

Due to the large variety of concrete mixtures used for relatively small volume production runs, it is impractical to require separate trial batches for all

**Standard****Commentary**

laboratory testing and evaluation is not required.

Concrete mixtures shall be proportioned and/or evaluated for each individual project with respect to strength, absorption, volume change, and resistance to freezing and thawing where such environments exist, as well as desired surface finish (color and texture). Mixtures shall have adequate workability for proper placement and consolidation.

mixture designs. Initial mixture proportions can be based on previously used concrete mixture designs for which sufficient data is available to predict strength, durability, and workability of the new design. Tests for strength and air content should be conducted during the preparation of color and texture samples to confirm the applicability of the reference concrete mixture.

**5.2 Prestressing**

This section does not apply to Category AT.

**5.3 Pretensioning**

This section does not apply to Category AT.

**5.4 Post-Tensioning of Plant-Produced Products**

This section does not apply to Category AT.

**6.2 Testing****C6.2 Testing****6.2.3 Production Testing****C6.2.3 Production Testing**

The requirements for frequency of testing during production are modified for Category AT products as follows.

Due to the relatively low volume of materials used in production of category AT products, the minimum testing frequency requirements are modified to levels more reasonable for the typical production cycles.

**1. Aggregates**

A sieve analysis (ASTM C136) and unit weight test (ASTM C29/C29M) shall be conducted in the plant with test samples taken at any point between and including stockpile and batching hopper. Such tests shall be carried out for each aggregate type and size at least once every 4 weeks, or for every 40 cu. yds. (31 m<sup>3</sup>) of an aggregate used in a 4 week period when usage in that period exceeds 40 cu. yds. (31 m<sup>3</sup>).

**2. Concrete Strength****2. Concrete Strength**

For each concrete mixture in use, a minimum of five compression test specimens, made in accordance with ASTM C31/C31M, shall be made weekly or for every 15 cu. yds. (11.5 m<sup>3</sup>) produced, whichever is more frequent. Three of these specimens shall be used to verify 28-day design strength, and at least one of the specimens shall be used to verify

When small volumes of concrete are used, and data is available to support the anticipated strength of a concrete mixture design, a reduced frequency of testing is appropriate. At least once each week, or for every 15 cu. yds., (11.5 m<sup>3</sup>) a set of tests should be conducted to verify concrete mixture design performance. This is a minimum requirement. Any indication of potential for reduced concrete

**Standard**

**Commentary**

concrete strength at the maturity being used for removal of products from their form/molds.

performance is cause for increased frequency of testing.

The use of 4 x 8 in. (100 x 200 mm) cylinder specimens is recommended.

Three compression specimens shall be made daily for each individual concrete mixture used. These specimens shall be made in accordance with ASTM C31/C31M, except that a “Chace Indicator” test, in accordance with AASHTO T-199, may be used to determine air content.

The three test specimens made each day may be tested at 28-days, or at any age deemed appropriate for the application (such as prior to shipping). These specimens may also be used to verify quality of production runs if the weekly test set indicates a potential problem.

**3. Air Content**

For periodic daily checks, a “Chace Indicator” test, in accordance with AASHTO T-199, may be used.

**4. Air Content**

The “Chace Indicator” will give an approximate value for the air content. Any indication that the air content is not within specified limits would be cause to test in accordance with ASTM C173/C173M or C231/C231M.

**6.2.4 Special Testing**

**C6.2.4 Special Testing**

**1. Heat of Hydration**

**1. Heat of Hydration**

This class of products does not involve “massive castings”.

**2. Concrete Coverage of Reinforcing Steel**

Testing is not applicable to Architectural Trim Units category.

Most of the products in this category are lightly reinforced to accommodate temperature shrinkage and creep. Many products are unreinforced. Adequate cover over reinforcement is rarely a problem.

**7.1 Requirements for Finished Product**

**C7.1 Requirements for Finished Product**

**7.1.2 Product Tolerances**

**C7.1.2 Product Tolerances**

**1. Sills, Lintels, Coping, Cornices, Quoins, Medallions**

These tolerances are the minimum acceptable criteria in the absence of specified requirements. Project specifications, or product application, may require more stringent tolerances.

a. Overall height and width of units, measured at the face(s) exposed to view  
..... ± 1/8 in. (± 3mm)

Refer to Section 7.1.2 for tolerances not listed here.

b. Total thickness of flange thickness  
..... ± 1/8 in. (± 3mm)  
Where one face will be installed in dead wall space or mortar joint

**Standard**

**Commentary**

- .....  $\pm 1/4$  in. ( $\pm 6$ mm), maximum
2. Bollards, Benches, Planters  
.....  $\pm 1/4$  in. ( $\pm 6$  mm), all dimensions
  3. Pavers
    - a. Width and thickness  
..  $+ 1/16$  in. (+ 1.5 mm), -  $1/8$  in. (- 3 mm)
    - b. Length 2 ft. (0.6 m) or less  
..  $+ 1/16$  in. (+ 1.5 mm), -  $1/8$  in. (- 3 mm)  
2 to 5 ft (0.6 to 1.5 m) .  $\pm 1/8$  in. ( $\pm 3$  mm)  
5 to 10 ft. (1.5 to 3 m)  
..  $+ 1/8$  in. (+ 3 mm), -  $3/16$  in. (- 4.5 mm)
  4. Size and location of rustications and architectural features . .  $\pm 1/16$  in. ( $\pm 1.5$  mm)
  5. Location of inserts and appurtenances:
    - a. On formed surfaces  
.....  $\pm 1/8$  in. ( $\pm 3$  mm)
    - b. On un-formed surfaces  
.....  $\pm 3/8$  in. ( $\pm 9$  mm)
  6. Bowing ..... L/360,  $1/8$  in. max (6 mm)
  7. Local smoothness  
.....  $\pm 1/8$  in. in 5 ft ( $\pm 3$  mm in 1.5 m)
  8. Warping:
    - a. Pavers  
.....The numerically greater of  $1/16$  in. (1.5 mm) or  $1/32$  in. per ft, (0.75 mm per 300 mm) of distance from nearest adjacent corner
    - b. Other products  
.....  $1/16$  in. per ft (1.5 mm per 300 mm) of distance from nearest adjacent corner,  $1/4$  in. maximum (3 mm)

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# APPENDIX K

## Metric Conversions

### Conversions Between US Customary (USC) and SI Units

| USC to SI                                                                                                                                              | Quantity                                | SI to USC                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 in. = 0.0254 m = 25.4 mm<br>1 ft. = 0.3048 m = 304.8 mm                                                                                              | <b>Length</b>                           | 1 m = 39.37 in.<br>1 m = 3.2808 ft                                                                                                                  |
| 1 in <sup>2</sup> = 645.2 mm <sup>2</sup><br>1 ft <sup>2</sup> = 9.290 x 10 <sup>-2</sup> m <sup>2</sup>                                               | <b>Area</b>                             | 1 m <sup>2</sup> = 1.55 x 10 <sup>3</sup> in <sup>2</sup><br>1 m <sup>2</sup> = 10.76 ft <sup>2</sup>                                               |
| 1 in <sup>3</sup> = 16,387 mm <sup>3</sup><br>1 ft <sup>3</sup> = 2.832 x 10 <sup>-2</sup> m <sup>3</sup><br>1 yd <sup>3</sup> = 0.7646 m <sup>3</sup> | <b>Volume</b>                           | 1 m <sup>3</sup> = 6.101 x 10 <sup>4</sup> in <sup>3</sup><br>1 m <sup>3</sup> = 35.311 ft <sup>3</sup><br>1 m <sup>3</sup> = 1.308 yd <sup>3</sup> |
| 1 lb = 4.448 N<br>1 k = 4.448 kN<br>1 lb/in = 175.1 N/m<br>1 lb/ft = 14.59 N/m<br>1 k/ft = 14.59 kN/m                                                  | <b>Force and Force per Unit Length</b>  | 1 N = 0.225 lb<br>1 kN = 0.225 k<br>1 N/m = 5.711 x 10 <sup>-3</sup> lb/in<br>1 N/m = 0.0685 lb/ft<br>1 kN/m = 0.0685 k/ft                          |
| 1 psi = 6.895 kPa<br>1 ksi = 6.895 MPa<br>1 psf = 47.88 Pa                                                                                             | <b>Stress and Modulus of Elasticity</b> | 1 kPa = 0.145 psi<br>1 MPa = 0.145 ksi<br>1 Pa = 0.0209 psf                                                                                         |
| 1 pcf = 16.02 kg/m <sup>3</sup><br>1 pcy = 0.5933 kg/m <sup>3</sup>                                                                                    | <b>Mass per Volume (Density)</b>        | 1 kg/m <sup>3</sup> = 0.0624 lb/ft <sup>3</sup><br>1 kg/m <sup>3</sup> = 1.6855 lb/yd <sup>3</sup>                                                  |
| T <sub>c</sub> = (T <sub>f</sub> - 32)/1.8                                                                                                             | <b>Temperature</b>                      | T <sub>f</sub> = (1.8 x T <sub>c</sub> ) + 32                                                                                                       |

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